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Socio-Demographic Determinants of Mortality in Bangladesh: A Time Series Analysis

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Abstract

Understanding the factors influencing the death rate in Bangladesh is essential for effective policy-making and addressing demographic challenges. This study aims to examine both the short-term dynamics and long-term equilibrium relationships between socio-demographic factors and the death rate of Bangladesh over a given period. It focuses on four key factors: adolescence fertility rate (AFR), life expectancy rate at birth, birth rate, and infant mortality rate (IMR). Taking an annual time series dataset from 1975 to 2021 from the World Bank (WB), the study uses the Johansen co-integration test, vector error correction model (VECM), and Granger causality test to analyze the relationships between these factors and death rate. The findings reveal short-term and long-term equilibrium links between the socio-demographic parameters and death rate. A substantial negative correlation exists between death rate and AFR and life expectancy. Additionally, a positive correlation is observed between the death rate and birth rate, and IMR. These findings provide valuable insights for decision-makers to address the death rate in Bangladesh, bridging a research gap and guiding effective socio-demographic policies.

Keywords: Socio-demographic determinants, Short-term dynamics, Long-term equilibrium, Time series analysis.

AMS Classification: 91D20, 62M10.

1. Introduction

The death rate is one of the burning issues in both underdeveloped and developing worlds including Bangladesh. Mortality statistics reflect a country's overall development and quality of life. The death rate is considered a key indicator of a nation's socio-demographic progress. Infant mortality rates (IMR) in developing nations are found to be significantly higher than those in developed countries (Barman and Talukdar, 2014). A high death rate weakens a country's economic stability and healthcare system, making it a growing concern for policymakers (Pérez-Stable and Hooper, 2023). Over the past three decades, global mortality rates have generally declined, although regional disparities persist. In 1990, the global death rate was about 9.5 per 1,000 people, and by 2023, it had decreased to around 8 per 1,000 (PRB, 2024). The death rate in Bangladesh has significantly reduced from 13.7 per 1,000 people in 1971, during the aftermath of the war and a developing healthcare system, to around 5 per 1,000 people in 2023 (PRB, 2024). This decline reflects advancements in public health, medical care, and overall living conditions over the decades of Bangladesh (Perry and Chowdhury, 2024). The higher fertility and mortality rates affect the country's economic development and health sectors (Fumagalli et al., 2024). The outbreak of Coronavirus Disease, which began in 2019 (COVID-19), significantly increased global awareness of public health and the healthcare sectors worldwide (Assefa et al., 2021). Moreover, to stimulate economic development, policy initiatives must address the mortality rate (Dix, 2024).

Bangladesh, a developing country in South Asia, has a population of approximately 173.6 million and a natural increase rate of 1.5% (PRB, 2024). After its independence, the country faced a higher death rate, with a death rate of 16.628 per 1,000 people in 1975, alongside a high birth rate of 46.175 per 1,000 people. Over the years, the death rate has decreased significantly, reaching 5 per 1,000 people in 2023 (PRB, 2024), though it remains a concern for policymakers (Assefa et al., 2021). Recent studies have explored the factors influencing child, infant, and neonatal mortality in Bangladesh, emphasizing the importance of socio-demographic factors such as education, income, and fertility in reducing mortality rates. The World Health Organization has pointed out that while the links between these factors and mortality are well-established, a long-term relationship involving factors like life expectancy, birth rate, and AFR has yet to be fully explored (WHO, 2024). This study intends to bridge this gap by investigating the impact of socio-demographic factors on overall mortality in Bangladesh using time series analysis, employing econometric methods like the Johansen co-integration test and vector error correction model (VECM). Previous research suggests that a comprehensive investigation of socio-demographic factors is essential to understand better how to reduce the mortality rate (Baltrus et al., 2019; Lawrence et al., 2024; Rahman and Alam, 2023). While links between factors such as education, income, fertility, and mortality have been explored, a robust long-term relationship between demographic factors such as life expectancy, birth rate, IMR, and AFR, and overall mortality remains largely unexplored. Consequently, it is essential to examine the impact of these socio-demographic factors on overall mortality to gain valuable insights into the specific context of Bangladesh. Therefore, the main aims of this are to examine both the short-term dynamics and long-term equilibrium relationships between socio-demographic factors and the death rate in Bangladesh.

The research aimed to address key questions regarding the relationship between socio-demographic factors and mortality rates in Bangladesh through time series analysis. Specifically, the study sought to examine:

(i) How do socio-demographic factors such as birth rate, IMR, AFR, and life expectancy influence the death rate in Bangladesh, both in the short and long term, and whether these impacts are positive or negative? And;

(ii) Does a causal association exist between the death rate and these socio-demographic factors over time in Bangladesh?

To address the above research questions, this study employs econometric methods such as the Johansen co-integration test and the VECM, which are considered highly suitable for analyzing the relationships between variables over time. The analysis uncovers significant connections between the death rate in Bangladesh and key socio-demographic factors, including AFR, LE, birth rate, and IMR. These findings provide critical insights into the complex interactions shaping mortality trends and contribute to filling existing knowledge gaps, which can inform and guide the development of targeted socio-demographic policies for Bangladesh.

The remaining sections of the article are organized as follows: The next section outlines the study hypotheses and synthesizes the existing literature on demographic determinants and death rates. Following that, we provide a detailed explanation of the methodologies used in this study. The subsequent section presents the results from the time series data analysis and discusses the results and practical implications. The article concludes by addressing the study's limitations and proposing potential directions for future research.

2. Review of literature

The death rate in Bangladesh is shaped by a variety of socio-demographic factors, similar to both developed and developing nations. Key determinants include the birth rate, IMR, AFR, and life expectancy, all interacting in complex ways to influence overall mortality trends. As in other countries, these factors highlight the importance of addressing public health and socio-economic conditions to reduce mortality rates. Studies have shown that improvements in health infrastructure, education, and socio-economic conditions can lead to significant declines in mortality, underscoring the need for targeted policies. These factors include age (Fessler and Navarrete, 2005; La Vecchia et al., 1998), gender (Seifart et al., 2020; Villar et al., 2007), education (Halpern-Manners et al., 2020; Hummer and Hernandez, 2013), income (Rocco et al., 2021; Ward and Viner, 2017), occupation (Debelu et al., 2023; Ravesteijn et al., 2013), access to healthcare services (Alkire et al., 2018; Kruk et al., 2018), total fertility rate (TFR) (Utomo et al., 2021; Vollset et al., 2020), AFR (Noori et al., 2022; Utomo et al., 2021), IMR (Nath et al., 2021; Noori et al., 2022), life expectancy (Liu et al., 2022; Woolf and Schoomaker, 2019), etc. Accepting the influence of these factors is crucial for policymakers to design effective health interventions and improve public health outcomes. This study considered the effects of birth rate, AFR, IMR, and life expectancy on the death rate. These factors are interconnected and significantly affect public health and socio-economic development. The following reviewed literature explores how these demographic factors affect the death rate in Bangladesh.

Age is an essential determinant of death rates in Bangladesh, with higher mortality observed among both infants and the elderly. Malnutrition, infectious diseases, and inadequate maternal healthcare services severely influence child mortality. Socioeconomic factors also play a significant role in mortality rates, particularly among children under five. Children of mothers with more than six years of education have a significantly lower risk of death, highlighting the critical role of maternal education in reducing these disparities (Chowdhury et al., 2017). Despite a decline in child mortality rates from 128 to 23 per 1,000 from 1994 to 2023 (PRB, 2024), socioeconomic disparities persist, with children from lower-income households experiencing higher mortality rates. Although efforts like vaccination campaigns and increased contraceptive use have reduced mortality, socioeconomic inequality in factors affecting child survival remains a challenge. Continuing progress requires ongoing evaluation of health programs to address these disparities effectively.

While a middle-income country, Bangladesh has made significant progress in reducing maternal mortality, particularly in line with Millennium Development Goal (MDG) 5. Despite this progress, maternal mortality rates remain high. Studies using data from the Bangladesh Maternal Mortality Surveys (2013 and 2019) show a decline in maternal deaths from 186 per 100,000 live births in

2016 to 173 per 100,000 in 2017, a 6.99% decrease. Maternal diseases account for 13% of female deaths between 15 and 49 years old (NIPORT, 2019). This improvement is primarily attributed to better access to healthcare services, both public and private. The findings offer insights into how post-MDG health goals should be assessed globally, with a focus on expanding healthcare access to further reduce maternal mortality in Bangladesh (Ferdous et al., 2021).

The relationship between education and death rates is well-documented. Educated individuals have better health outcomes, with higher educational attainment linked to lower mortality rates. For instance, women with secondary or higher education in Bangladesh have a significantly lower IMR without education, as indicated by data from the Bangladesh Demographic and Health Survey (BDHS) 2017-18 (NIPORT, 2020). Additionally, income and occupational status play crucial roles in mortality, as low-income households often face barriers to healthcare, nutritious food, and safe housing, leading to higher death rates (Hossain et al., 2024; Hossain, 2019).

High birth rates are often linked to higher infant and child mortality, especially in areas with limited healthcare resources, like rural Bangladesh. The high birth rates in rural regions have been associated with increased infant mortality due to inadequate healthcare infrastructure (Rahman, 2018). Family planning programs have helped reduce the birth rate, contributing to lower mortality rates. Similarly, the AFR, which measures births per 1,000 women aged 15-19, is another crucial factor influencing mortality. High AFR is associated with increased health risks for both mothers and infants, as adolescent mothers face higher risks of complications during pregnancy and childbirth. The AFR in Bangladesh has decreased, contributing to better maternal and infant health outcomes (Khan and Harris, 2023).

In Bangladesh, high-risk fertility practices such as increased parity, early or late pregnancy, and short birth intervals continue to contribute to perinatal mortality. A study examining 8,930 singleton pregnancies from the BDHS 2017-18 found that women with high-risk fertility behaviors had 1.87 times higher odds of perinatal mortality compared to women without such behaviors (NIPORT, 2020). Furthermore, the likelihood of perinatal death increased with the frequency of these high-risk behaviors. The study highlights the importance of contraception use to space pregnancies, as well as the need for educational programs addressing the risks of high-risk fertility behaviors. Improved access to maternal healthcare services is also crucial for better birth outcomes (Alam et al., 2021).

A study analyzed annual data from 1972 to 2013 to assess how economic progress influences life expectancy in Bangladesh. Using advanced statistical methods like structural break unit root tests and ARDL model limits testing, the study found that financial development, globalization, economic growth, and income inequality all significantly impact LE. The research established a feedback loop between income inequality and LE, and between life expectancy and financial development. The study concluded that globalization and economic growth contribute to improving LE, offering valuable insights for policymakers aiming to enhance life expectancy in Bangladesh (Khan, 2020).

3. Research hypothesis of the study

In line with the study's objectives and research questions, the following hypotheses are formulated to examine the relationship between the death rate and socio-demographic factors in Bangladesh:

(i) There is a unidirectional or bidirectional relationship between death rate and different socio-demographic variables (such as birth rate, IMR, life expectancy, and death rate) in the short run.

(ii) There is a long-term equilibrium relationship between death rate and different socio-demographic variables (such as birth rate, IMR, life expectancy, and death rate) in Bangladesh.

(iii) Different socio-demographic variables (such as birth rate, IMR, life expectancy, and death rate) have a positive/negative significant relation with the death rate in Bangladesh.

4. Data and methods

Both descriptive and analytical methods were employed to examine the influence of socio-demographic factors on the mortality rate in Bangladesh. . A clear and evidence-based understanding of the relationship between socio-demographic factors and mortality are explained in the following ways:

4.1 Explanation and bases of data

This study utilized secondary annual data from the World Bank's (WB) Health Nutrition and Population Statistics database. Data for all relevant variables, including death rate, birth rate, IMR, AFR, and life expectancy, were collected from 1975 to 2021 to examine both short-run and long-run associations among these variables. Birth rate, IMR, AFR, and life expectancy were the independent variables. The overall death rate is considered the dependent variable because it provides a comprehensive view of population health, reflecting the impact of socio-demographic factors across all age groups. Unlike child or infant mortality, it captures broader public health and socio-economic conditions, making it ideal for analyzing long-term trends and interrelationships. This approach allows for a holistic assessment of health systems and policy implications that affect the entire population, not just specific cohorts. Its broader scope supports inclusive research outcomes, guiding policies improve overall mortality rates and effectively allocating resources across age demographics. The definitions of these variables are presented in Table 1.

Table 1: Variables and their descriptions

Variables	Descriptions
Death Rate (DR)	The crude death rate indicates the number of deaths occurring during the year per 1,000 population estimated at midyear. Subtracting the crude death rate from the crude birth rate provides the rate of natural increase, which is equal to the rate of population change in the absence of migration.
Birth Rate (BR)	The crude birth rate indicates the number of live births occurring during the year per 1,000 population estimated at midyear. Subtracting the crude death rate from the crude birth rate provides the rate of natural increase, which is equal to the rate of population change in the absence of migration.
Infant Mortality Rate (IMR)	Infant mortality rate is the number of infants dying before reaching one year of age per 1,000 live births in a given year.
Adolescent Fertility Rate (AFR)	The adolescent fertility rate is the number of births per 1,000 women ages 15 and19.
Life Expectancy (LE)	Life expectancy at birth indicates the number of years a new born infant would live if prevailing patterns of mortality at the time of its birth were to stay the same throughout its life.

4.2 Model specification

This study goals to examine the relationship between socio-demographic factors (birth rate, IMR, AFR, and life expectancy) and death rate in Bangladesh by using a modified model of the Cobb-Douglas function (Cobb and Douglas, 1986) with time series data. The model is shown as follows:

$$DR_t = \alpha + \beta_1 BR_t + \beta_2 IMR_t + \beta_3 AFR_t + \beta_4 LE_t + \epsilon_t\,, \tag{1}$$

where DR_t represents the death rate in year t, BR_t represents birth rate in year t, IMR_t represents the IMR in year t, AFR_t represents AFR in year t, LE_t represents life expectancy in year t; α is a constant term, and β_1, β_2, β_3 and β_4 are the regression coefficients of the independent variables, namely BR_t, IMR_t, AFR_t, *and* LE_t, respectively; *and* ε_t represents the error term.

4.3 Analytical tools

To fulfil the research objectives, this study employs a quantitative empirical analysis that integrates both descriptive and empirical approaches. Descriptive statistical analysis presents background features such as the mean and standard deviation (SD). At the same time, the normality of the variables is assessed through skewness, kurtosis, and the Jarque-Bera (JB) test. Graphical representations illustrate the trends of the study variables, and percentage (%) change is used to show the degree of change over time. Annual data series are empirically analyzed using the Granger causality test, Johansen co-integration test, VEC model, and the Augmented Dickey-Fuller (ADF) and Philips-Perron (PP) unit root tests. All tests and data analyses use Stata (Version 15) and Eviews (Version 9).

Percentage change

Percentage change standardizes, compares, and communicates changes effectively, clearly showing growth or decline. Its sign indicates an increase (+) or decrease (−), making trends easy to interpret across different contexts. The percentage change was calculated as follows (Chapman, 2008):

$$\text{Percentage change} = \frac{new\ value - old\ value}{old\ value} \times 100.$$

Unit root test

Initially, to avoid mistakes in estimation, we examined the constancy of the annual data series to determine the order of integration [$I(d)$], where d is the order of integration] of the variables in the model in examination (Ghedabna, 2015). The stationarity and sequence of integration of each yearly data series were examined using the broadly recognized ADF (Dickey and Fuller, 1981) and PP (Phillips, 1988) tests for unit root test. The following equation is estimated by the ADF unit root test (Enders, 2008):

$$\Delta y_t = \alpha_0 + \gamma y_{t-1} + \sum_{i=2}^{\rho} \beta_i \Delta y_{t-i} + \epsilon_i\,, \tag{2}$$

where y_t is a stochastic trend-centered random walk with drift. Eq. (2) becomes the first difference (Δ) and has a unit root if the coefficient $\gamma = 0$. The PP test for unit root verifies the outcomes of the ADF test, and the PP test's regress is as follows:

$$y_t = \alpha_0 + \gamma_t + \delta y_{t-1} + \sum_{i=1}^{\rho} \beta_i \Delta y_{t-1} + \epsilon_t\,, \tag{3}$$

In Eq. (3), γ_t may be $0, \mu$ *or* $\mu + \beta_t$, and $\mathcal{E}_t$ is $I(0)$ may not be homoscedastic. The ADF and PP tests can be used when the error term ($\mathcal{E}_t$) is not white noise. The hypothesis of the ADF test can be expressed as:

i. The null hypothesis, H_0: variable has a unit root;
ii. The alternative hypothesis, H_a: variable has no unit root.

The variable is considered to have no unit root if the null hypothesis is rejected at the 0.05, 0.01, or 0.10 significance level. At these significance levels, a variable is deemed stationary. Conversely, if the null hypothesis is not rejected, the variable has a unit root and is thus considered non-stationary. To convert a non-stationary variable into a stationary one, the forward difference operator (Δ) can be applied.

4.4 Co-integration test

The co-integration test is an econometric method for determining a potential long-term correlation between time series processes. To identify the long-run equilibrium relationship among the time series, stationarity tests were conducted before to performing the Johansen co-integration test. Selecting the appropriate form of the co-integration test and determining the correct lag order is crucial. In this study, three traditional approaches, namely the Akaike Information Criterion (AIC), Schwarz Criterion (SC), and Hannan-Quinn Criterion (HQ) were employed to calculate the lag length. Additionally, two other criteria, the likelihood ratio (LR) and the final prediction error (FPE), were considered.

Because co-integration creates a synthetic stationary series from a linear combination of two or more non-stationary series, it is an appropriate method for transforming the time series into a stationary form. The trace and maximum eigenvalue tests are the sources of the two LR tests that Johansen's method provides for determining the number of co-integrating vectors (r).

$$\lambda_{trace\ (r)} = -T \sum_{\mathrm{i=r+1}}^{\mathrm{n}} \ln(1 - \lambda_{\mathrm{i}}), \tag{4}$$

$$\lambda_{\max(r,r+1)} = -Tln(1 - \lambda_{i+1}), \tag{5}$$

where n is the number of endogenous variables, λ_i i-th the greatest eigenvalue, and T is the sample size (T = 47 for this study). The aforementioned process rely on how the matrix's eigenvalues and rank are related (Enders, 2008).

The hypothesis for this test can be expressed as:

The null hypothesis, H_0: no co-integration in the equation;
The alternative hypothesis, H_a: co-integration in the equation.

The short-run relationship is indicated by the acceptance of H_0, in which case the vector autoregression (VAR) model is examined. Conversely, the acceptance of H_a suggests the presence of a co-integration relationship (long-term correlations between the variables), and VECM is carried out. Following VECM, the variables are subjected to the Granger causality test, which assesses a time series' ability to forecast its future values based on the historical values of a related time series.

4.5 Lag selection criteria

In the context of the Johansen co-integration test, selecting the appropriate lag order is vital because the lags used can affect the test results. This selection process is typically conducted through unrestricted VAR analysis, where criteria like AIC are applied to determine the optimal lag length.

4.6 Vector error correction model (VECM)

The co-integration of variables in the model indicates a long-run equilibrium relationship. However, there may still be temporary deviations from this equilibrium. When a set of variables shows one or more co-integrating relationships, the VECM is employed to analyze both short-term fluctuations and adjustments toward long-term equilibrium. The VECM specifies how the endogenous variables relate to multiple co-integrating equations. It is applicable when the data series are stationary at the first difference. They are parameterizations of VAR(p) models in levels as follows:

$$\Delta y_t = \alpha\beta' y_{t-1} + \Gamma_1 \Delta y_{t-1} + \Gamma_2 \Delta y_{t-2} + \cdots + \Gamma_{p-1} \Delta y_{t-p+1} + \varepsilon_t. \tag{6}$$

Eq. (6) is a VECM where $\Delta y_t = y_t - y_{t-1}$, $t = 1, 2, \ldots\ldots, T$; $\alpha\beta' y_{t-1}$ is the lagged error correction term (ECT), $y_{t-1}$is the non-stationary variable, Γ is the matrix of variables, β is the co-integrating matrix, β' is the transposed matrix of β, α is the loading matrix, p is the lag order of the model in its VAR form, and $\mathcal{E}_t$is the normally distributed error term.

If a coefficient in the co-integrating model exhibits a statistically significant negative sign, it suggests a long-term causal relationship between the variable in question and the other variables in the system. On the other hand, if the coefficient of the lagged value of the variable is non-zero, it indicates short-term causation.

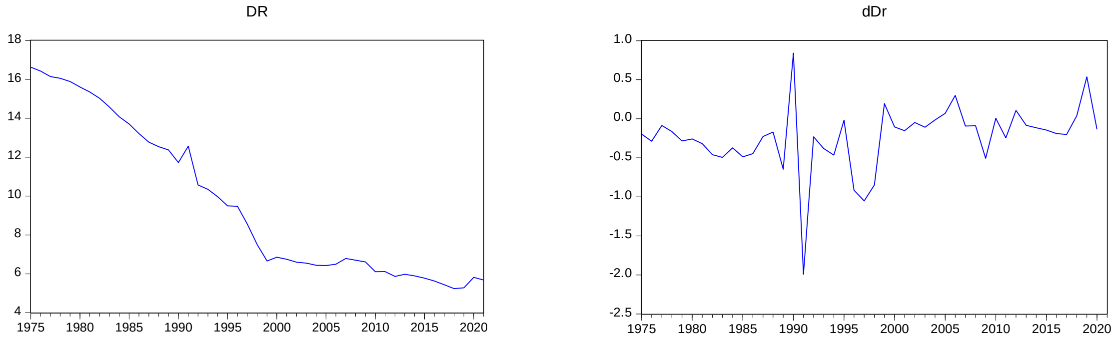
4.7 Granger causality test

Co-integration is a statistical concept indicating a long-term relationship between two or more non-stationary time series variables. However, it does not specify the direction of causality. To investigate causal relationships in a time series dataset, the Granger causality test is employed. This test examines potential causality patterns between variables using probabilistic reasoning. Like co-integration, Granger causality testing requires that the data series be stationary.

Like a hypothesis test, the Granger causality test assesses whether one variable may predict another. For instance, if variable X causes variable Y, X is expected to help forecast Y. Rejecting the null hypothesis (typically at a significance level of 0.05 or lower) indicates a statistically significant causal relationship between the variables. This suggests that modelling the influencing variable can improve forecasts of the influenced variable.

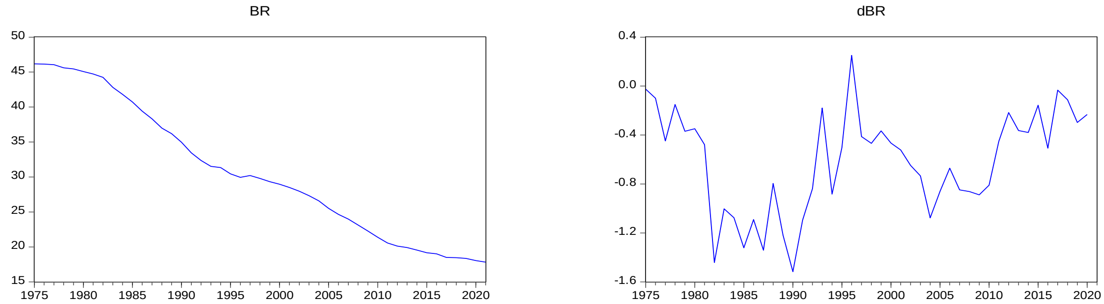
5. Findings

The study examines the influences of birth rate, IMR, AFR, and life expectancy on the death rate in Bangladesh. Using annual time series data from 1975 to 2021, the results of the econometric investigation are displayed in the following sections. The results indicate long-term relationships among the variables, with significant unidirectional and bidirectional causalities between socio-demographic factors and death rate. Specifically, this study finds important unidirectional causation from the independent variables to the death rate. The descriptive statistics for the chosen variables, illustrating their behavior over time, are presented in Table 2. These statistics include skewness, kurtosis, mean, median, SD, minimum, and maximum values, along with the corresponding p-values for the JB test. Table 3 shows the exact data for the study's starting year (1975) and final year (2021), as well as the percentage change from 1975 to 2021. This change indicates a decreasing trend in death rate (-65.84%), BR (-61.40%), and IMR (-84.66%); AFR (-65.24%) and an increasing trend in life expectancy (43.93%). As seen in Figs. 2-6, a graphical analysis was also conducted for the study variables at their levels and first differences to complement the tabular analysis.



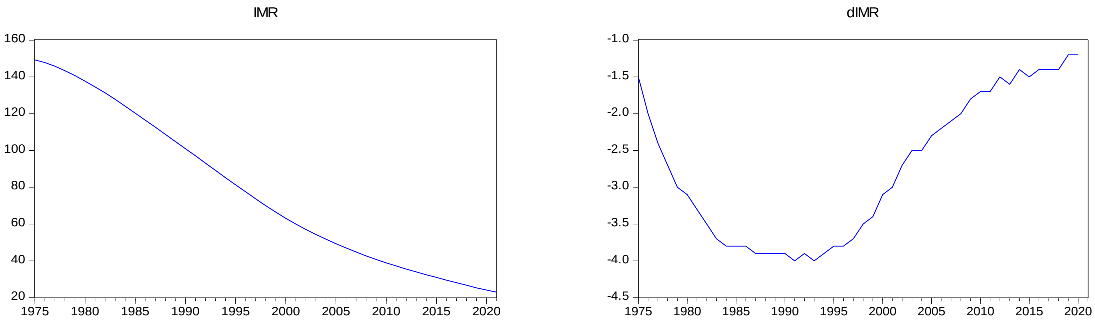
(a) (b)

Fig. 1: The evolution of death rate during 1975-2021in Bangladesh (a) and the same time series in the first difference (b)



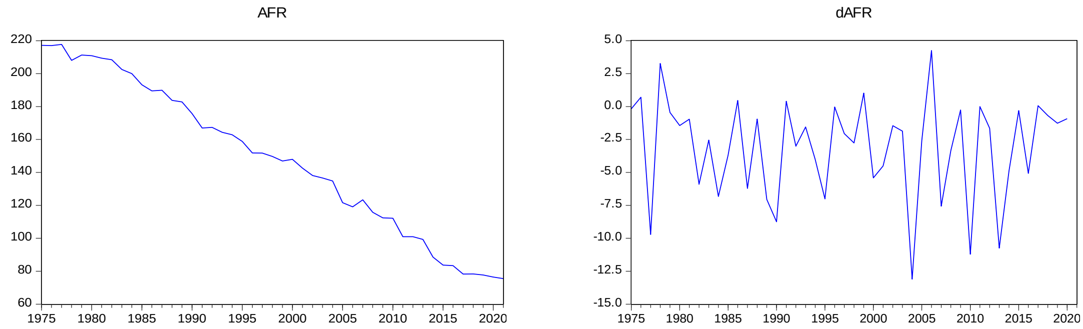
(a) (b)

Fig. 2: The evolution of birth rate during 1975-2021in Bangladesh (a) and the same time series in the first difference (b)



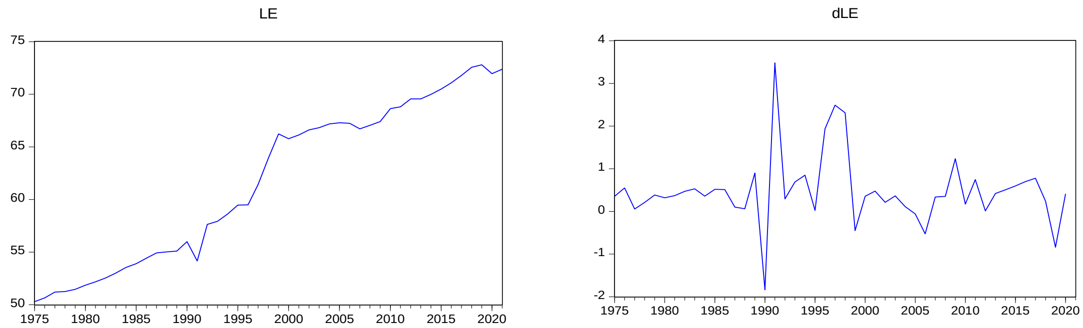
(a) (b)

Fig. 3: The evolution of infant mortality rate during 1975-2021in Bangladesh (a) and the same time series in the first difference (b)



(a) (b)

Fig. 4: The evolution of adolescence fertility rate during 1975-2021in Bangladesh (a) and the same Time series in the first difference (b)



(a) (b)

Fig. 5: The evolution of life expectancy during 1975-2021 in Bangladesh (a) and the same time series in the first difference (b)

Table 2: Descriptive statistics of the variables

Variables	N	Mean	Median	Maximum	Minimum	SD	Skewness	Kurtosis	Jarque-Bera
DR	47	9.623745	7.511	16.628	5.241	3.951057	0.506064	1.672414	5.457651
BR	47	30.69774	29.79	46.175	17.821	9.577359	0.280261	1.771563	3.570519
IMR	47	77.8	70	149.3	22.9	41.6564	0.31413	1.685859	4.154947
AFR	47	148.6345	149.733	217.745	75.496	46.40996	-0.08219	1.755831	3.08433
LE	47	61.78849	63.917	72.806	50.292	7.643487	-0.10071	1.445505	4.811679

Note: 'DR, Death rate', 'BR, Birth rate', 'IMR, Infant mortality rate', 'AFR, Adolescent fertility rate', 'LE, Life expectancy'; 'SD, Standard deviation'

Table 3: Percentage changes of the study variables from 1975 to 2021

Variables	**1975**	**2021**	**Changes (%)**
Death rate (DR)	16.62	5.68	-65.84
Birth rate (BR)	46.17	17.82	-61.40
Infant Mortality Rate (IMR)	149.3	22.9	-84.66
Adolescent fertility rate (AFR)	217.20	75.49	-65.24
Life expectancy (LE)	50.29	72.38	43.93

All of the data series, however, became stationary ($p < 0.05$) once these series were transformed to their first difference. As a result, at the first difference, all variables were stationary [I (1)]. These results were helpful since the VAR model cannot be used to select the lag duration requirement. ADF and PP tests were used to ascertain the sequence of integration for the data series to prepare for the co-integration study of the dependent variable (death rate) and the independent variables (socioeconomic factors). All variables were determined to be statistically significant ($p < 0.05$) at the first-order difference, as Table 4 demonstrates. Given that their *p*-values were higher than 0.05, the tests showed that the variables death rate, birth rate, IMR, and life expectancy were not stationary at a level in either of the unit root tests. Table 4 shows that all variables were be statistically significant ($p < 0.05$) at the first-order difference. The tests revealed that the variables death rate, birth rate, IMR, and life expectancy were not stationary at a level in both unit root tests, as $p > 0.05$. However, all the data series became stationary (p < 0.05) once these series were transformed to their first difference. As a result, at the first difference, all variables were stationary [I (1)]. Since the VAR model cannot be used to select the lag duration requirement, these results were helpful (i.e., I (0)).

Table 4: Results of unit root tests.

Variables	At level					At first difference				
	ADF	Prob.[a]	PP	Prob.[a]	Decision	ADF	Prob.[a]	PP	Prob.[a]	Decision
DR	-0.271	0.9902	-0.134	0.9926		-7.960	0.0000	-7.892	0.0000	I(1)
BR	0.303	0.9963	-0.774	0.9678		-3.475	0.0421	-3.372	0.0552	I(1)
IMR	3.505	1.0000	1.490	1.0000		-6.789	0.0000	-5.942	0.0000	I(1)
AFR	-4.034	0.0079	-4.006	0.0086	I(0)	-8.439	0.0000	-8.439	0.0000	I(1)
LE	-1.745	0.7308	-1.862	0.6741		-7.237	0.0000	-7.218	0.0000	I(1)

Note: ‘DR, Death rate’, ‘BR, Birth rate’, ‘IMR, Infant mortality rate’, ‘AFR, Adolescent fertility rate’, ‘LE, Life expectancy’; ‘ADF, Augmented Dickey-Fuller test for unit root’, ‘PP, Phillips and Perron test for unit root’, ‘aMacKinnon (1996) one-sided *p*-values’.

Lag selection criteria were used to find the ideal lag length for the VECM. . Table 5 indicates that the majority of criteria recommended a lag length of two when the AIC was employed. As a result, a lag order of two was used for this annual time series dataset, and the VECM and the Johansen co-integration test were subsequently estimated. Choosing a valid test form and the proper lag order are prerequisites for the co-integration test. The number of co-integration equations in this study was ascertained using the Johansen co-integration test. These formulas aid in determining the long-term link between the birth rate, IMR, AFR, and life expectancy as independent factors and the death rate, which is the dependent variable.

Table 5: Lag order selection criteria: VAR order selection criteria (unrestricted VAR).

Lag	LogL	LR	FPE	AIC	SC	HQ
0	-510.56		6151.45	22.9138	23.1145	22.9886
1	-96.9485	827.22	.000196	5.64215	6.8466	6.09116
2	-6.34994	181.2*	.000196	2.72666*	4.93481*	3.54984*

Note: * indicates lag order selected by the criterion, LR: Likelihood Ratio test statistic (each test at 5% level), FPE: Final Prediction Error, AIC: Akaike Information Criterion, SC: Schwarz Information Criterion, HQ: Hannan-Quinn Information Criterion.

The findings in Table 6 confirmed the 1st hypothesis of the study, which states there is a unidirectional or bidirectional relationship between death rate and different socio-demographic variables (such as birth rate, IMR, life expectancy, and death rate) in the short run. At a significance level of $p < 0.05$, the critical values of the maximum and trace eigenvalue statistics, respectively, showed that alternative hypothesis 1 has been accepted and the null hypothesis is rejected. Five co-integrating equations were identified at this significance level in both tests. Co-integration is essential to establish Granger causality, indicating long-term stable relationships between the variables. Without co-integration and stationary variables, Granger causality tests are invalid. The error-correction model reflects the long-run adjustment in the co-integrated time series. The VECM was carried out in response to evidence of co-integration linkages (Engle and Granger, 1987).

Table 6: Johansen co-integration test for death rate as a dependent variable and socio-demographic factors as independent variables.

Hypothesis	Eigenvalue	Trace Statistics	0.05 Critical Value	Prob.**	Max-Eigen Statistics	0.05 Critical Value	Prob.**
None *	0.771376	132.8813	69.81889	0.0000	66.40551	33.87687	0.0000
At most 1 *	0.457246	66.47576	47.85613	0.0004	27.49946	27.58434	0.0513
At most 2 *	0.342705	38.97629	29.79707	0.0033	18.88300	21.13162	0.1003
At most 3 *	0.252814	20.09329	15.49471	0.0094	13.11485	14.26460	0.0753
At most 4 *	0.143650	6.978441	3.841466	0.0082	6.978441	3.841466	0.0082

Note: '*, rejection of the hypothesis at 0.05 level', '**MacKinnon et al. (1999) *p*-values'.

The VECM is employed to identify the number of co-integration equations among the variables, which was determined by performing the Johansen co-integration test. The results indicate that while the variables maintain long-run equilibrium relationships, they exhibit short-term disequilibrium. The VECM captures this short-term imbalance and dynamic structure. Its primary purpose is to account for short- and long-term adjustments in the variables and deviations from their equilibrium. Table 7 presents both the short- and long-run effects, and the co-integration equation results for the death rate and socio-demographic factors. The appropriate lag order for the VECM, determined using the FPE criterion, is two, consistent with the lag order of the VAR model. The co-integration vector of the VECM, $\beta = (1\ -0.311666\ -0.203076\ 0.209986\ 0.847932)$, is displayed in Table 7, while the adjustment parameters matrix α is found in Table 8. Based on the t-statistics, the coefficients for AFR and life expectancy are statistically significant.

Table 7: Results of co-integration equation.

Co-integrating Equation	CointEq1
DR	1.000000
BR	-0.311666[0.44980]
IMR	-0.203076[0.12737]
AFR	0.209986[0.05378]
LE	0.847932[0.37613]

Note: 'DR, Death rate', 'BR, Birth rate', 'IMR, Infant mortality rate', 'AFR, Adolescent fertility rate', 'LE, Life expectancy at birth; *t*-statistics in [ ].

Table 8: Estimation results of the vector error correction model and tests for socio-demographic variables.

Error Correction	Δ(DR)	Δ (BR)	Δ (IMR)	Δ (AFR)	Δ (LE)
CointEq1	-0.050977	-0.123348	0.209693	-0.915570	0.146786
	(0.13479)	(0.10220)	(0.02374)	(1.27738)	(0.27837)
	[-0.37820]	[-1.20698]	[8.83427]	[-0.71676]	[0.52731]
Δ (DR(-1))	-1.241019	-0.514838	-0.298557	-7.828360	3.272609
	(0.98061)	(0.74350)	(0.17269)	(9.29319)	(2.02519)
	[-1.26555]	[-0.69246]	[-1.72890]	[-0.84238]	[1.61595]
Δ (DR(-2))	2.089237	0.206446	0.022841	-5.630008	-3.666369
	(0.88810)	(0.67335)	(0.15639)	(8.41642)	(1.83412)
	[2.35249]	[0.30659]	[0.14605]	[-0.66893]	[-1.99898]
Δ (BR(-1))	-0.201714	0.642806	0.001350	2.387017	0.539805
	(0.25355)	(0.19224)	(0.04465)	(2.40287)	(0.52364)
	[-0.79556]	[3.34375]	[0.03024]	[0.99340]	[1.03087]
Δ (BR(-2))	-0.125966	0.011824	0.112335	2.237362	0.247404
	(0.25973)	(0.19693)	(0.04574)	(2.46143)	(0.53640)
	[-0.48499]	[0.06004]	[2.45603]	[0.90897]	[0.46123]
D(IMR(-1))	0.522863	1.098531	0.317641	8.607105	-0.991582
	(0.86435)	(0.65535)	(0.15221)	(8.19136)	(1.78507)
	[0.60492]	[1.67626]	[2.08683]	[1.05075]	[-0.55549]
Δ (IMR(-2))	-0.332692	-0.823136	0.471176	-6.348092	0.560990
	(0.75717)	(0.57408)	(0.13334)	(7.17562)	(1.56372)
	[-0.43939]	[-1.43383]	[3.53370]	[-0.88468]	[0.35875]
Δ (AFR(-1))	0.012904	-0.024867	-0.010851	-0.432058	-0.036991
	(0.02071)	(0.01571)	(0.00365)	(0.19630)	(0.04278)
	[0.62297]	[-1.58333]	[-2.97471]	[-2.20096]	[-0.86471]
Δ (AFR(-2))	0.027778	-0.007553	-0.010762	-0.473015	-0.057704
	(0.02106)	(0.01597)	(0.00371)	(0.19956)	(0.04349)
	[1.31914]	[-0.47309]	[-2.90227]	[-2.37027]	[-1.32688]
Δ (LE(-1))	-0.466475	-0.181732	-0.146261	-3.525956	1.380557
	(0.48073)	(0.36449)	(0.08466)	(4.55583)	(0.99281)
	[-0.97035]	[-0.49860]	[-1.72769]	[-0.77394]	[1.39055]
Δ (LE(-2))	1.039902	0.260430	0.004650	-1.543524	-1.837058
	(0.45614)	(0.34584)	(0.08033)	(4.32277)	(0.94202)
	[2.27980]	[0.75303]	[0.05789]	[-0.35707]	[-1.95012]
R^2	0.355517	0.588085	0.996172	0.252992	0.275692
Log likelihood (LL): -25.50088					
Akaike information criterion (AIC): 3.931858					
Schwarz criterion (SC): 6.405394					

Note: 'DR, Death Rate', 'BR, Birth Rate', IMR, Infant mortality rate', 'AFR, Adolescence Fertility Rate', 'LE, Life Expectancy Rate'; Standard errors in ( ) and t-statistics in [ ], 'Δ, the first difference'.

Consequently, both AFR and life expectancy have a positive impact on the death rate. Thus, the long-run co-integration equation can be expressed as follows:

$$DR_t = 0.311666BR_t + 0.203076IMR_t - 0.209986AFR_t - 0.847932LE_t \quad (7)$$

According to Eq. (7), assuming all other factors remain constant, a 1% increase in the birth rate and IMR will lead to a 0.3116% and 0.2020% rise in the death rate, respectively. Conversely AFR, life expectancy will result in 0.2099% and 0.8479% decrease on death rate.

The VEC model, based on the remaining endogenous and exogenous variables, estimates five distinct models- one for each endogenous variable. This study focuses on the first equation of the

VECM. The matrix α = (−0.050977, −0.123348, 0.209693, −0.915570, 0.146786) contains the adjustment coefficients for correcting disequilibrium in the co-integration equation. The VECM results show a long-run equilibrium relationship between the variables, as indicated by the negative and statistically significant ECT parameter (-0.050977, t-statistic = -0.37820). The negative α value suggests that the death rate is an endogenous variable, confirming the model's dynamic stability and alignment with theoretical expectations.

The study also confirms strong long-run equilibrium causality between the death rate and socio-demographic factors. The ECT coefficient of -0.050977 indicates that deviations from long-run equilibrium are corrected at 5.09% per period. This reflects a moderate speed of adjustment from disequilibrium to equilibrium. Furthermore, the predictor variables explain 35% of the variance in the dependent variable (R^2 = 0.355517). Although the R^2 value is below 0.55, the model has low AIC and SC values, indicating the reasonable estimation. Table 8 provides the detailed results.

The study used the Granger causality test to examine the causal relationships between the variables. The results show that all data series became stationary at their first difference, confirming the variables as $I(1)$. This makes the Granger causality test appropriate for the co-integrated variables, allowing for predicting potential causal links. Table 9 shows the results of the Granger tests with two lags. The analysis revealed unidirectional and bidirectional causalities between death rate and birth rate, IMR and death rate, death rate and IMR, death rate and AFR, life expectancy and death rate, death rate and life expectancy;,IMR and birth rate, birth rate and IMR, AFR and birth rate, birth rate and AFR, birth rate and life expectancy, IMR and birth rate, AFR and IMR, IMR and AFR, life expectancy and IMR, IMR and life expectancy, AFR and life expectancy, suggesting that changes in one factor would lead to changes in another.

Table 9: Granger causality test between the variables.

Null Hypothesis:	Observation	F-Statistic	Prob.	Decision	Direction of Causality
BR does not Granger Cause DR	45	0.25626	0.7752	Accept	None
DR does not Granger Cause BR		0.60613	0.5504	Reject	DR to BR
IMR does not Granger Cause DR	45	6.07343	0.0050	Reject	IMR to DR
DR does not Granger Cause IMR		1.91602	0.1605	Reject	DR to IMR
AFR does not Granger Cause DR	45	0.30817	0.7365	Accept	None
DR does not Granger Cause AFR		0.91527	0.4086	Reject	DR to AFR
LE does not Granger Cause DR	45	5.50231	0.0077	Reject	LE to DR
DR does not Granger Cause LE		5.14799	0.0102	Reject	DR to LE
IMR does not Granger Cause BR	45	2.33300	0.1101	Reject	IMR to BR
BR does not Granger Cause IMR		4.33548	0.0198	Reject	BR to IMR
AFR does not Granger Cause BR	45	2.05448	0.1415	Reject	AFR to BR
BR does not Granger Cause AFR		2.79241	0.0732	Reject	BR to AFR
LE does not Granger Cause BR	45	0.25282	0.7778	Accept	None
BR does not Granger Cause LE		4.12567	0.0235	Reject	BR to LE
AFR does not Granger Cause IMR	45	1.71468	0.1930	Reject	AFR to IMR
IMR does not Granger Cause AFR		2.51872	0.0933	Reject	IMR to AFR
LE does not Granger Cause IMR	45	3.07560	0.0572	Reject	LE to IMR
IMR does not Granger Cause LE		3.89891	0.0284	Reject	IMR to LE
LE does not Granger Cause AFR	45	0.43826	0.6482	Accept	None
AFR does not Granger Cause LE		1.35102	0.2705	Reject	AFR to LE

Note: ‘DR, Death Rate’, ‘BR, Birth Rate’, IMR, Infant mortality rate’, ‘AFR, Adolescence Fertility Rate’, ‘LE, Life Expectancy Rate’;‘* significant at 10%’, ‘** significant at 5%’.

6. Discussion

The test findings show that the variables have long-term associations with one another. When co-integration is found, it suggests that there are long-term movements in the variables together and departures from this equilibrium relationship. Life expectancy is associated with the death rate, as evident in the literature. For example, an expanded Global Burden of Disease (GBD) 2015 report examined the overall, cause-specific, and predicted years of life lost (YLL) for Iran and its neighbors between 1990 and 2015. Observed YLL measurements were computed by multiplying the deaths by the standard life expectancy at each age. The socio-demographic index (SDI) was derived by considering the overall fertility rate, average years of education, and per capita income (Moradi-Lakeh et al., 2017). Another study showed that death rates are associated with socio-demographic factors, examining cause-specific death rates and percentages across genders and locations (Alam et al., 2014).

The death rate, birth rate, and IMR have a causal relationship. Significant but distinct effects on mortality were discovered for preceding and subsequent birth intervals, with the former concentrating in the neonatal period and the latter during early childhood. Interestingly, most studies on this topic have consistently indicated a relationship between mortality and a short preceding birth interval despite wide variations in geographical locations, analytical techniques, and data quality (Koenig et al., 1990).

According to our results, if IMR increases, the death rate will also increase, and vice versa. Currently, both IMR and death rates are declining and they have a long-run relationship. In Bangladesh, the IMR appears to be approximately 150 per thousand live births, exhibiting year-to-year fluctuations with no apparent long-term trend. This rate is significantly higher than in many other countries, though similar figures have been observed in Yemen (163 per 1,000 in 1982) and Senegal (155 per 1,000 in 1982) (Ahmed, 1991). An increase in AFR will decrease in the death rate. Therefore, the government should address this issue, which depends on various factors. The authors contend that, in light of these data, donors ought to take a rights-based stance towards adolescent fertility and reorient their attention from the immediate to the indirect causes of pregnancy, such as violations of human rights, gender disparity, child marriage, and socioeconomic marginalization (Glassman et al., 2012).

Life expectancy affects the death rate and other socio-demographic elements. In our analysis, life expectancy is negatively related to the death rate and has a causal relationship with independent variables. This study aligns with the United States (US) situation. For most of the previous 60 years, life expectancy in the US has climbed; however, after 2014, this trend halted, and life expectancy declined. The death rate among young and middle-aged adults of all racial groups from specific causes has risen substantially. This trend began in the 1990s, with the Ohio Valley and New England experiencing the most significant relative increases (Woolf and Schoomaker, 2019).

Therefore, birth rate, AFR, IMR, and life expectancy are significant demographic factors influencing the death rate in Bangladesh. High birth rates and AFR contribute to higher death rates. The potential reasons for these findings could be due to inadequate healthcare services and maternal health challenges. Although there have been improvements in the healthcare system in Bangladesh, they are still not sufficient. Conversely, increasing life expectancy indicates greater awareness among citizens regarding health, nutrition, and other factors, as well as improvements in public health and healthcare services, leading to lower death rates. Policymakers must focus on integrated health and social policies that address these demographic factors to continue reducing the death rate and improving overall public health outcomes in Bangladesh.

This study contributes to the literature by exploring long-term associations between demographic factors (life expectancy, birth rate, IMR, AFR) and the death rate in Bangladesh. It confirms co-integration among these variables, indicating they move together over time with short-term fluctuations. The study expands on previous research by linking socio-demographic factors like education, income, and fertility to mortality outcomes, providing valuable insights into Bangladesh's context. It reinforces findings on the relationship between short birth intervals and higher mortality, emphasizing the need for improved maternal healthcare. Additionally, the study highlights the impact of adolescent fertility rates on mortality and suggests that addressing child marriage, gender inequality, and socioeconomic marginalization is crucial in reducing death rates. Finally, it underscores the importance of integrated health and social policies to improve public health, offering actionable insights for policymakers to reduce mortality and enhance life expectancy.

7. Practical implications

The study's findings carry important policy implications for identifying the critical factors behind Bangladesh's decline in death rates. Based on these results, the following policy recommendations are proposed: i) The government should develop programs and initiatives aimed at reducing both the birth rate and the infant mortality rate to help lower the overall death rate; ii) Government agencies should consider designing policies to increase life expectancy and address adolescent fertility; iii) Strategies for managing the death rate should prioritize efforts to reduce infant mortality, with support from private healthcare organizations; and iv) The government should implement effective legislation and awareness campaigns to decrease the death rate further . By adopting these measures, the government can enhance public health and well-being while effectively controlling the death rate.

8. Conclusions

This study analyzes annual time series data from 1975 to 2021 to assess the impact of socio-demographic factors on Bangladesh's death rate. The findings of this study highlight the long-term associations between key socio-demographic factors- such as life expectancy, birth rate, IMR, and AFR; and the death rate in Bangladesh. The presence of co-integration among these variables suggests that they are interrelated over time, with fluctuations reflecting departures from an equilibrium relationship. The study emphasizes that increasing IMR is associated with higher death rates, while improvements in life expectancy and reductions in AFR contribute to lower mortality. These results align with existing literature that shows the impact of socio-demographic factors, including fertility and education, on mortality outcomes. Although Bangladesh has made progress in healthcare, challenges remain, particularly in maternal health services, which continue to affect mortality rates. To effectively reduce the death rate and improve public health, policymakers must focus on integrated health and social policies that address these demographic factors and promote awareness, healthcare access, and socio-economic development.

9. Limitations and future directions of the study

This study has several limitations that future research could address. Firstly, as the research was conducted within the context of Bangladesh, its findings may need to be more generalizable to other developing nations. To validate these results, future studies should use longer time series data and more advanced analytical techniques across a broader range of developing countries. Secondly, the study relied exclusively on secondary data, limiting insights into the socio-demographic factors affecting mortality. Future research should incorporate primary data collection for a more comprehensive understanding. Lastly, this study examined only a limited set of socio-demographic variables. Future investigations should consider additional factors such as age, gender, race, ethnicity, income, education, marital status, occupation, geography, and lifestyle to better understand of their influence on mortality rates.

Abbreviations:

ADF: Augmented Dickey-Fuller; AFR: Adolescence fertility rate; AIC: Akaike information criterion; ARDL: Autoregressive Distributed Lag; BDHS: Bangladesh Demographic and Health Survey; COVID-19: Coronavirus Disease in 2019; ECT: Error correction term; FPE: Final prediction error; GBD: Global Burden of Disease; HQ: Hannan-Quinn Criterion; IMR: Infant mortality rate; JB: Jarque-Bera; LR: Likelihood ratio; MDG: Millennium development goal; PP: Phillips and Perron; SC: Schwarz Information Criterion; SD: Standard deviation; SDI: socio-demographic index; TFR: Total fertility rate; US: United Sates; VAR: Vector auto regression; VECM: Vector error correction model; YLL: predicted years of life lost.

Author contributions: FH and MNIM contributed to the study's conceptualization, developed the methodology, conducted data curation, performed formal analysis, and interpreted the results. Additionally, FH, MAI and MMI wrote the article's first draft and reviewed and edited it. FH, MMI and MNK reviewed and edited the article and validated the research. All authors have read and agreed to the final version of the manuscript.

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