







Trends and long-term variation explaining nutritional determinants of child linear growth: analysis of Bangladesh Demographic and Health Surveys 1996–2018

Khandaker Tanveer Ahmed¹ , Md Karimuzzaman^{1,2,*} , Sabrina Afroz¹,
Md Moyazzem Hossain^{1,3} , Syeda Shahanara Huq¹, Faruq Abdulla⁴ and
Azizur Rahman⁵ 

¹Department of Statistics, Jahangirnagar University, Savar, Dhaka 1342, Bangladesh: ²DREXEL Dornsife School of Public Health, DREXEL University, USA: ³School of Mathematics, Statistics and Physics, Newcastle University, Newcastle upon Tyne, Tyne and Wear, UK: ⁴Cancer Care and Research Trust Bangladesh (CCRTB), Dhaka 1204, Bangladesh: ⁵School of Computing and Mathematics, Charles Sturt University, Albury, NSW, Australia

Submitted 26 June 2021: Final revision received 25 September 2023: Accepted 20 October 2023: First published online 27 October 2023

Abstract

Objective: To examine the height-for-age z-score (HAZ) of 0–35 months' children along with stunting prevalence to identify trends, changes and available nutrition-sensitive and specific determinants that could help explain the long-term variation in child linear growth using successive Bangladesh Demographic and Health Surveys (BDHS) data from 1996 to 2018.

Design: The BDHS pooled data are used for determining the key outcome variables HAZ, stunting and severe stunting. Trends, kernel-weighted local polynomial smoothing illustrations, pooled multivariable linear probability model (LPM), ordinary least squares method (OLS) and regression decomposition were used.

Participants: Mothers having 0–35 months' children, the most critical age range for growth faltering.

Results: The mean HAZ increased by 0.91(±1.53) with 0.041 annual average change, while the percentages of stunting (−26.63 ± 0.54) and severe stunting (−21.12 ± 0.48) showed a reduction with 1.21 and 0.96 average annual changes, respectively. The average HAZ improvement (0.42 ± 1.56) in urban areas was less than the rural areas (1.16 ± 1.44). Similar patterns followed for stunting and severe stunting. The prenatal doctor visits (3064.65 %), birth in a medical facility (1054.32 %), breastfeeding initiation (153.18 %) and asset index (144.73 %) demonstrated a huge change. The findings of OLS, LPM and regression decomposition identified asset index, birth order, paternal and maternal education, bottle-fed, prenatal doctor visit, birth in a medical facility, vaccination, maternal BMI and ever-breastfed as influencing factors to predict the long-term changes of stunting and severe stunting.

Conclusion: The nutrition-sensitive and specific factors identified through regression decomposition describing long-term variation in child linear growth should be focused further to attain the sustainable development goals.

Keywords
Malnutrition
Linear growth
Infant and child nutrition
Regression decompositions
Bangladesh

According to the WHO, about 149 million under-five children suffer from stunting worldwide^(1–3), while 45 % of deaths among them are related to undernutrition⁽⁴⁾, and most of these are concentrated in low- and middle-income countries^(1,3,4). Asia's stunting prevalence (52 %) is the world's highest, and South Asian countries hold 36 % (53.7 million) of the worldwide burden of stunted children^(1,3).

However, from 2012 to 2022, the percentage of stunted children came down from 26.3 % to 22.3 %, which was lower than WHO's expected reduction in that period⁽¹⁾. Low- and middle-income countries, however, face precarious malnutrition complexity, and a large number of children and women are suffering from at least one kind of malnutrition, including abnormally low weight for age

*Corresponding author: Email karimuzzaman.statju@gmail.com

© The Author(s), 2023. Published by Cambridge University Press on behalf of The Nutrition Society. This is an Open Access article, distributed under the terms of the Creative Commons Attribution licence (<http://creativecommons.org/licenses/by/4.0/>), which permits unrestricted re-use, distribution and reproduction, provided the original article is properly cited.





(underweight), low height-for-age (stunted), low weight for height (wasted) and micronutrient deficiencies such as iron deficiency and anaemia^(5–7).

Stunting refers to the abnormally slow increase in children's height or length, which results from the cumulative effects of chronic undernourishment. It represents a condition where children cannot reach their full linear growth potential. Stunted children are a particular group among those who have problems with their linear growth of height⁽⁸⁾. However, researchers have shown that early childhood stunting has negative implications, such as worse scholastic and economic attainment, as well as reduced workplace productivity^(9,10). It has been revealed that the physical effects of stunted children and their influence on their cognitive position contributed to poverty, particularly in low- and middle-income countries, by limiting an individual's ability to live meaningful lives⁽⁷⁾. Stunting has functional consequences that persist into adulthood, including decreased workability or disability, and in females, increased mortality risk and adverse birth outcomes are frequently observed^(11–14).

Various multifaceted nutrition-sensitive and nutrition-specific factors can contribute to stunting. Nutrition-sensitive factors indirectly influence nutrition outcomes through contextual factors like socioeconomic, cultural and environmental influences. They include social determinants of health, agricultural practices, food systems and economic conditions. Nutrition-specific factors are direct interventions that directly address immediate causes of malnutrition, such as inadequate dietary intake and poor feeding practices⁽¹⁵⁾. Promoting breastfeeding, providing nutrient supplements and implementing nutrition education programmes may play a vital role to lessen childhood malnutrition. As with other types of malnutrition, childhood stunting is associated with the mother's nutritional status⁽¹⁶⁾, for example education, wealth, age of delivery, previous birth interval and mothers' BMI, regional and environmental factor (number of children in a household, the size of the family, improved sanitation and access to safe drinking water)^(17,18). Moreover, chronic illnesses associated with inadequate nutritional value, suboptimal newborns and lifetime development, and impaired health and productivity are all risk factors^(19–21). It is also related to proximate factors like birth order, mother's age at marriage, immediate breastfeeding, childhood diarrhoea, vaccination status and vitamin deficiency^(22–27). However, particularly in Bangladesh, poverty, insufficient treatment, gender biases in decision-making, inadequate breastfeeding and complementary feeding rates, insufficient sanitation, environmental variables and recurring illnesses are only a few of the numerous factors of stunting that have been thoroughly investigated^(11,18,20,22,28,29). Also, many studies consider factors including the age of parents and child, health condition of both parents, birth spacing, paternal and maternal education, and access to media for determining childhood malnutrition^(7,12,13,17,20,28,30–45). Moreover, the study of malnutrition is exceptionally crucial for a South

Asian developing country like Bangladesh, as it is a member of the world's most stunted countries (under-five-year-old children account for 36 % of stunted children, and 12 % of these children are severely stunted) and is attempting to achieve the Sustainable Development Goals (12 of the 17 sustainable development goal contain nutritional indicators, particularly in goal 2). Additionally, Bangladesh's nutrient indicators pattern has been ostentatiously inconsistent over time, even though the country has significantly reduced childhood stunting rates in recent decades. Conspicuously, most of the studies related to Bangladesh stunting employed a statistical measure of chi-square, or trends and time series analysis or regression models, including linear, binomial, linear, logistic or Poisson considering involve either one or two sets of Bangladesh Demographic and Health Survey (BDHS) data.

Stunting, on the other hand, is a type of malnutrition that develops before a child's second birthday and is linked to insufficient nutritional intake due to food insecurity, poor diet quality and inappropriate prenatal nutrition, according to a recent study⁽²²⁾. Thus, instead of studying under-five children, focusing on their early growth is more vital. As a result, we are aware of including data from children aged 0–35 months (the age range where growth faltering may occur the most⁽²⁰⁾ and identify any nutrition-sensitive and specific (NSS) variables that explain the long-term variation in child linear growth).

A previous research pursued similar goals as this analysis; however, they used only the BDHS datasets from 2004 and 2017/18⁽⁴⁶⁾. Nisbett et al. (2017) investigated Bangladesh's nutritional change story, but their data came from various sources, including BDHS data from 1996 to 2011 and other sources⁽⁴⁷⁾. The target population was under-five children, and mixed methods were used to investigate various aspects of nutritional deficiencies rather than focusing on NSS factors that cause children's linear growth. Huda et al. (2018) employed the decomposition approach in a study with similar objectives to this one; however, the data were only from the BDHS between 2004 and 2014, and the target population was under-five children⁽⁴⁸⁾.

Considering all BDHS datasets, this study aimed to investigate the long-term trends in child linear growth using data from the repeated cross-sectional BDHS survey spanning from 1996 to 2018. That is this study provides insights into the factors influencing child linear growth over time. The utilisation of this extensive dataset allows for a comprehensive examination of the long-term variation in child linear growth, contributing to our understanding of the dynamics and determinants of childhood nutritional status. A comprehensive analysis was conducted in this study, encompassing all available BDHS data from 1996 to the latest dataset in 2017–2018. This study assesses the influence of NSS determinants on child linear growth. Notably, it is worth mentioning that

Table 1 List and definition of study variables

| Brief title | Definition |
|---|--|
| Outcome variables | |
| HAZ | The height-for-age z-score (HAZ) was calculated and measured using the 2006 WHO child growth standard. |
| Stunting (in %) | Children's Rate with $HAZ \leq -2$ SD |
| Severe stunting (in %) | Children's Rate of with $HAZ \leq -3$ SD |
| Independent variables | |
| Asset index (1–10) | By using a clustered principal component analysis with five continuously measured durables, adjusted by loading weights and rescaled from 1 to 10. However, we adapted the same sort of procedure of related study ^(50–52) . |
| Maternal education (in years) | Mother's Years of Schooling |
| Paternal education (in years) | Father's Years of Schooling |
| Prenatal doctor visit (0/1) | Mothers who have done prenatal visit receive a prenatal visit by a doctor (Dummy = 1) |
| 4+ ANC visits (0/1) | Mothers have been visiting four or more antenatal care (ANC) (Dummy = 1) |
| Iron during pregnancy (0/1) | Mothers received iron supplementation during pregnancy (Dummy = 1) |
| Born in medical facility (0/1) | Infant born in hospitals or in other medical facilities (Dummy = 1) |
| Maternal BMI (kg/m^2) | BMI of mother |
| Maternal height (0/1) | Dummy = 1, height of mother ≥ 145 cm |
| All vaccinations (0/1) | Dummy = 1, Bacillus Calmette-Guerin vaccine against tuberculosis; three shots of Diphtheria, Pertussis and Tetanus vaccine; two shots of Polio; measles antigen-containing vaccine between 1996 and 2014 and/or three shots of pentavalent vaccination in 2014 given to the children |
| Birth order (rank) | Order of the birth of a child in the family |
| Preceding birth interval (in years) | Interval of years between the current child's birth and previous child |
| Open defecation (0/1) | Dummy = 1, household has no facilities of a latrine or a toilet |
| Water tube well (0/1) | Dummy = 1, tube well was the source of household drinking water |
| Water source-piped (0/1) | Dummy = 1, pipes were the source of household drinking water |
| Women's decision-making (0/1) | Dummy = 1, Have the right of deciding how to spend her earnings |
| Breastfeeding duration (in months) | Months of breastfeeding to the child |
| Early initiation of breastfeeding (0/1) | Dummy = 1, infant breastfed within 1 h of birth. |
| Ever breastfed (0/1) | Dummy = 1, child has been breastfed ever |
| Bottle-feeding (0/1) | Dummy = 1, child was bottle-fed on the previous day |

there has been a lack in the literature utilising these total datasets to investigate this specific topic. Furthermore, this study considered the linear growth of children aged 0–35 months using advanced statistical methods named regression decomposition, which is a novelty for studies employing BDHS data.

Methods

Data

The data were collected with the proper consent of the authorities from the website 'https://dhsprogram.com/' and they are open access for use⁽⁴⁹⁾. Since this research was based on secondary data accumulated from the BDHS from 1996 to 2017/2018, all included mothers and infants during that time span are the study's target population. For consistency, only mothers with children aged 0–35 months were included in the study from all the BDHS datasets. The questions included in this study were the same across the BDHS datasets from 1996 to 2017/2018. The BDHS sample includes everyone who lives in noninstitutional housing units across the country. The surveys used a sampling frame based on the Bangladesh Bureau of Statistics' list of enumeration areas (EA) from the People's Republic of Bangladesh's most recent Population and Housing Census at the time of surveying. The primary sample unit for the survey is an EA, which has

an average of 120 households. The country was divided into some administrative divisions, Barisal, Chittagong, Dhaka, Khulna, Mymensingh (as of 2018), Rajshahi, Rangpur (as of 2011) and Sylhet.

Each division is segmented into more zilas and upazilas. An upazila's urban area is divided into wards, which are subdivided further into mohallas. Union parishads (UP) and mouzas within UP separate an upazila's rural land. The survey used a stratified sample of households in two stages. In the first step, EA were chosen with a probability proportional to their size, with some in urban regions and others in rural areas. A detailed household listing operation was carried out in all the selected EA to provide a sampling frame for the second-stage selection of households. Each EA chose a set number of homes systematically to collect data. This allowed us to get accurate statistics for health and demographic indicators at national, urban, rural and divisional levels. Additionally, the data were pre-processed using the proper method, taking the aforementioned research factors into account, and then pooled according to their respective years (Table 1). However, the sampling, data collection, enumeration, design and overall description can be found in the published report of BDHS and DHS methodology^(50,51).

Study variables

The height-for-age z-score (HAZ) is considered as the main dependent variable, and this research examines the

prevalence of stunting and severe stunting, since stunting is now the standard measure for tracking pledges and progress toward global (and national) chronic child undernutrition targets. The HAZ is a measurement used to evaluate a child's linear growth and nutritional status by comparing their height to the expected height for their age. Stunting is a condition characterised by a child having a significantly lower height-for-age than the norm, indicating chronic malnutrition and insufficient growth during early childhood. Severe stunting is an advanced form of stunting, signifying a more severe level of chronic malnutrition and pronounced growth faltering, with a child's height-for-age considerably below the expected standard. Based on prior research using a similar framework and earlier regression and decomposition studies of HAZ, certain time-varying covariates at the child, family and parental levels were selected^(30,32,36,52–58). These covariates are simple additions to nutrition models that represent NSS determinants that are thought to affect child's growth outcomes in children over time (Table 1)

Statistical methods

The analysis techniques were adapted from a recent study on child stunting in Nepal⁽⁵³⁾. The average and weighted prevalence of child linear growth outcome, as well as time-variant factors, were calculated for each individual survey year using 'svyset' command in STATA⁽⁵⁹⁾ version 16, which accounted for the DHS sampling weight factor and adjustment for the SE for the multistage clustered sampling design have been made. This approach ensured the appropriate consideration of the complex survey design and the correlation among individuals within the same cluster^(60–62). The 'anthro' package in RStudio⁽⁶³⁾ version 3.2.0 was used to calculate HAZ, with all extreme values exceeding the 6 SD range omitted⁽⁶²⁾.

To determine the significant determinants of child stunting, this study used a two-stage regression and decomposition method. For the HAZ outcome, that are continuous, pooled data were used from all available BDHS to fit multivariable ordinary least squares regression models. Multivariable linear probability models (LPM) with a robust variance estimator were used to analyse the binary stunting outcomes and identify key determinants of stunting. Kernel-weighted local polynomial graphs were used to assess the linearity assumption between HAZ and continuous variables. The LPM approach was chosen for its ability to estimate associations with both continuous and binary outcomes simultaneously, allowing for a comprehensive analysis of the impact. The interpretation of estimates is based on the coefficients' magnitude and statistical significance, indicating the change in the outcome associated with a unit change in the predictor variable. The use of LPM in similar studies supports its suitability for this analysis⁽⁵³⁾.

Besides, several conventional statistical measures were also used. The following multivariate regression equation

(Eq. 1) for child *i* at time *t* was used to assess the relation of growth outcome (*N*), with the *k* years, vectors of NSS determinants (*X*)time-variable (i.e. independent variables mentioned in Table 1), vectors of time-invariant control variables (μ_i)such as, maternal age (5 years interval), maternal occupation dummy variable, a child sex dummy variable, religion and division dummy variables and survey round dummy variables, dummy year variable(*T*), which characterise the trend effects and SE ($\varepsilon_{i,t}$),

$$N_{i,t} = \beta X_{i,k} + \mu_i + \varepsilon_{i,t}. \tag{1}$$

The coefficients associated with the specified determinants, displaying statistical significance with a p-value below 0.1, constitute the parameters represented by the vector of coefficients (β) on (*X*). These parameters hold a fundamental role in the investigation of factors impacting child linear growth. More precisely, the objective centres on discerning the most efficacious nutrition-sensitive and nutrition-specific determinants for elucidating variations in linear growth outcomes among children aged 0–35 months. Secondly, the parameters (estimated from the first stage regression equations) were used to perform the defined statistical decomposition (Eq. 2) (By considering the assumption of zero mean error and coefficients are time-invariant). This study analysed the earliest BDHS round in 1996 (*t* = 1)and recent BDHS round in 2018 (*t* = *k*). Additionally, the analysis includes regression decomposition, calculating the mean change of each explanatory variable and multiplying the resulting coefficients on observed trends in linear growth outcomes for the 1996–2018 period to ascertain the contribution of NSS determinants (Eq. 2). This study examines the expected shift in linear growth outcomes as a function of a change in regressor during the course of the survey years (22 years), demonstrating the estimated influence of determinants and time-variant variables to child linear growth consequences.

$$\Delta \bar{N}_{i,t} = \beta(\bar{X}_{t-k} - \bar{X}_{t-1}). \tag{2}$$

Similar comparable calculations were conducted for other NSS factors to determine, over time, how well a determinant elucidates improvements in child's HAZ and stunting, and how well all of the independent time variables in the models illustrate changes in HAZ and stunting frequency. To ensure robustness, additional statistical analyses were performed. The comparison of LPM beta coefficients with average marginal effects from logistic regression models showed consistent findings. The Oaxaca-Blinder decomposition test revealed that 64 % of the observed coefficient differences were due to changes in covariate composition, while 36 % were attributed to changes in the coefficients themselves. Interaction terms and separate analyses for rural and urban samples provided insights into variations in predictor-child linear growth relationships. No evidence of multicollinearity was

found, as variance inflation factors were below the suggested threshold of 4.

This study employed an alpha level of $P < 0.1$ as statistically significant in the regression-decomposition analysis. This choice is based on the exploratory nature of the study, aiming to identify potential associations or trends for further investigation. Previous literature has demonstrated the effectiveness of this alpha level in detecting meaningful associations in similar analyses or populations⁽⁵³⁾.

Results

Trends in under-three child growth

The findings provide an overview of under three-year-old children's HAZ, stunting and severe stunting over time, using a total sample size of 20 821 out of 35 825 mothers with children aged 0–35 months (valid samples for calculating HAZ and stunting for children 0–35 months) from seven BDHS surveys between 1996 and 2018. Bangladesh has seen a significant increase in HAZ for children aged 0–35 months, with the mean HAZ increasing by 0.91 (± 1.53), while the mean HAZ increased by 1.16 (± 1.44) in rural areas and by 0.42 (± 1.56) in urban areas. Rural areas have a significantly lower prevalence of stunting (-33.07 ± 0.5) and extreme stunting (-23.08 ± 0.46) than urban areas (-12.71 ± 0.52) and (-12.93 ± 0.45), respectively. Between 1996 and 2018, there has been a substantial decrease in the occurrence of stunting (-26.63 ± 0.54) and severe stunting (-21.12 ± 0.48). Moreover, the mean annual reduction for HAZ, stunting and severe stunting was 0.15, 1.21 and 0.96, respectively (Table 2). Additionally, using kernel density graphs, a marginal change in the HAZ distribution was observed from 1996 to 2018 (Fig. 1). Figure 1(b) demonstrates a notable increase in the average HAZ from 1996 to 2018, while Figure 1(a) illustrates that the distribution of HAZ has remained consistent without significant changes despite this improvement.

Trends in nutrition-sensitive and specific determinants

With 20 821 samples, this analysis discovered major changes in certain NSS determinants. There were major increases in prenatal doctor visits (3064.65%), birth in a medical facility (1054.32%), all vaccinations (155.07%), breastfeeding initiation (153.18%), asset index (144.73%), open defecation (-96.9%), antenatal care visits (-86.89%) and water source: piped (65.79%) and a minor difference in preceding birth interval (34.57%), birth order (-29.33%), breastfeeding period (-22.6%), paternal education (-20.27%), water source-tube well (-11.75%) and maternal BMI (11.01%), but this study found tiny differences in maternal education (6.75%), maternal height (5.28%) or breastfed ever (1.24%). There were no data on

Table 2 Changes in mean height-for-age z-score and stunting prevalence for different samples of children aged 0–35 months from Bangladesh Demographic and Health Surveys (BDHS) 1996–2018

| Sample | HAZ (sd) | | | Stunting (%) (sd) | | | Severe Stunting (%) (sd) | | |
|------------|----------|--------|-------|-------------------|--------|--------|--------------------------|--------|--------|
| | Total | Rural | Urban | Total | Rural | Urban | Total | Rural | Urban |
| 1996 | -2.05 | 1.71 | 1.71 | 56.03 | 0.5 | 44.3 | 30.64 | 0.46 | 22.77 |
| 2000 | -1.78 | 1.54 | 1.54 | 47.26 | 0.5 | 41.36 | 20.65 | 0.40 | 16.86 |
| 2004 | -1.72 | 1.44 | 1.42 | 44.50 | 0.5 | 40.49 | 17.66 | 0.38 | 14.9 |
| 2007 | -1.54 | 1.46 | 1.45 | 40.03 | 0.5 | 33.93 | 15.42 | 0.36 | 12.55 |
| 2011 | -1.48 | 1.70 | 1.66 | 40.5 | 0.49 | 36.07 | 18.41 | 0.39 | 15.6 |
| 2014 | -1.38 | 1.52 | 1.49 | 37.87 | 0.49 | 35.92 | 13.14 | 0.34 | 11.47 |
| 2018 | -1.14 | 1.46 | 1.51 | 29.40 | 0.46 | 31.59 | 9.52 | 0.29 | 9.84 |
| Change (%) | 0.91 | 1.53 | 1.44 | -26.63 | 0.54 | -12.71 | -21.12 | 0.48 | -12.93 |
| Change (%) | 44.39 | 54.98 | 25.45 | -47.52 | -57.07 | -28.69 | -68.93 | -72.26 | -56.79 |
| N | 20 821 | 12 463 | 8358 | 20 821 | 12 463 | 8358 | 20 821 | 12 463 | 8358 |

HAZ: height-for-age z-score
Study estimates from the BDHS 1996 to 2018 rounds, using sampling weights. Stunting (%) refers to HAZ ≤ 2 sd and severe stunting (%) to HAZ ≤ 3 sd.

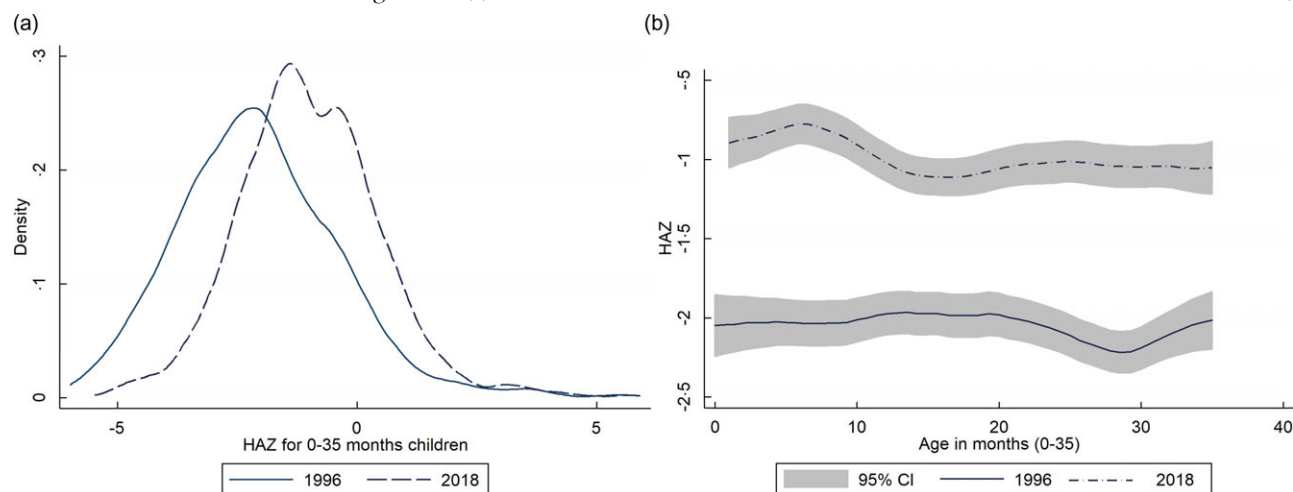


Fig. 1 (a) Shifts in HAZ distribution among children aged 0–35 months: Kernel density estimate from BDHS 1996–2018; (b) shifts in HAZ among children aged 0–35 months by child’s age: Local polynomial smoothing predictions with 95 % CI estimated from BDHS 1996–2018.

iron intake during pregnancy in BDHS 1996, but from BDHS 2018, it was found that 76.54% of mothers have taken iron during pregnancy (Table 3).

In addition, several graphs have been shown as a non-parametric estimate to elucidate the associations amid continuous time-variant regressors and HAZ (Fig. 2). There are approximately linear relationships until a certain point; however, with the values of the continuous time-variant predictor variable being high, the linearity collapses. Moreover, the association between asset index and HAZ is almost a curve with the slope not so steep and upward with higher asset index values. Paternal and maternal education maintains an almost linear relationship with HAZ, but the linearity breaks subtly at six years of education, although paternal education with HAZ is not straight throughout. An upward linear relationship between maternal BMI and HAZ is evident from Fig. 2(d). Besides, birth order shows an approximately downward linear relation with HAZ. Lastly, the relationship between preceding birth orders and HAZ is an upward line, which is a bit curvy here and there; hence, the linearity is disrupted. To sum up, it is discernible that all the continuous time-variant independent variables have an almost linear relationship with HAZ, but when the value of these variables is high at their respective levels, due to the lower frequency of samples at that value or higher, the linearity has not seen further (Fig. 2).

Regression decomposition

The multivariate linear regression models identified some determinants significantly associated ($P < 0.10$) with the improvement of HAZ, such as all vaccination (β (SE): 0.002 (0.004); $P = 0.001$), paternal education (β (SE): 0.04 (0.006); $P = 0.07$), prenatal doctor visit (β (SE): 0.002 (0.009);

$P = 0.04$), asset index (β (SE): 0.053 (0.031); $P = 0.06$), maternal BMI (β (SE): 0.036 (0.008); $P = 0.04$), maternal height (β (SE): 0.017 (0.01); $P = 0.08$), initiation of breastfeeding (β (SE): 0.003 (0.004); $P = 0.07$) and open defecation (β (SE): -0.001 (0.002); $P = 0.07$). Although LPM run for the stunting and severe stunting estimation almost carried the same as for the determinant’s significant association like the ordinary least squares models, some exceptions are also seen, especially for maternal education (β (SE): -0.09 (0.002); $P = 0.06$) for stunting and (β (SE): -0.18 (0.013); $P = 0.06$) severe stunting, born in a medical facility (β (SE): 0.002 (0.003); $P = 0.06$) for stunting and (β (SE): 0.009 (0.003); $P = 0.07$) severe stunting, bottle feeding (β (SE): 0.007 (0.005); $P = 0.08$) for stunting, birth order (β (SE): -0.068 (0.01); $P = 0.06$) for severe stunting, and ever-breastfeeding (β (SE): -0.025 (0.002); $P = 0.009$) for severe stunting (Table 4).

Moreover, mean HAZ has seen gradual augmentation by years from 1996 to 2018 in 0.91 (± 1.53), contributed by some nutrient determinants by a significant amount. The decomposition of those changing factors along with the asset index has been contributed most by 0.21 (23.08%). Moreover, initiation of breastfeeding has loaded on HAZ by 0.15 (16.48%) and prenatal doctor visit has the same contribution too, by 0.15 (16.48%). Other factors contributed in less amount, for example all vaccination by 0.08 (8.79%), maternal BMI by 0.08 (8.79%), maternal height by 0.07 (7.69%) and open defecation by 0.06 (6.59%). Paternal education, however, contributed negatively towards HAZ by 0.03 (3.3%). Although the mean HAZ of BDHS 2018 was improved by 0.91 than BDHS 1996, only 0.8 (87.9%) could be estimated by the decomposition of predicted change by the determinants. Rest could be the change due to the effects of the determinants that were NS in the multivariate linear regression (Table 5).

Table 3 Trends in means (sd) of NSS determinants among mothers of child aged 0–35 months

| | Asset index (1–10) | | Paternal education (years) | | Maternal education (years) | | Prenatal doctor visit (%) | | ANC visits (%) | | Iron during pregnancy (%) | | Born in a medical facility (%) | |
|------------|----------------------------------|------|---------------------------------|------|----------------------------|------|-----------------------------|------|--------------------|------|-------------------------------------|-------|--------------------------------|------|
| | Means | SD | Means | SD | Means | SD | Means | SD | Means | SD | Means | SD | Means | SD |
| 1996 | 2.75 | 1.34 | 3.70 | 4.97 | 3.26 | 1.55 | 2.39 | 0.04 | 6.1 | 0.97 | 0.0 | | 4.40 | 0.43 |
| 2000 | 3.14 | 1.65 | 3.74 | 6.47 | 3.10 | 1.60 | 27.07 | 0.79 | 0.65 | 0.75 | 33.35 | 0.65 | 10.1 | 0.9 |
| 2004 | 3.48 | 1.04 | 3.17 | 2.35 | 2.83 | 1.60 | 34.83 | 0.86 | 0.32 | 0.56 | 52.03 | 1.41 | 11.70 | 1.1 |
| 2007 | 4.11 | 1.27 | 3.54 | 2.24 | 3.29 | 1.50 | 39.46 | 0.91 | 0.35 | 0.66 | 50.16 | 1.17 | 16.5 | 0.94 |
| 2011 | 4.87 | 1.76 | 3.72 | 3.54 | 3.41 | 1.36 | 42.80 | 0.94 | 0.37 | 0.84 | 0.0 | | 27.3 | 1.22 |
| 2014 | 5.87 | 1.98 | 3.67 | 2.45 | 3.35 | 1.38 | 39.29 | 0.90 | 0.40 | 1.1 | 0.0 | | 23.3 | 0.87 |
| 2018 | 6.73 | 2.13 | 2.95 | 1.66 | 3.48 | 3.70 | 75.64 | 0.43 | 0.80 | 0.91 | 76.54 | 0.42 | 50.79 | 1.08 |
| Change | 3.98 | 1.57 | -0.75 | 0.82 | 0.22 | 1.91 | 73.25 | 0.86 | -5.3 | 0.94 | 76.54 | 0.42 | 46.39 | 0.97 |
| Change (%) | 144.73 | | -20.27 | | 6.75 | | 3064.65 | | -86.89 | | ** | | 1054.32 | |
| n | 33 287 | | 25 768 | | 26 143 | | 30 856 | | 27 971 | | 22 428 | | 29 745 | |
| | Preceding birth interval (years) | | Open defecation (%) | | Water Source: piped (%) | | Water source: tube well (%) | | Ever breastfed (%) | | Duration of breast-feeding (months) | | Maternal BMI (kg/m2) | |
| 1996 | 3.76 | 2.00 | 58.1 | 0.62 | 3.8 | 0.8 | 90.2 | 0.8 | 96.6 | 0.3 | 21.99 | 11.75 | 20.07 | 2.32 |
| 2000 | 4.08 | 2.25 | 44.8 | 0.7 | 6.3 | 0.85 | 89.5 | 0.95 | 97.1 | 0.4 | 22.12 | 12.18 | 19.86 | 1.02 |
| 2004 | 3.98 | 2.28 | 41.0 | 0.6 | 7.3 | 0.72 | 84.5 | 0.9 | 98.1 | 0.2 | 23.60 | 12.18 | 19.80 | 0.9 |
| 2007 | 4.41 | 2.49 | 17.6 | 0.5 | 6.1 | 0.54 | 80.4 | 0.6 | 97.6 | 0.3 | 22.95 | 11.19 | 20.46 | 1.02 |
| 2011 | 4.52 | 2.49 | 10.8 | 0.4 | 9.0 | 0.6 | 78.3 | 0.67 | 96.3 | 0.4 | 25.40 | 8.86 | 20.87 | 0.9 |
| 2014 | 4.99 | 2.78 | 6.1 | 0.55 | 7.5 | 0.95 | 80.9 | 0.75 | 97.2 | 0.5 | 19.46 | 8.25 | 21.68 | 1.18 |
| 2018 | 5.06 | 2.88 | 1.8 | 0.37 | 6.3 | 0.79 | 79.6 | 0.86 | 97.8 | 0.3 | 17.02 | 15.15 | 22.28 | 3.94 |
| Change | 1.30 | 2.43 | -56.3 | 0.54 | 2.5 | 0.86 | -10.6 | 0.78 | 1.2 | 0.4 | -4.97 | 1.6 | 2.21 | 1.12 |
| Change (%) | 34.57 | | -96.9 | | 65.79 | | -11.75 | | 1.24 | | -22.6 | | 11.01 | |
| n | 26 765 | | 35 782 | | 35 780 | | 35 780 | | 35 647 | | 35 501 | | 35 689 | |
| | Maternal height >= 145 cm (%) | | Initiation of breastfeeding (%) | | Bottle feed (%) | | All vaccination (%) | | Birth order (rank) | | | | | |
| 1996 | 81.5 | 0.61 | 31.4 | 0.76 | 0.0 | | 25.6 | 0.67 | 3.0 | 2.16 | | | | |
| 2000 | 83.5 | 0.55 | 36.2 | 0.80 | 9.8 | 0.45 | 29.4 | 0.54 | 2.8 | 1.99 | | | | |
| 2004 | 84.6 | 0.73 | 52.2 | 1.16 | 9.7 | 0.52 | 36.9 | 0.75 | 2.87 | 1.95 | | | | |
| 2007 | 85.4 | 0.45 | 64.2 | 1.05 | 0.0 | | 47.4 | 0.86 | 2.54 | 1.73 | | | | |
| 2011 | 87.1 | 0.80 | 71.8 | 1.28 | 8.2 | 0.76 | 61.1 | 0.95 | 2.36 | 1.56 | | | | |
| 2014 | 87.5 | 0.75 | 74.4 | 1.20 | 12.9 | 0.9 | 79.8 | 0.9 | 2.18 | 1.43 | | | | |
| 2018 | 85.8 | 0.78 | 79.5 | 1.31 | 13.4 | 0.55 | 65.3 | 0.48 | 2.12 | 1.27 | | | | |
| Change | 4.3 | 0.65 | 48.1 | 1.22 | 13.4 | 0.55 | 39.7 | 0.76 | -0.88 | 1.07 | | | | |
| Change (%) | 5.28 | | 153.18 | | - | | 155.07 | | -29.33 | | | | | |
| n | 35 811 | | 31 867 | | 31 660 | | 27 508 | | 35 825 | | | | | |

Abbreviations: ANC: Antenatal Care;

Study estimates from the BDHS 1996 to 2018 rounds, using sampling weights.

**Change (%) of Iron during pregnancy is unavailable due to the absence of data in BDHS 1996, BDHS 2011, and BDHS 2014 surveys.

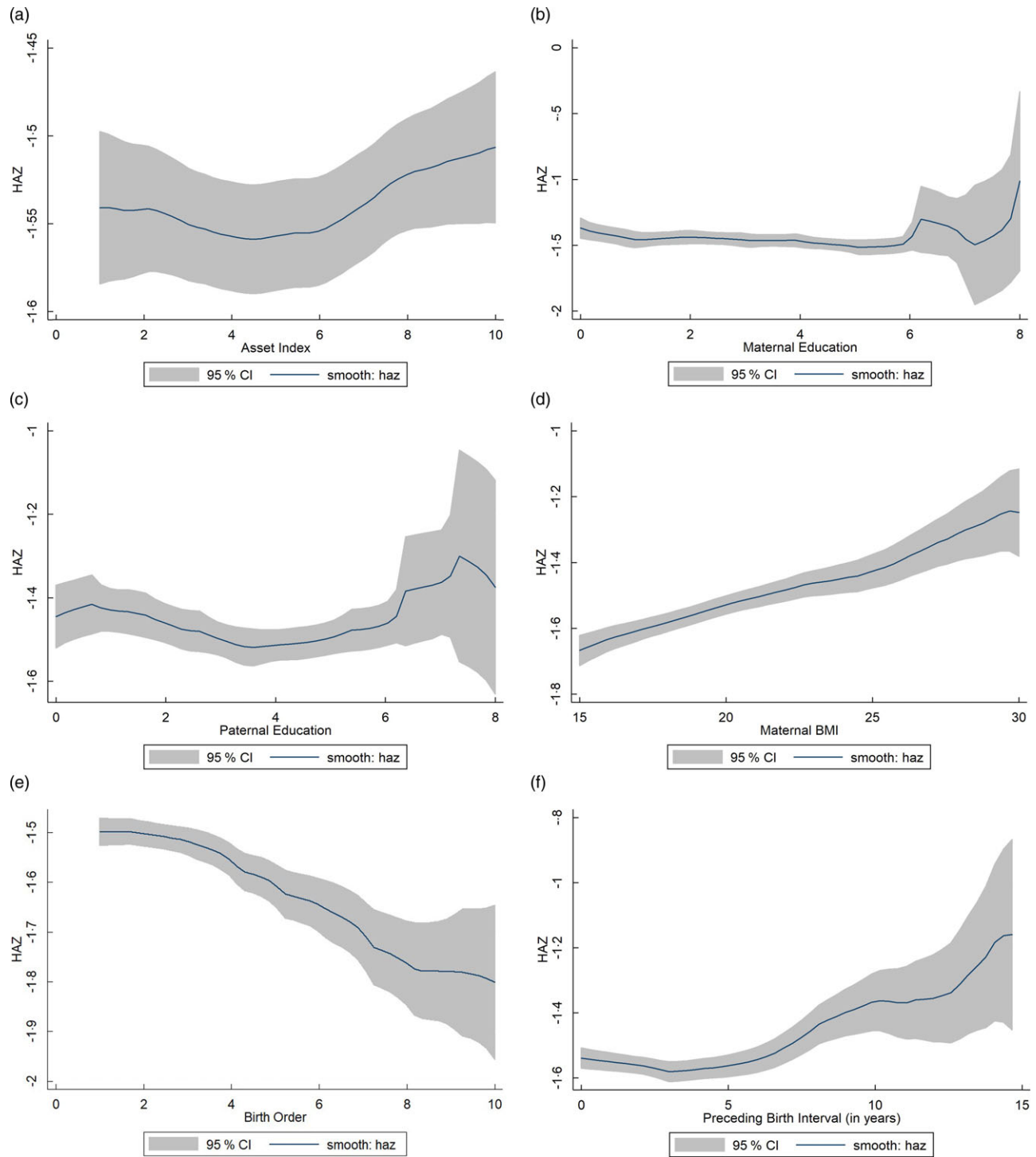


Fig. 2 Non-parametric estimates of the relationships between height-for-age z-score (HAZ) and (a) asset index, (b) maternal education, (c) paternal education, (d) maternal BMI, (e) birth order, (f) preceding birth interval. Local polynomial smoothing predictions with 95 % CI estimated from BDHS 1996–2018.

Discussions

Bangladesh, a developing country with a large population, faces severe nutritional problems, particularly among children, and has experienced severe stunting cases over

the years. However, the recent trend indicates some improvement, as this study discovered that the annual average change in height-for-age was 0.041 from 1996 to 2018. On the other hand, more significant improvement was observed in rural areas, with HAZ increasing by 0.053

Table 4 Determinants of child (0–35 months) linear growth outcomes in pooled regression models

| Dependent variable | HAZ | | Stunting | | Severe stunting | |
|------------------------------------|----------|-------|----------|-------|-----------------|-------|
| | OLS | SE | LPM | SE | LPM | SE |
| Asset index | 0.053* | 0.031 | -0.15* | 0.01 | -0.13** | 0.009 |
| Paternal education | 0.04* | 0.006 | -0.07* | 0.01 | -0.11 | 0.009 |
| Maternal education | 0.075 | 0.003 | -0.09* | 0.002 | -0.18* | 0.013 |
| Prenatal doctor visit | 0.002** | 0.009 | -0.004* | 0.007 | -0.001* | 0.003 |
| ANC visits | 0.001 | 0.009 | -0.001 | 0.02 | -0.009 | 0.007 |
| Iron during pregnancy | 0.043 | 0.003 | -0.004 | 0.004 | -0.017 | 0.026 |
| Born in a medical facility | 0.006 | 0.005 | 0.002* | 0.003 | 0.009* | 0.003 |
| Maternal BMI | 0.036** | 0.008 | -0.021 | 0.011 | -0.009** | 0.002 |
| Maternal height | 0.017* | 0.01 | -0.012* | 0.003 | -0.025 | 0.026 |
| Initiation of breastfeeding | 0.003* | 0.004 | -0.021 | 0.03 | 0.013 | 0.012 |
| Bottle feed | -0.031 | 0.014 | 0.007* | 0.005 | 0.018 | 0.003 |
| All vaccination | 0.002*** | 0.004 | -0.009 | 0.006 | -0.013** | 0.008 |
| Birth order | 0.006 | 0.001 | -0.03 | 0.007 | -0.068* | 0.01 |
| Preceding birth intervals | 0.096 | 0.02 | -0.013 | 0.04 | -0.009 | 0.005 |
| Open defecation | -0.001* | 0.008 | 0.003 | 0.001 | 0.015 | 0.008 |
| Water Source: piped | 0.008 | 0.007 | -0.048 | 0.023 | -0.006 | 0.003 |
| Water source: tube well | 0.1 | 0.002 | -0.032 | 0.011 | 0.09 | 0.008 |
| Ever breastfed | 0.07 | 0.006 | -0.012 | 0.003 | -0.025* | 0.009 |
| Duration of breastfeeding (months) | 0.014 | 0.004 | -0.01 | 0.015 | -0.019 | 0.007 |
| Adjusted R ² | 0.367 | | 0.344 | | 0.329 | |

HAZ: height-for-age z-score; LPM: linear probability model with a robust variance estimator; OLS: ordinary least squares.

Study estimates from the BDHS 1996 to 2018 rounds.

Stunting refers to HAZ ≤ -2 sd and severe stunting to HAZ ≤ -3 sd. The regressions include several omitted time-invariant controls, such as maternal age (5 years interval), maternal occupation dummy variable, a child sex dummy, religion and division dummy variables and survey round dummy variables.

**P*-value < 0.05.

***P*-value < 0.01.

****P*-value < 0.001.

Table 5 Decomposition in long-term predicted variations of regression outcomes

| Dependent variable | HAZ | Stunting (%) | Severe stunting (%) |
|-----------------------------|-------|--------------|---------------------|
| Asset index | 0.21 | -0.59 | -0.51 |
| Paternal education | -0.03 | 0.05 | - |
| Maternal education | - | -0.02 | -0.04 |
| Prenatal doctor visit | 0.15 | -0.31 | -0.06 |
| Born in a medical facility | - | 0.11 | 0.4 |
| Maternal BMI | 0.08 | - | -0.02 |
| Maternal height | 0.07 | -0.05 | - |
| Initiation of breastfeeding | 0.15 | - | - |
| Bottle feed | - | 0.09 | - |
| All vaccination | 0.08 | - | -0.5 |
| Birth order | - | - | 0.06 |
| Open defecation | 0.06 | - | - |
| Ever breastfed | - | - | -0.03 |

HAZ: height-for-age z-score.

Study estimates from the BDHS 1996 to 2018 rounds. The decomposition analysis and estimates are provided only for the independent variables that showed a significant association with HAZ, stunting and severe stunting. Stunting refers to HAZ ≤ -2 sd and severe stunting to HAZ ≤ -3 sd. The predicted nutritional change was determined using a linear decomposition at means. Changes in the mean of each time-varying variable (Table 3) were multiplied by the corresponding β coefficient (Table 4).

annually during this period, while no such improvement was observed in urban areas, with an annual average of 0.019. The average annual change in stunting and extreme stunting was 1.21% and 0.96%, respectively. Rural areas (1.5% and 1.05%, respectively) improved significantly more than urban areas (0.58% and 0.59%). While

Bangladesh's achievement in reducing stunting in children under three is commendable, the World Health Assembly's and sustainable development goal programme's target of 40% reduction in stunted children by 2025 is still a long way off^(6,64–67).

As demonstrated by the findings of this study, multivariate linear regression models identified several determinants significantly associated with HAZ, including factors such as all vaccination, paternal education, prenatal doctor visits, asset index, maternal BMI, maternal height, initiation of breastfeeding and open defecation. Notably, LPM used to estimate stunting and severe stunting generally aligned with the ordinary least squares models, reinforcing the significance of many determinants. However, exceptions were observed, particularly for maternal education, being born in a medical facility, bottle feeding, birth order and ever breastfeeding, where the LPM suggested potentially stronger impacts on stunting and severe stunting outcomes. These distinctions provide a nuanced understanding of the determinants influencing child linear growth and stunting, offering valuable insights into the factors affecting child health in the studied population. All of these factors have a beneficial effect on HAZ and stunting and are associated with health care. These advancements provide hope for reducing potential stunting rates. Nonetheless, some other variables, some nutrition-specific and nutrition-sensitive determinants, such as parental education, maternal height, BMI and breastfeeding, should be emphasised more to accelerate



the low rate of stunting. As a developing country, Bangladesh must prioritise these points to ensure a brighter future for children and mothers. Bangladesh has tightened its grip on stunting children under five in recent years, but the rate remains around 36%, with 12% severely stunted. These children are at an increased risk of infection, impaired cognitive and physical development, and death. The reason for concern is that stunting's effects may last into adulthood and may result in future reductions in these children's work capacity^(6,11–14,33).

Malnutrition has a negative impact on children, their families and the entire country. Additionally, a generation's childhood and adulthood may fail spectacularly. There have been noticeable changes in the distribution of stunting and extreme stunting as measured by endurance curves and index scales. Recent research has identified nearly identical patterns of declining recessions followed by increased socioeconomic inequality^(64,65). Findings revealed that stunting and severe stunting decrease significantly as the asset index increases. The asset index contributes 23.08% to HAZ and significantly reduces stunting and extreme stunting. The association between stunting births and shorter-interval second-order births may arise due to household competition for food. Infants' and young children's feeding habits are critical for preventing infectious diseases and malnutrition in children. According to the WHO, infants should be breastfed exclusively for the first six months of life^(64,66,67). It is well-known that breastfeeding is almost universal in Bangladesh. Researchers highlighted that 43% of children in Bangladesh are breastfed within an hour of birth, and 60% of children receive supplementary food before reaching the sixth month⁽²⁹⁾. However, this study discovered that approximately 79.5% of children under the age of three were breastfed within an hour of birth in 2018, up from 31% in 1996, and breastfeeding initiation has a significant HAZ effect and can account for its 16.48% improvement. According to a Bangladesh Integrated Nutrition Program survey, 34.1% of mothers began breastfeeding immediately after birth, while 49.9% did so within 24 h of birth⁽²⁹⁾.

Bangladesh is clearly on its way to becoming a less stunting country, as stunting and severe stunting have decreased by only 1.21% and 0.96% annually, respectively, despite significant improvements in prenatal doctor visits, medical facility uses, breastfeeding and all vaccinations. Surprisingly, urban areas exhibit a significantly lower rate of improvement across all three outcomes, a point that should be emphasised more. Additionally, asset index and prenatal doctor visits were identified as predictors of changes in all three outcomes, whereas paternal education and maternal height explain predicted changes in HAZ and stunting. Furthermore, maternal BMI and all infant vaccinations appear to be associated with HAZ and severe stunting. Additionally, breastfeeding for HAZ, bottle feeding for stunting and having been breastfed

at any point appear to predict the changes resulting in severe stunting. Besides, maternal education and birth in a medical facility tend to be linked with stunting and severe stunting. However, based on the current rate of progress in stunting and child linear growth, the WHO and the country's sustainable development goal programme's target of 40% stunting reduction by 2025 appears far from achievable^(6,64,66,67). On the other hand, Bangladesh will achieve its goal if widespread awareness is generated, and appropriate measures are taken to improve the circumstances of specific nutritional and nutrition-sensitive determinants (identified in the study) that contribute to HAZ and stunting.

Strengths, limitations and future scopes

This study covers all successive data extracted from the BDHS (1996–2018) to examine trends and changes in child linear growth. Robust participant numbers, including mothers with children aged 0–35 months, contribute to a strong dataset for analysis. Statistical methods, such as kernel-weighted local polynomial smoothing, multivariable LPM, ordinary least squares and regression decomposition, are employed to explore factors associated with HAZ, stunting and severe stunting. However, there are some limitations to consider. Data collected through the BDHS may be subject to recall and reporting biases. The study's findings are limited to the information collected in the survey and may not capture all relevant variables or nuances. Although the analysis adjusts for various factors, there may be unmeasured confounders that could influence the relationship between determinants and child linear growth. The study's findings may be context-specific to Bangladesh and may not directly apply to other populations or countries with different socioeconomic and cultural settings. Causal relationships cannot be definitively established due to the study's observational nature. Ecological fallacy is a potential concern as conclusions about individuals are based on group-level data. Moreover, the use of the LPM approach in this study includes potential bias from reverse causality and omitted variable bias, inability to establish causal relationships, reliance on linearity assumptions and limited interpretability for binary outcomes compared to logistic regression.

Future research can focus on several areas, including longitudinal studies to assess long-term effects, mechanistic investigations to explore underlying mechanisms, context-specific studies to identify influential factors, effectiveness evaluations of interventions, examination of socioeconomic and policy factors, exploration of parental and environmental influences, and addressing equity and disparities. Future research can also explore alternative modelling approaches, such as logistic regression or advanced machine learning techniques, to address the limitations of the LPM approach. Additionally, this study

used an alpha level of $P < 0.1$ as the threshold for statistical significance in the regression-decomposition analysis. Considering more conservative approaches for statistical significance with very large datasets could be a direction for future research. These research directions can contribute to a deeper understanding of linear growth determinants and inform interventions and policies to improve child nutrition outcomes.

Conclusion

This research tried to explore significant NSS determinants that could better explain the long-term variation in child linear growth among Bangladesh's children aged 0–35 months, as well as to identify the condition of malnutrition through analysis and examination of stunted children. This empirical study examined fluctuations in the HAZ and the percentages of children in Bangladesh (0–35 months) from 1996 to 2018. As in stunting and severe stunting, the average annual decline is 1.21% and 0.96%, respectively, which is satisfactory but insufficient to meet the WHO and government-set targets. However, based on endurance curves and index scales, dramatic improvements in the distribution of stunting and extreme stunting have occurred.

The asset index, on the other hand, is significantly inversely related to stunting and severe stunting. The determinants that are significantly associated with improvement in HAZ, such as universal vaccination, paternal education, prenatal doctor visits, asset index, maternal BMI, maternal height, breastfeeding initiation and open defecation, should receive increased attention to achieve more significant improvement in HAZ and stunting. Maternal education and birth in a medical facility are also two significant risk factors for stunting. A child's birth order can also influence stunting, and the research presented here elicits that it has a significant association with stunting and severe stunting. The government of Bangladesh should place a greater emphasis on the study's findings and underlying factors. While this analysis attempts to incorporate all possible variables, numerous additional variables need to be analysed. Shifts in attitudes over time can also be seen in next year's BDHS data, as there have been tremendous changes in people's attitudes over the last six years. Additionally, the longitudinal research module may evolve; further in this regard, demographic problems also play a substantial role in stunting and the development of infants.

Acknowledgment

The authors are appreciative that the DHS programme allowed us to use the data for our purposes. The authors would like to thank the anonymous reviewers and the editor for their stimulus and valuable comments which were used to improve the manuscript.

Financial support

This research received no specific grant from any funding agency, commercial or not-for-profit sectors.

Conflict of interest

The authors declared no competing interest.

Authorship

M. K., K. T. A. and M. M. H. were responsible for formulating the research question; M. M. H., S. S. H., A. R. and F. A. were responsible for identifying and giving a guideline for the analysis technique; K. T. A. and M. K. were responsible for analysing data; K. T. A., M. K., F. A., S. A. and M. M. H. are responsible for writing the draft manuscript. K. T. A., M. K. and M. M. H. revised the manuscript. S. S. H. and A. R. supervised the study. All authors reviewed and approved the final version of the manuscript.

Ethics of human subject participation

Not applicable. It is not required as the survey was approved by the Ethics Committee of the ICF Macro at Calverton in the USA and by the Ethics Committee in Bangladesh.

Reference

1. WHO (2023) Levels and Trends in Child Malnutrition. Geneva: WHO.
2. Hasan MM, Kader A, Asif CA *et al.* (2023) Seasonal variation in the association between household food insecurity and child undernutrition in Bangladesh: mediating role of child dietary diversity. *Matern Child Nutr* **19**, e13465.
3. Benjamin-Chung J, Mertens A, Colford JM Jr *et al.* (2023) Early-childhood linear growth faltering in low-and middle-income countries. *Nature* **621**, 550–557.
4. Sturgeon JP, Mufukari W, Tome J *et al.* (2023) Risk factors for inpatient mortality among children with severe acute malnutrition in Zimbabwe and Zambia. *Eur J Clin Nutr* **77**, 895–904.
5. WHO (2021) Malnutrition. Fact Sheets. <https://www.who.int/news-room/fact-sheets/detail/malnutrition> (accessed June 2021).
6. UNICEF (2019) The State of the World's Children 2019: Children, Food and Nutrition—Growing Well in a Changing World. <https://www.unicef.org/reports/state-of-worlds-children-2019> (accessed June 2021).
7. Roth DE, Krishna A, Leung M *et al.* (2017) Early childhood linear growth faltering in low-income and middle-income countries as a whole-population condition: analysis of 179 Demographic and Health Surveys from 64 countries (1993–2015). *Lancet Glob Heal* **5**, e1249–e1257.
8. Leroy JL & Frongillo EA (2019) Perspective: what does stunting really mean? A critical review of the evidence. *Adv Nutr* **10**, 196–204.



9. Fink G, Peet E, Danaei G *et al.* (2016) Schooling and wage income losses due to early-childhood growth faltering in developing countries: national, regional, and global estimates. *Am J Clin Nutr* **104**, 104–112.
10. Black MM, Walker SP, Fernald LCH *et al.* (2017) Early childhood development coming of age: science through the life course. *Lancet* **389**, 77–90.
11. Black RE, Allen LH, Bhutta ZA *et al.* (2008) Maternal and child undernutrition: global and regional exposures and health consequences. *Lancet* **371**, 243–260.
12. Dewey KG & Begum K (2011) Long-term consequences of stunting in early life. *Matern Child Nutr* **7**, 5–18.
13. Grantham-McGregor S, Cheung YB, Cueto S *et al.* (2007) Developmental potential in the first 5 years for children in developing countries. *Lancet* **369**, 60–70.
14. Prendergast AJ & Humphrey JH (2014) The stunting syndrome in developing countries. *Paediatr Int Child Health* **34**, 250–265.
15. Hossain MM, Huq MN & Abdulla F (2023) Child nutrition requires affordable healthy food. *Science (80-)* **380**, 1115.
16. UNICEF (2021) UNICEF Conceptual Framework on Maternal and Child Nutrition. <https://www.unicef.org/documents/conceptual-framework-nutrition> (accessed May 18 2022).
17. Abdulla F, Rahman A & Hossain MM (2023) Prevalence and risk predictors of childhood stunting in Bangladesh. *PLoS One* **18**, e0279901.
18. Rahman A & Hossain MM (2022) Quantile regression approach to estimating prevalence and determinants of child malnutrition. *J Public Health (Bangkok)* **30**, 323–339.
19. De Onis M (2000) Measuring nutritional status in relation to mortality. *Bull World Health Organ* **78**, 1274.
20. Victora CG, Adair L, Fall C *et al.* (2008) Maternal and child undernutrition: consequences for adult health and human capital. *Lancet* **371**, 340–357.
21. Walker SP, Chang SM, Powell CA *et al.* (2007) Early childhood stunting is associated with poor psychological functioning in late adolescence and effects are reduced by psychosocial stimulation. *J Nutr* **137**, 2464–2469.
22. Rabbani A, Khan A, Yusuf S *et al.* (2016) Trends and determinants of inequities in childhood stunting in Bangladesh from 1996/7 to 2014. *Int J Equity Health* **15**, 186.
23. Rahman A & Hossain MM (2022) Prevalence and determinants of fever, ARI and diarrhea among children aged 6–59 months in Bangladesh. *BMC Pediatr* **22**, 117.
24. Abdulla F, Hossain MM, Karimuzzaman M *et al.* (2022) Likelihood of infectious diseases due to lack of exclusive breastfeeding among infants in Bangladesh. *PLoS One* **17**, e0263890.
25. Hossain MM, Abdulla F, Banik R *et al.* (2022) Child marriage and its association with morbidity and mortality of under-5 years old children in Bangladesh. *PLoS One* **17**, e0262927.
26. Hossain MM, Sobhan MA, Rahman A *et al.* (2021) Trends and determinants of vaccination among children aged 06–59 months in Bangladesh: country representative survey from 1993 to 2014. *BMC Public Health* **21**, 1578.
27. Hossain MM, Yeasmin S, Abdulla F *et al.* (2021) Rural-urban determinants of vitamin a deficiency among under 5 children in Bangladesh: evidence from National Survey 2017–2018. *BMC Public Health* **21**, 1569.
28. Jesmin A, Yamamoto SS, Malik AA *et al.* (2011) Prevalence and determinants of chronic malnutrition among preschool children: a cross-sectional study in Dhaka City, Bangladesh. *J Heal Popul Nutr* **29**, 494–499.
29. Ahmed T, Roy SK, Alam N *et al.* (2005) *National Nutrition Programme Baseline Survey 2004 Report*. Dhaka, Bangladesh: International Centre for Diarrhoeal Disease Research.
30. Rahman MS, Rahman MA, Maniruzzaman M *et al.* (2020) Prevalence of undernutrition in Bangladeshi children. *J Biosoc Sci* **52**, 596–609.
31. Sarma H, Khan JR, Asaduzzaman M *et al.* (2017) Factors influencing the prevalence of stunting among children aged below five years in Bangladesh. *Food Nutr Bull* **38**, 291–301.
32. Black RE, Victora CG, Walker SP *et al.* (2013) Maternal and child undernutrition and overweight in low-income and middle-income countries. *Lancet* **382**, 427–451.
33. Akram R, Sultana M, Ali N *et al.* (2018) Prevalence and determinants of stunting among preschool children and its urban–rural disparities in Bangladesh. *Food Nutr Bull* **39**, 521–535.
34. Rahman MS, Howlader T, Masud MS *et al.* (2016) Association of low-birth weight with malnutrition in children under five years in Bangladesh: do mother’s education, socio-economic status, and birth interval matter? *PLoS One* **11**, e0157814.
35. Islam MM, Alam M, Tariquzaman M *et al.* (2013) Predictors of the number of under-five malnourished children in Bangladesh: application of the generalized poisson regression model. *BMC Public Health* **13**, 11.
36. De Onis M, Dewey KG, Borghi E *et al.* (2013) The World Health Organization’s global target for reducing childhood stunting by 2025: rationale and proposed actions. *Matern Child Nutr* **9**, 6–26.
37. Mostafa KSM (2011) Socio-economic determinants of severe and moderate stunting among under-five children of rural Bangladesh - PubMed. *Malays J Nutr* **17**, 105–118.
38. Rahman A, Chowdhury S & Hossain D (2009) Acute malnutrition in Bangladeshi children: levels and determinants. *Asia-Pac J Public Heal* **21**, 294–302.
39. Das S & Gulshan J (2017) Different forms of malnutrition among under five children in Bangladesh: a cross sectional study on prevalence and determinants. *BMC Nutr* **3**, 1.
40. Hasan MT, Soares Magalhaes RJ, Williams GM *et al.* (2015) Forecasting the progress towards the target of Millennium Development Goal 1C in children under 5 years of age in Bangladesh. *Public Health Nutr* **18**, 1728–1736.
41. Rayhan MI & Khan MSH (2006) Factors causing malnutrition among under five children in Bangladesh. *Pak J Nutr* **5**, 558–562.
42. Sumon IH, Hossain MM, Ar Salan MS *et al.* (2023) Determinants of coexisting forms of undernutrition among under-five children: evidence from the Bangladesh demographic and health surveys. *Food Sci Nutr* **11**, 5258–5269.
43. Hossain MM, Abdulla F & Rahman A (2023) Prevalence and risk factors of underweight among under-5 children in Bangladesh: evidence from a countrywide cross-sectional study. *PLoS One* **18**, e0284797.
44. Hossain MM, Abdulla F & Rahman A (2022) Prevalence and determinants of wasting of under-5 children in Bangladesh: quantile regression approach. *PLoS One* **17**, e0278097.
45. Abdulla F, El-Raouf MMA, Rahman A *et al.* (2022) Prevalence and determinants of wasting among under-5 Egyptian children: application of quantile regression. *Food Sci Nutr* **11**, 1073–1083.
46. Kumar P, Rashmi R, Muhammad T *et al.* (2021) Factors contributing to the reduction in childhood stunting in Bangladesh: a pooled data analysis from the Bangladesh demographic and health surveys of 2004 and 2017–2018. *BMC Public Health* **21**, 2101.
47. Nisbett N, Davis P, Yosef S *et al.* (2017) Bangladesh’s story of change in nutrition: strong improvements in basic and underlying determinants with an unfinished agenda for direct community level support. *Glob Food Sec* **13**, 21–29.
48. Huda TM, Hayes A, El Arifeen S *et al.* (2018) Social determinants of inequalities in child undernutrition in Bangladesh: a decomposition analysis. *Matern Child Nutr* **14**, e12440.
49. DHS (2021) The DHS Program - Available Datasets. DHS Program Demographic and Health Surveys. <https://dhsprogram.com/data/available-datasets.cfm> (accessed June 2021).



50. National Institute of Population Research and Training (NIPORT) & ICF (2020) Bangladesh Demographic and Health Survey 2017–2018. Dhaka, Bangladesh; Rockville, MD: NIPORT and ICF.
51. DHS (2021) The DHS Program - DHS Methodology. DHS Program Demographic and Health Surveys. <https://dhsprogram.com/methodology/Survey-Types/DHS-Methodology.cfm> (accessed June 2021).
52. Headey D, Hoddinott J, Ali D *et al.* (2015) The Other Asian Enigma: explaining the rapid reduction of undernutrition in Bangladesh. *World Dev* **66**, 749–761.
53. Hanley-Cook G, Argaw A, Dahal P *et al.* (2022) Elucidating the sustained decline in under-three child linear growth faltering in Nepal, 1996–2016. *Matern Child Nutr* **18**, e12982.
54. Cunningham K, Headey D, Singh A *et al.* (2017) Maternal and Child Nutrition in Nepal: examining drivers of progress from the mid-1990s to 2010s. *Glob Food Sec* **13**, 30–37.
55. Headey DD & Hoddinott J (2015) Understanding the rapid reduction of undernutrition in Nepal, 2001–2011. *PLoS One* **10**, e0145738.
56. Headey D, Hoddinott J & Park S (2017) Accounting for nutritional changes in six success stories: a regression-decomposition approach. *Glob Food Sec* **13**, 12–20.
57. Menon P, Headey D, Avula R *et al.* (2018) Understanding the geographical burden of stunting in India: a regression-decomposition analysis of district-level data from 2015–2016. *Matern Child Nutr* **14**, e12620.
58. Headey D, Hoddinott J & Park S (2016) Drivers of nutritional change in four South Asian countries: a dynamic observational analysis. *Matern Child Nutr* **12**, 210–218.
59. StataCorp LP (1985) *Stata Survey Data Reference Manual*. Citeseer. College Station, TX: Stata Press.
60. Kreuter F & Valliant R (2007) A survey on survey statistics: what is done and can be done in stata. *Stata J* **7**, 1–21.
61. UCLA (2021) Applied Survey Data Analysis in Stata 13. Advanced Research Computing Statistical Methods and Data Analytics. <https://stats.oarc.ucla.edu/stata/seminars/applied-svy-stata13/> (accessed June 2021).
62. Schumacher D, Borghi E & Polonsky J (2019) R Package ‘anthro’: Computation of the WHO Child Growth Standards. 1–10. CRAN. <https://CRAN.R-project.org/package=anthro> (accessed May 2021).
63. RStudio (2011) New Open-Source IDE for R. <https://posit.co/blog/rstudio-new-open-source-ide-for-r> (accessed May 2021).
64. Darnton-Hill I & Mkparu UC (2015) Micronutrients in pregnancy in low- and middle-income countries. *Nutrients* **7**, 1744–1768.
65. Victora CG, De Onis M, Hallal PC *et al.* (2010) Worldwide timing of growth faltering: revisiting implications for interventions. *Pediatric* **125**, e473–e480.
66. WHO (2016) World Health Statistics 2016: Monitoring Health for the SDGs, Sustainable Development Goals. Geneva: WHO.
67. UN (2021) THE 17 GOALS | Sustainable Development. United Nations. <https://sdgs.un.org/goals> (accessed June 2021).