Population Growth, Economic Development and Food Security: A Comparative Study of Pakistan, Bangladesh and India

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Abstract

Addressing undernourishment in Pakistan, Bangladesh, and India remains a critical challenge. This study analyses World Bank data (2001–2021) using econometric techniques to examine the impact of population growth and GDP per capita on undernourishment levels. Findings reveal that population growth significantly exacerbates undernutrition across all three countries, with long-term demographic trends playing a key role. The study employs the Difference-in-Differences (DiD) method to establish a causal link between population growth and increasing undernourishment. Results indicate a strong positive correlation between population growth and undernutrition, while the effects of GDP per capita growth vary. In Bangladesh, economic growth helps alleviate undernourishment, whereas in Pakistan and India, its impact remains minimal or statistically insignificant. These findings highlight the need for targeted policies addressing both demographic and economic factors to improve food security. Key policy recommendations include promoting sustainable agricultural practices, improving rural infrastructure to minimise food losses, and strengthening social safety nets for vulnerable populations. Climate change adaptation and mitigation strategies are essential to counter environmental threats to food security. This study provides policymakers and stakeholders with valuable insights for combating undernourishment and enhancing food security in South Asia.

Keywords: Population Growth, Economic Development, Food Security, Undernourishment, Robust Regression, GDP per Capita, Panel Data Analysis, South Asia.

Introduction

The world is undergoing rapid changes influenced by population growth, urban expansion, technological advancements, and climate change. These developments present significant obstacles to eliminating hunger and poverty while striving to build sustainable agricultural practices and robust food systems. Over time, food security has evolved beyond emphasising food stocks to encompass providing adequate, safe, and nutritious access to food for leading a healthy life (Reddy, 2016). Food security is a state in which everyone consistently has physical and economic access to adequate, safe, and nutritious food that meets their dietary requirements and preferences for maintaining a healthy and active lifestyle (Ickowitz et al., 2019). Conversely, food

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insecurity arises when households and individuals lack the means to obtain enough quantity and quality of food to meet their basic dietary needs, representing a fundamental aspect of human poverty (Hashmi et al., 2018).

Despite global efforts, hunger remains a critical issue, with approximately 828 million people experiencing acute hunger and 2.3 billion lacking sufficient access to food. Recent reports indicate that although undernourishment in Asia declined in 2024, South Asia continues to face significant challenges with food insecurity and child malnutrition (FAO & UN, 2022 and 2025; UNICEF/FAO, 2025). Global and regional assessments highlight persistent disparities in access to adequate nutrition and emphasise the need for sustained efforts to achieve food security by 2030. The prevalence of undernourishment has increased, particularly in Sub-Saharan Africa, with slow progress in regions like West Africa, especially Nigeria (Hambloch et al., 2022; Adeyemi et al., 2022; Ullah et al., 2023). Around two billion people worldwide suffer from hidden malnutrition, with developing countries spending more of their disposable income on food than developed nations (Salam et al., 2022). The Sustainable Development Goals (SDGs) aim to eliminate hunger and address all forms of undernourishment by 2030, integrating these goals into a broader development agenda (Fanzo et al., 2020). Urbanisation plays a pivotal role in shaping food security. By 2011, more than half of the world's population lived in urban areas, projected to increase to two-thirds by 2050 (van Zutphen et al., 2023). Cities are forecasted to consume 80% of the global food supply and generate 85% of worldwide economic output. Rapid urbanisation, population growth, and climate change pose significant challenges for Pakistan, Bangladesh, and India.

Food Security Challenges in South Asia

Ensuring food security remains a critical issue in South Asia, particularly in Pakistan, Bangladesh, and India, where a significant portion of the population struggles to obtain adequate nutrition (Rehman et al., 2020). A multifaceted interplay of factors such as population growth, economic progress, climate change, and inefficiencies in food distribution systems influences the region's food security challenges. This analysis examines the unique obstacles each country faces and proposes holistic approaches to address these pressing concerns. Pakistan, a developing nation with a low-income economy, faces considerable difficulties in its agricultural sector, exacerbated by rapid population growth and urbanisation. Despite a five-fold increase in wheat production over the last six decades, the country remains reliant on wheat imports (World Bank 2023), particularly from marginal sources. The government's wheat-focused food policy, which heavily subsidises urban consumers, has led to discrepancies in food supply and distribution, negatively impacting rural farmers and urban populations. Around 40 per cent of households in Pakistan face food insecurity, highlighting the struggle to provide enough nutritious and safe food for a significant portion of the population (Farrukh et al., 2020). The agricultural sector is particularly vulnerable to climate change because it relies on rainfall for irrigation, which can reduce agricultural productivity. Altered rainfall patterns, rising temperatures, and increased extreme weather events, such as floods and droughts, further exacerbate the situation. The COVID-19 pandemic has worsened food insecurity, pushing 20-30 per cent of the population—approximately 40-62 million people—into acute food insecurity, driven by economic, environmental, and climatic challenges (Ubaid-ur-Rehman et al., 2021). The catastrophic 2022 floods added to these issues, displacing 33 million people and requiring an estimated $16.3 billion for recovery and rebuilding efforts (World Bank 2022)

Despite achieving food self-sufficiency, Bangladesh continues to struggle to ensure its population has access to nutritious food. The country's high population density and vulnerability to climate change significantly affect agricultural productivity and food security (Islam et al., 2020). Challenges such as climate change impacts, population growth, and limited arable land pose significant obstacles to achieving food security in Bangladesh. Although progress has been achieved in alleviating poverty and malnutrition, tackling the underlying causes of food insecurity remains a crucial priority (Fahim et al., 2021). India's food security challenges stem from uneven economic development, resulting in disparities in food access and distribution (Kumar et al., 2020). With over 194 million individuals affected, India is home to a significant number of malnourished people globally. In India, food insecurity is strongly associated with poverty, limited access to nutritious food, and insufficient food storage and distribution systems. Climate variability, dwindling water resources, and soil degradation pose additional challenges to food security in India.

Addressing the Challenges: A Comprehensive Strategy

Tackling food security challenges in Pakistan, Bangladesh, and India requires a comprehensive approach that encompasses multiple strategies. Critical actions include adopting sustainable agricultural techniques, such as conservation farming and drought-tolerant crop varieties, to bolster resilience against climate variability. Enhancing rural infrastructure, including roads, storage facilities, and cold chain systems, minimises post-harvest losses and improves market access. Expanding food assistance initiatives and reinforcing social safety nets are crucial to ensuring vulnerable groups have reliable access to adequate nutrition. Promoting crop diversification and introducing nutrient-dense, climate-resilient crop varieties can improve dietary standards and strengthen adaptation to environmental changes.

Additionally, implementing climate change mitigation and adaptation strategies—such as disaster risk management and early warning systems—is imperative for safeguarding food security. Sustainable and inclusive solutions are essential to address the problem's intricate, multifaceted nature. Recent studies underscore the urgency of these interventions. The importance of sustainable farming practices in meeting increasing food demands while protecting the environment is emphasised, as is the need to empower smallholder farmers by enhancing their access to resources and markets to improve food security (Smith et al., 2023; Jones et al., 2024).

Literature Review

This section explores the relationship between population growth, economic development, and food security, highlighting ongoing debates in neighbouring countries. Analysing data from 1990 to 2021 using the Dynamic Common Correlated technique, findings indicate that climate change negatively affects food availability, whereas renewable energy sources enhance short-term food security. To mitigate climate change impacts, the study emphasises investments in climate adaptation services, resilient infrastructure, drought-tolerant crops, improved farming practices, and advanced weather forecasting systems (Rehman et al., 2024). Pakistan faces significant challenges related to population growth and food insecurity, driven by limited access to family planning, low literacy rates, and rapid urbanisation. The solid strategies can collectively support population control while enhancing food production capacity for a sustainable future (Sabir & Nawaz, 2023).

Food utilisation and sustainability have declined in Pakistan, with food insecurity affecting 8% of non-farmers and 4% of farmers between 2008 and 2018. Although food availability and access have improved, stronger public policy measures are needed. Data from HIES 2018-19 reveals that 40.2% of households experience food insecurity, with Balochistan (53.3%) being the worst affected, followed by KP (49.5%), Sindh (43.9%), and Punjab (35.5%). Additionally, 44.6% of the population faces a protein deficit, while over 55.9% do not consume a balanced diet (Ahmad & Saboor, 2022; Mansha, Yang, ul Mustafa, & Nasim, 2022). Household size, gender, employment, and social safety nets influence food security. Targeted regional strategies and inclusive policies focusing on agriculture, trade, and income generation are essential to achieving zero hunger (Hameed et al., 2022). Financial inclusion significantly improves food security in South Asia, particularly in India, Pakistan, and Bangladesh. Access to financial services enhances income stability and agricultural productivity, thereby reducing food insecurity. Similarly, adequate food and clean water are essential for survival, yet over a billion people suffer from dietary energy shortages, with many more facing nutrient deficiencies (Shahid, 2022).

Additionally, overweight prevalence among children aged 24-59 months increased from 2004 to 2014, especially among girls and children from wealthier, more educated households, indicating the need for targeted public health programs (Sultana & Sabau, 2023; Shah et al., 2021; Shawon et al., 2020). Despite achieving self-sufficiency in food production, Bangladesh continues to struggle with food security and quality, necessitating greater efforts from the government and NGOs to promote dietary diversification (Roy et al., 2019). Research in Bangladesh found a negative relationship between population growth and per capita GDP growth, underscoring the economic challenges posed by rapid population expansion. To address these issues, policies should focus on family planning, media development, and education (Chowdhury et al., 2019). Agriculture is crucial to India's food security by enhancing productivity, improving infrastructure, and adopting sustainable practices. Strengthening the agricultural sector is vital for long-term food security in the country (Saurkar & Agrawal, 2022; Ul Mustafa, Abro, & Awan, 2021). A review of 26 studies on food security and economic growth from 2004 to 2021 revealed a complex relationship. While most studies found a positive impact of economic growth on food security, some showed no correlation or a negative effect. Food security remains critical in India due to its large population and agricultural dependence. Policies like the NFSA (2013) and the National Food Security Mission have helped reduce hunger and malnutrition, but poverty, poor infrastructure, and climate change persist (Fernandes & Samputra, 2022).

The challenges posed by India's overpopulation threaten food security. Adequate measures, including policy reforms and resource management, are necessary to control population growth and ensure sustainable food availability (Yoganandham et al., 2023). Recent studies add further depth to these conclusions. Reddy and Rahut (2025) identify smallholder farmer sustainability as a key channel through which economic development influences food security outcomes in South Asia, underscoring the role of institutional strengthening and well-targeted policy interventions. In parallel, Mahbub et al. (2025) document substantially higher levels of food and nutrition insecurity in climate-exposed regions of Bangladesh, underscoring the importance of location-specific climate adaptation measures. Collectively, this evidence suggests that effective reductions in undernourishment require integrated strategies that address population dynamics, unequal economic progress, and environmental vulnerability simultaneously.

Data and Methodology

The research utilises annual data sourced from the World Bank, spanning from 2001 to 2020, to examine the impact of population growth rates (pg) and GDP per capita growth rates (gdppcg) on the prevalence of undernourishment (undernur) in Pakistan, Bangladesh, and India. Figure 01 illustrates the percentage of the population experiencing undernourishment in these nations over the 2001-2021 period. It shows a general decline in undernourishment over the years, with occasional fluctuations. Bangladesh decreased from 15.6% in 2001 to 11.2% in 2021, India from 18.3% to 16.6%, and Pakistan from 20.8% to 18.5%. These trends demonstrate efforts and advances to alleviate hunger and enhance food security in South Asia.

Figure 01: Percentage of the population experiencing undernourishment in three neighbouring countries

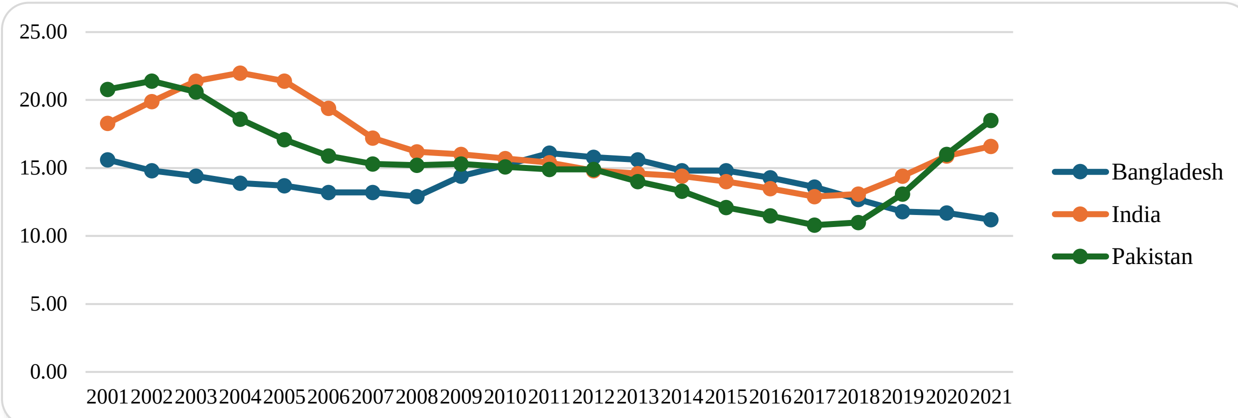


Figure 02 illustrates Bangladesh's annual GDP growth rates, showing steady growth with a peak at 7.8819% in 2019, a dip to 3.4480% in 2020 due to global economic challenges, and a rebound to 6.9387% in 2021. India displays significant fluctuations, reaching a high of 9.0503% in 2021 after a contraction of -5.8311% in 2020. Pakistan's growth is more variable, with highs like 7.8313% in 2004 and lows including -1.2741% in 2020, recovering to 6.5139% in 2021. The data reflect varied economic performances influenced by domestic and global factors over the two decades. The study utilized three econometric techniques: robust ordinary least squares (OLS) with MM-estimation, fully modified ordinary least squares (FMOLS) for cointegration, and difference-in-differences (DiD) analysis. These methods were independently applied to explore potential long-term relationships, cointegration and causal link between dependent variable and predictors.

Figure 02: GDP growth (annual percent) among three neighbouring countries

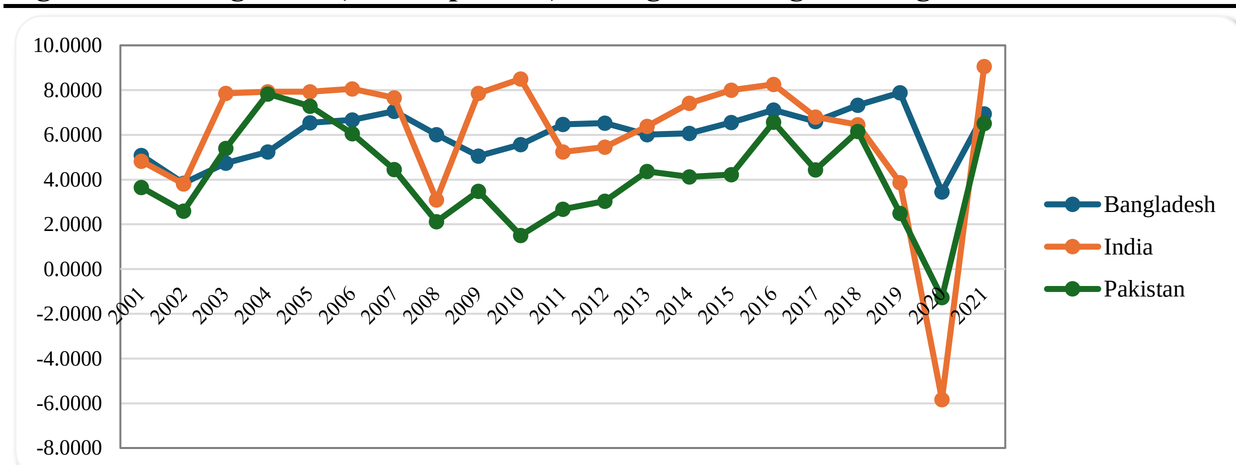
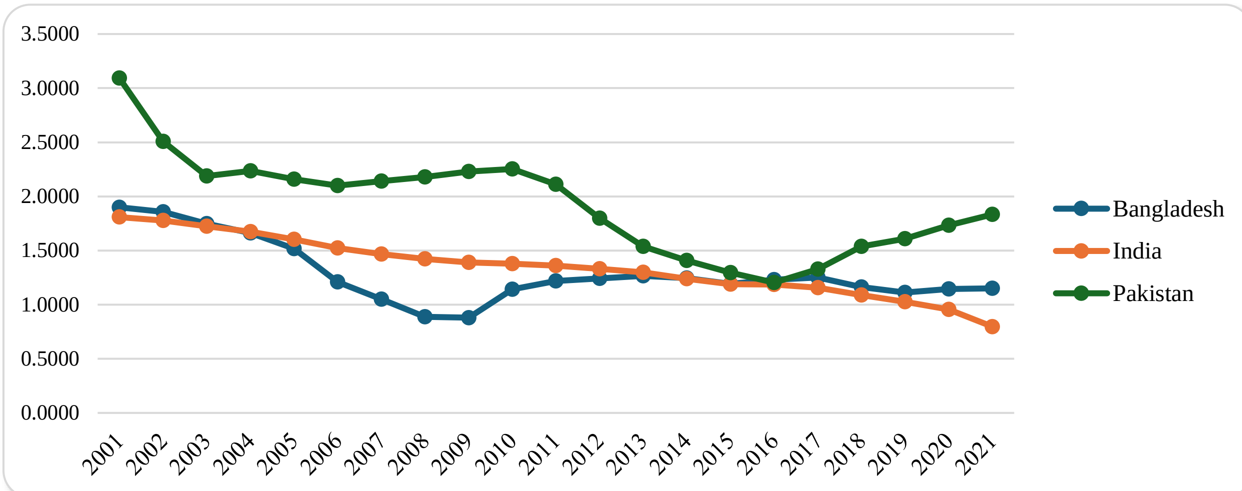


Figure 03 presents annual population growth rates for Bangladesh, starting at 1.8993% in 2001, declining to a low of 0.8801% in 2009, and stabilizing around 1.14%-1.25% in subsequent years. India consistently decreased from 1.8084% in 2001 to 0.7972% in 2021. Pakistan started with the highest growth rate of 3.0921% in 2001, gradually decreasing with minor fluctuations, ending at 1.8341% in 2021. Overall, these countries have exhibited a trend of declining population growth rates over the past two decades.

Figure 03: Population growth (annual percent) among three neighbouring countries



Given the linearity assumptions inherent in robust OLS, FMOLS methods, and the Difference-in-Differences (DiD) approach, DiD technique has been used to estimate the average treatment effect by comparing changes in average outcomes over time between the treatment and control groups. Due to the sensitivity of OLS estimators to outliers, robust least squares methods such as M-estimation, S-estimation, and MM-estimation have been utilized. M-estimation mitigates the influence of outliers in the dependent variable, S-estimation in the independent variables, and MM-estimation combines both methods. MM estimation was explicitly applied to data from Pakistan, Bangladesh, and India using the precise objective specification, scale estimator, and covariance type. The coefficient covariance matrix has been computed using Huber's method (Type II) for unbiased estimates, as shown in Equation (1).

$$\wedge \frac{\left[\frac{1}{N-K}\right]\sum_{i=1}^{N}\psi_{c(r_i^2)}}{\left[\left(\frac{1}{N}\right)\sum_{i=1}^{N}\psi'_c\, r_i\right]2}\, W^{-1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$\wedge = 1 + \frac{N}{K}\frac{\sum_{i=1}^{N}[\psi'_C(r_i)\overline{\psi'_c}]}{(\overline{\psi'_C})2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

$$\overline{\psi'} = \left(\frac{1}{N}\right)\sum_{i=1}^{N}\psi'_c\,(r_i)$$

$$W_{js} = \sum_{i=1}^{N} \psi_c' (r_i) x_{ij} x_{is}$$
$$j, s = 1, \dots, k$$

Where $\psi_c(.) = \rho_c'(.)$ and x_{ij} represents the value of jth regressor for observation i. Pedroni employs an approach that estimates the cointegrating relationship for each unit individually before pooling the residuals to test for cointegration across the panel (Pedroni, 2004). Engle and Granger observed that a linear combination of the I(1) series can achieve stationarity, indicating cointegration. The study utilizes a fully modified OLS (FM-OLS) weighted approach, applying a pooled OLS estimator for the cointegrated panels with heterogeneous long-run cross-section variances, estimating a long-run variance $(\widehat{\Lambda})$ and the regressors $(\widehat{\Omega})$ is essential; please refer to equations (3) and (4) for further details.

$$\widehat{\gamma_{12\iota}+} = \hat{\gamma}_{12i} - \omega_{12\iota}\widehat{\Omega_{22\iota}^{-1}}\,\widehat{\Lambda_{22\iota}} \quad \dots \dots (3)$$

$$\widehat{y_{\iota t}^{++}} = \widehat{y_{\iota t}} - \widehat{\omega_{12\iota}}\widehat{\Omega_{22}^{-1}}\widehat{\mu_2} - \widehat{\omega_{2.1\iota}^{-\frac{1}{2}}}\left(\widehat{\omega}_{2.1i}^{-\frac{1}{2}} X_{it}' - \widehat{\omega_{12\iota}} X_{it}\right)^{\prime\alpha_0} \quad \dots \dots (4)$$

Here, α_0 denotes the previous estimate of a long-run coefficient. Equation (5) provides a detailed representation of the arrangement of the weighted variables.

$$\widehat{X_{\iota t}^{*}} = \widehat{\Omega_{22\iota}^{-1/2}}.\ \widehat{X_{\iota t}}$$

$$\hat{y}_{\iota t}^{*} = \widehat{\omega_{1.2\iota}^{-1/2}}.\widehat{y_{\iota t}^{++}} \quad \dots \dots (5)$$

$$\widehat{\gamma_{\iota}^{*}} = \widehat{\omega_{1.2\iota}^{-1/2}}.\widehat{\gamma_{12\iota}^{+}}.\widehat{\Omega_{22\iota}^{-1/2}}$$

Equations (6) and (7) present the estimator and its asymptotic covariance, respectively.

$$\widehat{\alpha_{fw}} = \left(\sum_{i=1}^{N}.\sum_{t=1}^{T} \widehat{X_{it}^{*}\widehat{X_{it}^{*\prime}}})^{-1} \sum_{i=1}^{N}.\sum_{t=1}^{T} (\widehat{X_{it}^{*}}\,\widehat{y_{it}^{*}} - \widehat{\gamma_{12\iota}\,{*}'}\right) \quad \dots \dots (6)$$

$$\widehat{V_{fw}} = \left(\frac{1}{N}\sum_{i=1}^{N} (\frac{1}{T^2}\sum_{t=1}^{T} \widehat{X_{it}^{*}}\widehat{X_{it}^{*\prime}}\right) \quad \dots \dots (7)$$

The (DiD) utilizes longitudinal data from treatment and control groups to estimate the causal effect by establishing a counterfactual (Goodman-Bacon, 2021; Bhavani et al., 2022). DiD focuses on assessing changes in outcomes over time rather than absolute levels. While it can utilize cross-sectional data, most studies employ panel data. At the treatment date (D^*), selected subjects receive the treatment (group T) while others do not (group NT). The data includes a time series of the outcome variable, Y, for periods before and after treatment. To estimate the average treatment effect on the treated (ATET), a fixed effects model is employed with fixed effects for cross-sections and a dummy variable indicating treatment.

Where g is a constant specific to each individual (i) and indicates treatment ($g = 1$) or non-treatment ($g = 0$), $D_{g,t}$ takes the value of 1 when an observation undergoes treatment. Under this identification, the average treatment effect on the treated (ATET) equates to the value of ϑ. The estimation of ϑ aligns with the results obtained from panel two-way fixed effects regression (TWFE), as in Equation (8). The calculation of ATET may also be integrated into the OLS regression model framework, as illustrated in Equation (9).

$$Y = \alpha_0 + \alpha_1 D + \alpha_2 T + \alpha_3 (D.T) + \varepsilon \ldots \ldots \quad (8)$$

In the model, D represents a dummy variable that equals one if our observation occurs after D^*, while T is a dummy variable that equals one if the observation belongs to a treated group. The average treatment effect on the treated (ATET) corresponds to the value of α_3, this evaluates the additional effect of belonging to the treatment group following (D^*). A critical assumption for obtaining unbiased estimates (ϑ) in Difference-in-Differences (DiD) analysis is the parallel trends assumption. This assumption posits that the treatment and control groups exhibit parallel outcome trends without treatment. It ensures that the outcome difference between groups will remain constant without treatment. DiD is well-suited for impact assessment and yields robust results. When comparing a treatment group to a control group that is either consistently untreated or always treated, changes in the control group's outcomes before and after the treatment date should accurately represent the untreated variations within the treatment group.

Results and Analysis

Before presenting the estimation results, we conducted unit root tests on the series levels using the ADF-Fisher Chi-square and ADF-Choi Z-stat tests, independent across cross-sections. These tests assist in determining the integration orders of the series, where the null hypothesis suggests the presence of a unit root. Table 1 summarizes the findings: most variables were non-stationary at the 5% significance level. Exceptions include undernourishment in India, GDP per capita growth in Pakistan and India, and population growth in Bangladesh, which were stationary at the 1% and 10% significance levels, respectively. The tests were conducted with individual effects and linear trends across 53 observations, with lag length selection based on the Schwarz Information Criterion (SIC). Specifically, for Pakistan, the ADF-Fisher chi-square statistic is 13.853 (p = 0.031), and the ADF-Choi Z-stat is -1.790 (p = 0.037); for Bangladesh, the ADF-Fisher chi-square statistic is 16.015 (p = 0.014), and the ADF-Choi Z-stat is -2.326 (p = 0.010); for India, the ADF-Fisher chi-square statistic is 21.334 (p = 0.0016), and the ADF-Choi Z-stat is -1.835 (p = 0.033). Individual series tests revealed that undernourishment is stationary in India (p = 0.003), GDP per capita growth is stationary in both Pakistan (p = 0.055) and India (p = 0.009), and population growth is stationary in Pakistan (p = 0.027) and Bangladesh (p = 0.0073).

Table 1: Results of the Group Unit Root Test for Food Security Indicators in Pakistan, Bangladesh, and India

Null Hypothesis: Presence of a unit root (individual unit root process) Variables: Prevalence of undernourishment (undernur), GDP per capita growth (gdppcg), and Population growth (pg).						
Exogenous factors: Individual effects and individual linear trends						
Automatic selection of maximum lags						
Total number of observations: 53						
Automatic lag length selection based on SIC: 1 to 3	Pakistan		Bangladesh		India	
Number of cross-sections included: 3						
Method	Statistic	Probability	Statistic	Probability	Statistic	Probability
ADF-Fisher chi-square test	13.853	0.031	16.015	0.014	21.334	0.0016
ADF - Choi Z-statistic	-1.790	0.037	-2.326	0.010	-1.835	0.033
Undernourishment		0.668		0.2178		0.003
GDP per capita growth		0.055		0.2099		0.009
Population growth		0.027		0.0073		0.976

***Probabilities for Fisher tests are calculated using an asymptotic chi-square distribution, while all other tests assume asymptotic normality.*

Table 2 presents the MM-robust results, displaying comparable standard errors for coefficients across the models in Pakistan, Bangladesh, and India. The MM estimate for Bangladesh is notably more extensive than that of Pakistan and India. The goodness of fit measures, R^2 statistics, and test outcomes are similar across MM estimations, as Pakistan shows the highest values and Bangladesh the lowest. Using the MM-robust method, we observe a statistically significant positive effect of population growth on undernourishment at the 1% significance level in all three countries. GDP per capita growth affects undernourishment negatively at the 1% level exclusively in Bangladesh, while it demonstrates a positive impact in Pakistan and India. We conducted the analysis using Robust Ordinary Least Squares, setting the logarithm of the Prevalence of Undernourishment (UNDERNUR) as the dependent variable. The adjusted sample size included 20 observations, with all adjustments accounted for. We applied MM-estimation, configured with S-settings that featured tuning at 1.547645, a breakdown value of 0.5, 200 trials, a subsample size of 3, refinement at 2, and 5 comparisons. We employed a bi-square weighting function with a tuning parameter of 4.684 for M-settings and scaled the H-matrix. We calculated standard errors and covariance using the Huber Type II method.

Table 2: Comparison of Robust MM Estimation Results for Food Security Indicators in Pakistan, Bangladesh, and India

Dependent Variable: Logarithm of the Prevalence of Undernourishment (UNDERNUR)				
Variable (Pakistan)	Coefficient	Std. Error	z-Statistic	Probability
Constant (C)	1.9515	0.1188	16.4168	0.000
Population growth (annual %)	0.40081	0.0624	6.4197	0.000
Annual percentage change in GDP per capita (first difference)	0.0227	0.0095	2.3832	0.017
Variable (Bangladesh)				
Constant (C)	2.7874	0.1051	26.5050	0.000
First difference of Population growth (annual %)	0.3759	0.1380	2.7223	0.006
Log of GDP per capita growth (annual %)	-0.0781	0.0669	-1.1674	0.243
Variable (India)				
Constant (C)	2.4180	0.0441	54.8230	0.000
Log of Population growth (annual %)	1.1450	0.1262	9.0710	0.000
First difference of GDP per capita growth (annual %)	0.0037	0.0069	0.5295	0.596
Robust statistics				
		Pakistan	Bangladesh	India
Coefficient of determination (R-squared)		0.65401	0.2443	0.4746
Adjusted coefficient of determination (R-squared)		0.61331	0.1498	0.4129
Rw-squared (Robust R-squared)		0.76622	0.3945	0.9024
Adjusted Robust R-squared		0.76622	0.3945	0.9024
Akaike Information Criterion (AIC)		19.9908	22.162	33.881
Schwarz criterion		24.6864	27.289	39.405
Residual sum of squares (Deviance)		0.16777	0.0953	0.1297
Scale		0.10337	0.0719	0.0653
Rn-squared statistic		45.4679	8.6165	82.823
Prob. (Rn-squared statistic)		0.0000	0.0134	0.0000
Non-Robust statistics				
Mean Dependent Variable		2.7057	2.6385	2.7860
S.E. of regression		0.10526	0.0940	0.1940
S.D. dependent var		0.1921	0.0912	0.1670
Sum squared resid		0.1883	0.1411	0.6370

Note: Random number generator: rng=kn, seed=693673060 for Pakistan; seed= 1867785089 for Bangladesh and seed=698414356 for India

The robust least squares analysis highlights significant factors influencing undernourishment in Pakistan, Bangladesh, and India. In Pakistan, population growth and GDP (per capita growth) have substantial effects, with a 1% increase in population growth leading to a 0.40 increase in the log of undernourishment and a 1% GDP per capita growth resulting in a 0.02 increase. The model explains 65% of the variation in undernourishment. In Bangladesh, only population growth significantly impacts undernourishment, with a 1% increase leading to a 0.38 rise in the log of undernourishment; while GDP per capita growth is not significant, the model explains 24% of the variation. In India, population growth significantly impacts undernourishment, with a 1% increase causing a substantial 1.15 increase in the log of undernourishment, whereas GDP per capita growth is not significant. The model explains 47% of the variation. The robust statistics indicate reliable models, particularly for India, with a Rw-squared value of 0.9024, highlighting the importance of policies addressing population growth and economic development to combat undernourishment in these countries.

Table 3: Panel Cointegration Analysis Results Applying the Panel Fully Modified Least Squares (FMOLS) Method to Examine the Prevalence of Undernourishment

Dependent Variable: Prevalence of Undernourishment (UNDERNUR)				
Variables	Coefficient	Std. Error	t-Statistic	Prob.
Population growth (annual %)	5.809	1.269	4.580	0.000
First difference of GDP per capita growth (annual %)	0.179	0.111	1.75	0.011
Summary Statistics				
R-squared	0.5237	Mean dependent var	15.0070	
Adj. R-squared	0.4870	S.D. dependent var	2.5310	
S.E. of regression	1.8127	Sum squared resid	170.879	
Long-run variance	6.4023			

Source: Author's calculations using World Bank data (2021)

This study explores the prevalence of undernourishment using panel cointegration analysis, focusing on the relationship between population growth and GDP per capita growth. The dependent variable, undernourishment, is analyzed through the Panel Fully Modified Least Squares (FMOLS) method under a fixed-effect framework. Population and GDP per capita growth are the key regressors, with a constant term addressing fixed effects in the trend specification. The dataset includes balanced observations from 2001 to 2020 across three country groups. The adjusted dataset spans 2003 to 2021, covering 19 time periods and three cross-sections, resulting in 57 balanced observations. We applied a pooled estimation approach, included a deterministic constant (C), and added a trend regressor (@TREND). We calculated coefficient covariances using the default method and estimated long-run covariance with a Bartlett kernel and Newey-West bandwidth. Findings in Table 3 indicate a significant positive association between population growth, GDP per capita growth and undernourishment. Population growth has a coefficient of 5.809 and a t-statistic of 4.580 ($p = 0.000$), while GDP per capita growth shows a coefficient of 0.179 with a t-statistic of 1.75 ($p = 0.011$). R-squared value of 0.5237 indicates that our model explains 52.4% of the variance in undernourishment prevalence.

Table 4: Pedroni residual cointegration test results for food security indicators

Series: Prevalence of undernourishment (undernur), GDP per capita growth (gdppcg), Population growth (pg)				
	Stat.	Prob.	Weighted Stat.	Prob.
Panel v-Stat.	1.268	0.103	0.765	0.222
Panel rho-Stat.	0.646	0.740	0.895	0.815
Panel PP-Stat.	1.050	0.853	1.370	0.914
Panel ADF-Stat.	-1.441	0.075	-1.054	0.146

Alternative hypothesis: individual A.R. coefficients (between-dimension)				
	Statistic		Prob.	
Group rho-Stat.	1.634		0.948	
Group PP-Stat.	2.129		0.983	
Group ADF-Stat.	-0.340		0.366	
Cross-section-specific outcomes				
Phillips-Peron calculations (non-parametric)				
Cross ID	AR (1)	Variance	HAC	Bandwidth
Pakistan	0.645	1.933	1.933	0
Bangladesh	0.982	0.345	0.739	3
India	0.900	1.34	2.658	2
Augmented Dickey-Fuller calculations (parametric)				
Cross ID	AR (1)	Variance	Lag	Max. lag
Pakistan	0.423	0.677	1	3
Bangladesh	0.744	0.159	2	3
India	0.902	0.279	2	3

Source: Author's calculations using World Bank data (2021)

Table 4 presents the results of the Pedroni residual cointegration test, analyzing food security indicators such as the prevalence of undernourishment, GDP per capita growth, and population growth from 2001 to 2021 (Pedroni, 2000). The analysis includes 63 observations from three cross-sections. The test evaluates the null hypothesis of no cointegration with no deterministic trend assumption and automatic lag length selection based on SIC, with a maximum lag of 3. Newey-West bandwidth selection and Bartlett kernel were applied during the test. The results indicate no cointegration under the alternative hypothesis of standard A.R. coefficients (within-dimension), as reflected in the Panel v-statistic (1.268, p = 0.103) and the panel rho-statistic (0.646, p = 0.740). Similarly, the Panel PP-Statistic (1.050, p = 0.853) and the ADF-Statistic (-1.441, p = 0.075) fail to reject the null hypothesis. When testing under the alternative hypothesis of individual A.R. coefficients (between-dimension), the Group rho-statistic (1.634, p = 0.948), Group PP-Statistic (2.129, p = 0.983), and Group ADF-Statistic (-0.340, p = 0.366) also do not provide evidence to reject the null hypothesis of no cointegration. The cross-sectional results display the AR(1) coefficients, variances, and bandwidths for the Phillips-Peron and Augmented Dickey-Fuller tests for each country group (Pakistan, Bangladesh, and India), offering insights into the individual dynamics of the series.

Table 5: Results of Difference-in-Differences (DiD) Analysis for Prevalence of Undernourishment

Dependent variable: prevalence of undernourishment, % of the population (undernur)				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
Population Growth (% Annual)	2.719	0.784	3.470	0.001
Summary statistics				
R-squared	0.691	Mean dependent var		15.36
Adjusted R-squared	0.509	S.D. dependent var		2.728
S.E. of regression	1.911	Akaike info criterion		4.416
Sum squared resid	142.522	Schwarz criterion		5.232
Log-likelihood	-115.109	Hannan-Quinn criteria.		4.737
F-statistic	3.795	Durbin-Watson stat		0.250
Prob(F-statistic)	0.0001			

Source: Author's calculations using World Bank data (2021)

The research employs the two-way fixed-effects (TWFE) approach, utilizing a single treatment data framework to assess the Average Treatment Effect on the Treated (ATET) for undernourishment prevalence. This technique evaluates changes in undernourishment by comparing treated and untreated groups before and after the treatment date. Table 5 reports the (DiD) results, analyzing the impact of population growth over 21 years using 63 balanced panel observations across three cross-sections. The DiD estimation shows that population growth significantly increases undernourishment prevalence, with a coefficient of 2.719 and a t-statistic of 3.470 ($p = 0.001$). The model explains 69.1% of the variation in undernourishment, with an AIC of 4.416, confirming a good fit. An F-statistic of 3.795 ($p = 0.0001$) highlights the regression's statistical significance. Figure 04 illustrates population growth's effect on undernourishment, using 2011 as the average treatment date. The "Always" and "Never" categories represent consistently treated and untreated groups.

Figure 04: DiD Estimation results for undernourishment and treatment date (2011)

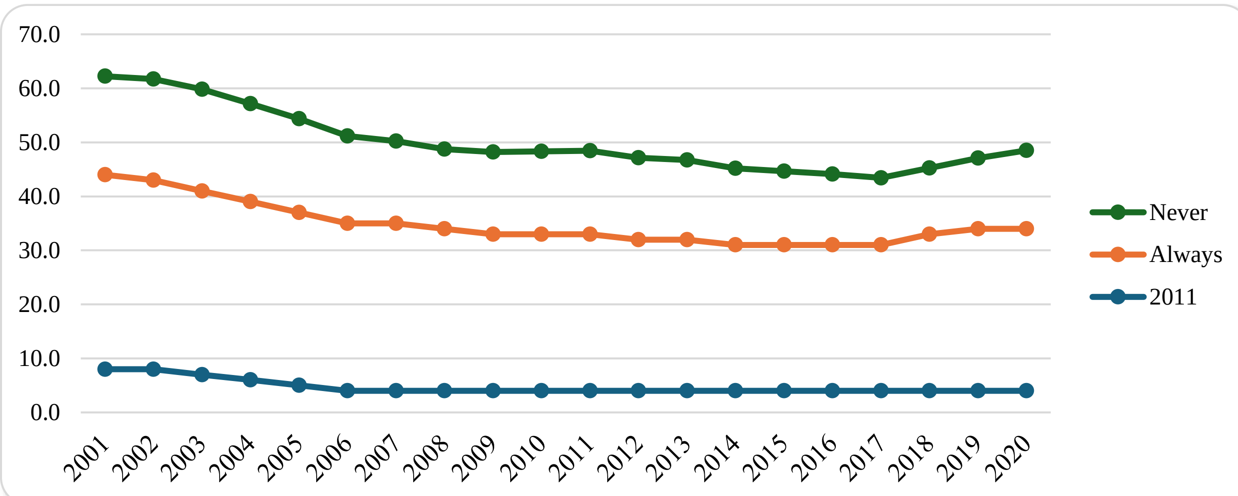


Table 6 summarizes trends in the prevalence of undernourishment based on different treatment and observation dates. The figure presents the average prevalence of undernourishment for three categories: the group treated in 2011 (marking the typical single treatment date for assessing the effect of population growth on undernourishment), the consistently treated group, and the group that was never treated. The mean prevalence of undernourishment generally decreases over time for all groups. For example, in 2001, the mean prevalence of undernourishment was 8.0% for the 2011 treatment group, 36.0% for the always-treated group, 18.2% for the never-treated group, and 21.0% overall. By 2020, these values had decreased to 4.0%, 30.0%, 14.5%, and 16.0%, respectively. Overall, the mean prevalence of undernourishment across all groups decreased from 5.3% in 2001 to 16.8% in 2020.

Table 6: Summary of Trends in Mean Undernourishment Rates

Obs. Date	*2011*	*Always*	*Never*	*All*
2001	8.0	36.0	18.2	21.0
2002	8.0	35.0	18.7	20.3
2003	7.0	34.0	18.8	20.3
2004	6.0	33.0	18.2	19.7
2005	5.0	32.0	17.4	19.3
2006	4.0	31.0	16.2	18.3
2007	4.0	31.0	15.2	17.7
2008	4.0	30.0	14.8	17.0
2009	4.0	29.0	15.2	16.0
2010	4.0	29.0	15.3	15.7
2011	4.0	29.0	15.5	15.3
2012	4.0	28.0	15.2	15.3
2013	4.0	28.0	14.7	15.0
2014	4.0	27.0	14.2	14.3
2015	4.0	27.0	13.6	14.3
2016	4.0	27.0	13.1	14.3
2017	4.0	27.0	12.4	14.0
2018	4.0	29.0	12.3	14.0
2019	4.0	30.0	13.1	15.0
2020	4.0	30.0	14.5	16.0
All	5.3	29.4	15.4	16.8

Source: Author's calculations using World Bank data (2021)

Conclusion and Recommendations

The study on food security in Pakistan, Bangladesh, and India underscores the intricate linkages between population growth, economic development, and undernourishment. Findings confirm a cointegration relationship and causal dynamics among these factors, emphasizing the need for targeted policies to tackle food security challenges effectively. Recommended measures include implementing government support programs for marginalized communities, enhancing rural and urban infrastructure, fostering cooperative planning, and promoting sustainable agriculture. Strengthening social safety nets and informal institutions is also critical.

Limitations and Future Research: The study acknowledges data aggregation, model complexity, and causality nuances as limitations, suggesting future research focus on granular data, bidirectional causality, and climate change impacts. Evaluating the effectiveness of specific policies and exploring feedback loops is essential for a deeper understanding. Addressing these challenges demands comprehensive economic, social, and environmental strategies.

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