The relative effects of socioeconomic inequalities and nutritional factors in explaining child linear growth in Bangladesh

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The relative effects of socioeconomic inequalities and nutritional factors in explaining child linear growth in Bangladesh

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ABSTRACT

Background: While nutrition is essential, an individual's socioeconomic position (SEP) within hierarchical societies can be influential in determining adequate child growth. This study assessed the relative effects of SEP inequalities and nutritional factors (NF) on linear growth, i.e., height-for-age-Z-score (HAZ), using data from Bangladesh.

Methods: Data from mother-child dyads were analysed using: 1) the nationally representative 'Food Security Nutrition Surveillance Project (FSNSP)' (2011–2014), n=37,929 (children <5 years); and 2) an evaluation of a multisectoral nutrition programme, Suchana, targeting the most vulnerable households in northeast Bangladesh (2016 and 2019), n=13,062 (children <2 years). Applying polychoric principal component analysis, a composite SEP scale was constructed combining parental education, occupation, land ownership, assets, and other household characteristics. Difference in HAZ between SEP groups [FSNSP: "richest" (5th quintile) vs. "poorest" (1st quintile); Suchana: "poor" (SEP values median and above) vs. "poorest" (below median)] reflected SEP inequalities. The NF included child's minimum dietary diversity (MDD) and morbidity status. Multiple linear regression model for the HAZ outcome included SEP groups and NF as main variables of interests, adjusted for covariates (child age, sex, birth order, wasting, maternal short stature, BMI, household size). Standardised beta coefficients were utilised to compare relative effects of SEP and NF.

Results: In both contexts, SEP group inequalities was significantly associated with a larger difference in HAZ (FSNSP: 0.22 SD units, 95% CI: 0.19,0.25; Suchana: 0.13 SD units, 95% CI: 0.09,0.17). Achieving MDD was significantly associated with better HAZ (0.06, 95% CI: 0.03,0.09) for FSNSP, but not for Suchana. However, morbidity and HAZ had no significant association in either model.

Conclusions: This research suggest socioeconomic inequalities have stronger effects on HAZ than NF, raising questions about international development priorities. Efforts to achieve optimal linear growth for children would require an integrated approach: prioritising this to address the wider issue of social inequalities rather than just nutrition.

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DECLARATION AND STATEMENT OF COPYRIGHT

The work presented in this thesis is based on research carried out at the Department of Anthropology at the University of Durham, England. No part of this thesis has been submitted elsewhere for any other degree or qualification and it is all my own work unless referenced to the contrary in the text.

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ABBREVIATIONS

ANC	Antenatal care
A&T	Alive & Thrive
BDHS	Bangladesh demographic health survey
BRAC	Bangladesh Rural Advancement Committee
CBN	Cost of basic needs
CCs	Concentration curves
CE	Christian Era
CIXs	Concentration indices
DGFP	Directorates General Family Planning
DGHS	Directorates General of Health Services
DHS	Demographic health survey
EU	European Union
FCDO	Foreign, Commonwealth and Development Office
FSNSP	Food Security and Nutritional Surveillance Project
GoB	Government of Bangladesh
HAZ	Height-for-age Z-score
HIES	Household Income Expenditure Survey
icddr,b	International centre for diarrhoeal disease research, Bangladesh
IEC	Information, education, and counselling
INFS	Institute of Nutrition and Food Science
IUGR	Intra uterine growth retardation
IYCF	Infant and young child feeding
LMIC	Low middle income countries
LAZ	Length for age Z score
LBW	Low birth weight
MDG	Millennium development goal
MDD	Minimum dietary diversity
MDD-W	Minimum Dietary Diversity for Women
MNP	Multiple Micronutrient Powder
MoHFW	Ministry of Health and Family Planning
NF	Nutritional factor
PCA	Principal component analysis
pPCA	polychoric principal component analysis
PNC	post-natal care
SD	Standard deviations
SDG	Sustainable development goal
SGA	Small gestational age
SEP	Socioeconomic position
SES	Socioeconomic status
UN	United Nations
UNICEF	United Nations Children's Fund
WAZ	Weight-for-age Z-score
WHO	World Health Organization
WHZ	Weight-for-height Z-score

1. CHAPTER 1

INTRODUCTION

Overview of the research

This PhD research examines the variability in linear growth in children under five years of age in Bangladesh. Linear growth retardation implies that children are too short for their age. The main objective of this study is to compare the role of nutritional factors and socioeconomic inequalities in explaining variabilities in linear growth. The research utilised data from a nationally representative sample in rural areas, as well as data from an intervention specifically targeting poor and very poor households within a region characterised by high levels of malnutrition.

Over time, Bangladesh has made impressive progress on achieving several sustainable development goals (SDGs); such as SDG1 (no poverty): reducing poverty (% below national upper poverty line decline from 32% in 2010 to 21% in 2019); SDG2 (zero hunger): prevalence of undernourishment decline from 16% in 2017 to 10% in 2020, SDG3 (good health and wellbeing): under-five mortality rate continuously declined (from 447/100,000 live birth to 163/100,000 live birth in 2020); SDG4 (quality education): students completing primary, lower secondary and upper secondary education in 2019 were 83%, 65% and 29%, respectively; and SDG 5 (gender inequality): the global gender gap index 2021 ranked Bangladesh 71 out of 146 countries, and it consistently was faring better that India and Pakistan over the years (Bangladesh Planning Commission, 2022). Yet recent report reflects that there is accompanying rising income inequality, which indicates more needs to be done in reducing inequality (SDG10) (Bangladesh Planning Commission, 2022). It is known well that poverty and malnutrition are positively associated, and Bangladesh is predicted to move from low-middle-income-country (LMIC) status to middle income country, and has been cited as a model of poverty reduction (BRAC/USA, 2021; WB, 2020). However, the recent household income expenditure survey (HIES) 2022 found stark inequality, the poorest 10% of the Bangladeshi population only holds 1% of the national income, whereas 41% is contained within the top 10% of the population (The Business Standard, 2023). This poverty reduction at the overall country level masks the rising inequalities within it and its amplified impact on poorer households. To sustain the progress made and to have a beneficial impact across socioeconomic groups, researchers and policy makers need to combine efforts to examine and understand the role of inequalities on the nutritional status of children, so that longer term adversities can be reduced.

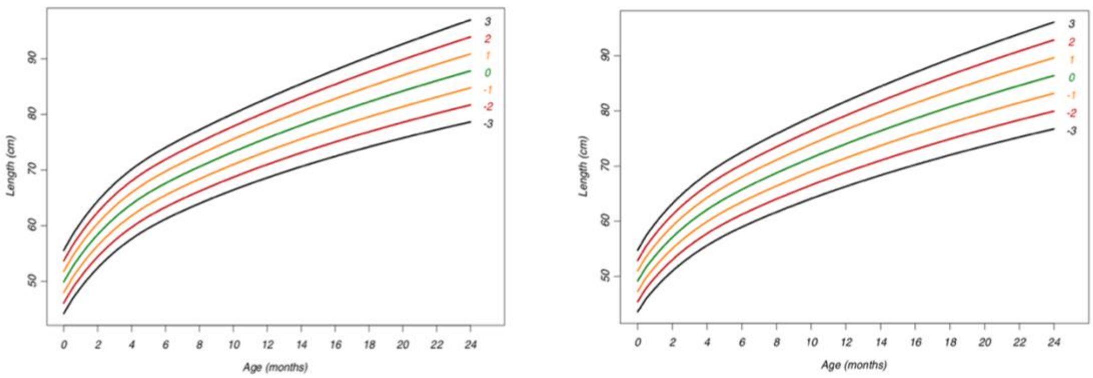
Socioeconomic inequalities negatively impact on the quality of life (Maleki et al., 2023), health care (Alamneh et al., 2022), disability adjusted life years (Hosseinpoor et al., 2013), an individual's life expectancy (Mondal & Shitan, 2013) among other factors and hinder people's enjoyment of human rights leading to discrimination, abuse, and a lack of access to justice. The effect of socioeconomic inequalities on health outcome, specifically on mortality and obesity, is more often studied in high-income countries (Wilkinson & Pickett, 2010), because obesity is a common nutritional problem there, while stunting is a widely prevalent problem studied in LMIC.

Within this context, my research investigates the impact of socioeconomic inequalities on linear growth in children aged 6-59 months in Bangladesh. It specifically examines two research questions: i) the relative importance of socioeconomic inequalities compared to nutritional factors in explaining variabilities in child linear growth at the national level; and ii) the relative importance of socioeconomic inequalities compared to nutritional factors in explaining variabilities in child linear growth in a programmatic context. These research questions aim to generate new insights to sustain a country's progress in other sectors and to guide strategies and resource allocation for reducing the prevalence of stunting and its associated negative lifelong consequences.

Linear growth and stunting: A widespread public health problem

Length/height-for-age Z-score (L/HAZ) is a statistical measure of linear growth, where the age and sex specific median length/height of the global population is considered as 0, and deviation from the median is expressed in standard deviation (SD) units. Linear growth serves as a comprehensive measure of children's overall welfare and serves as a reliable indicator of inequalities in human development (De Onis & Branca, 2016). This is evident in the millions of children worldwide who not only fail to achieve their linear growth potential because of suboptimal health conditions and inadequate nutrition and care but also suffer the severe irreversible physical and cognitive damage that accompanies stunted growth (De Onis & Branca, 2016). Following the WHO (2020) definition, stunting is referred to as resulting from 'suboptimal nutrition, inadequate care, and repeated infections'(WHO, 2020).

A child is considered to be stunted when his/her L/HAZ falls <-2 SDs of the World Health Organization (WHO) child growth standard median (WHO, 2006). The 'standard median' (Figure 1.1) depicts normal early childhood growth under optimal environmental conditions (De Onis & Branca, 2016). Although the WHO child growth standards are considered globally representative, there are disagreements on whether children from different regions or ethnicities can all have the same growth potential and if the WHO standard can be used universally to define stunting (Scheffler et al., 2020). A recent review on validation of the growth standards critiqued that no growth reference is superior to another, and that inter-country variation in social determinants of health, environmental and genetic factors questions the suitability of a one-size-fits-all approach of the WHO growth standards (Marume et al., 2022). While such interrogations continue and opinions in favours of local or international growth references/standards vary, no new growth standards that can be used across all populations have yet been recommended by scientific communities (Ziegler & Nelson, 2012). However, WHO introduced child growth standards (WHO, 2006), which were developed utilizing data from the WHO Multicentre Growth Reference Study (MGRS) that collected longitudinal data from a sample of healthy breastfed infants and young children across countries in five continents (Tanjung et al., 2020). The MGRS reflected that children from well-off populations in developing countries exhibit growth patterns similar to those of healthy, well-nourished children in developed countries. Hence, the argument favouring this WHO child growth standard suggests that it can be used to assess growth of children globally, regardless of ethnicity, socioeconomic status, or type of feeding (De Onis & Branca, 2016). It is also recognized that when health, environmental, and care needs are met, the potential for growth is universal up to at least 5 years of age (De Onis & Branca, 2016). The WHO child growth standard (WHO, 2006) symbolizes children's right to achieve their genetic growth potential (De Onis & Branca, 2016; Tanjung et al., 2020). This PhD research used the WHO growth standards (WHO, 2006) to assess linear growth of Bangladeshi children.



length-for-age z score for boys

length-for-age z score for girls

Figure 1.1 WHO length-for-age z score for boys and girls from birth to 24 months (WHO, 2006), with the green line indicating the median L/HAZ; yellow lines, red lines and black lines corresponds to 1SD, 2SD and 3SD, respectively.

Globally, the current rate of stunting is 21%, i.e., around 149 million children aged <5 years suffer from stunting or impairment of linear growth (United Nations, 2022). Most stunted children live in less developed countries in sub-Saharan Africa and South Asia (Figure 1.2). The WHO refers to four broad sub-forms of undernutrition: wasting [low weight-for-height Z-score (WHZ)], stunting [low length/ height-for-age Z-score (L/HAZ)], underweight [low weight-for-age Z-score (WAZ)], and deficiencies in micronutrients. Based on these WHO criteria, stunting is considered the most severe and chronic type of malnutrition compared to other forms of undernutrition (Victora et al., 2010).

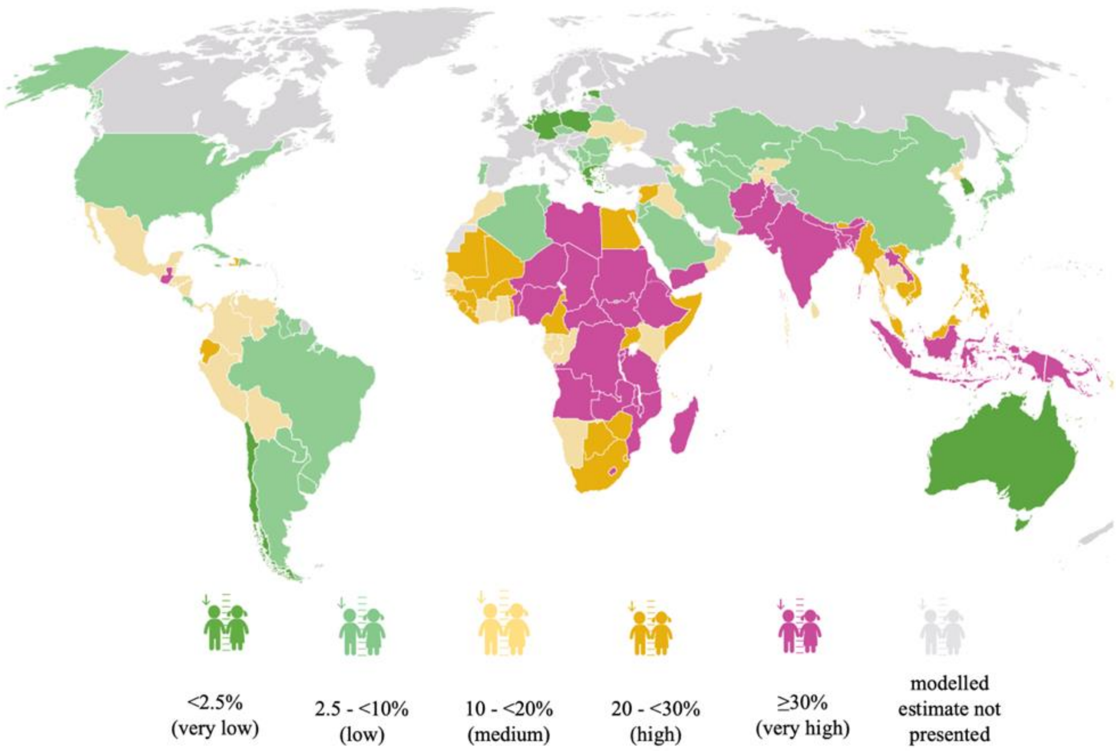


Figure 1.2 Percentage of stunted children under 5, by Global nutrition report 2021 (GNR, 2021)

Stunting has short-medium, and long-term consequences (Black et al., 2013). For example, poor linear growth in children is associated with reduced cognitive function (Black et al., 2013; Prendergast & Humphrey, 2014), decreased learning capacity (Martorell et al., 2010), and lower productivity (Hoddinott et al., 2013), increased morbidity and mortality (Aguayo & Menon, 2016; Black et al., 2008; Özaltin et al., 2010); poor birth outcome e.g., low birth weight (LBW), or small gestational age (SGA) in the next generation (Black et al., 2013), long-term health problems, e.g., chronic diseases (Gluckman et al., 2007; Hoddinott et al., 2013), such as cardio-metabolic diseases, overweight- a precursor of chronic diseases, in the case of rapid overfeeding of LBW children later in childhood (Barker, 2007), an increased risk of cephalopelvic disproportion which leads to dystocia (Wells, 2017) to name the most discussed adverse consequences.

Nutritional problems can continue across the life course, as illustrated in Figure 1.3. Inadequate nutrition often begins in utero and can continue into adolescence and adulthood, especially for girls and women. It also has intergenerational effects. Malnutrition during childhood, adolescence, and pregnancy has a cumulative negative impact on infant birthweight in the subsequent generation. Infants born with LBW and intrauterine growth retardation (IUGR) are malnourished and face a higher risk of mortality in the neonatal period or infancy. Even if they survive, they are unlikely to fully recover from growth deficits and may experience various developmental impairments. Therefore, LBW infants are more likely to be underweight or stunted during early life. The consequences of being born undernourished can extend into adulthood (Thompson & Cohen, 2012)

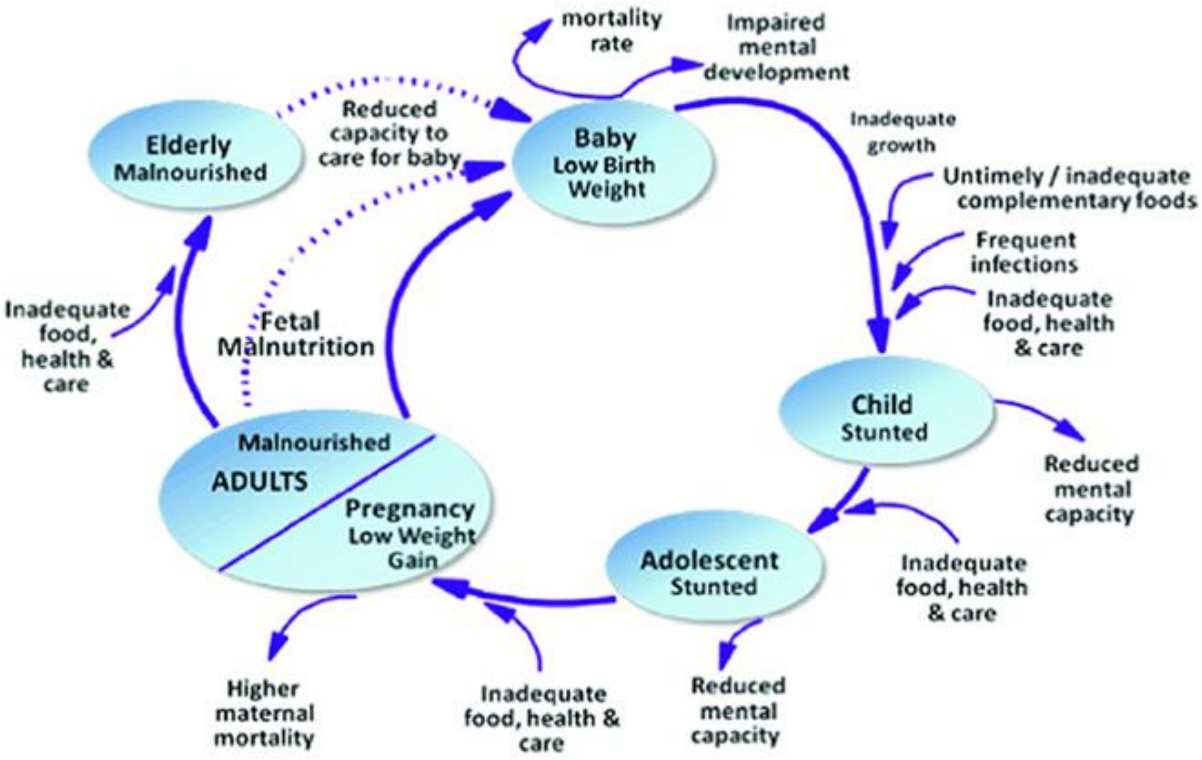


Figure 1.3 Nutrition throughout the life cycle (Thompson & Cohen, 2012)

Explaining linear growth retardation (stunting)

In the field of nutrition, several frameworks have been developed to understand stunting and impaired linear growth. While some of these frameworks focus on malnutrition in general, a few specifically address stunting, a few address nutrition action while others address inequality. In this review section, the following frameworks have been used to explore the factors associated with stunting and linear growth retardation.

I began my literature review by examining the UNICEF conceptual framework (UNICEF, 1991), which focuses specifically on child and maternal malnutrition. According to this framework (Figure 1.4), inadequate dietary intake and disease are identified as immediate causes of malnutrition.

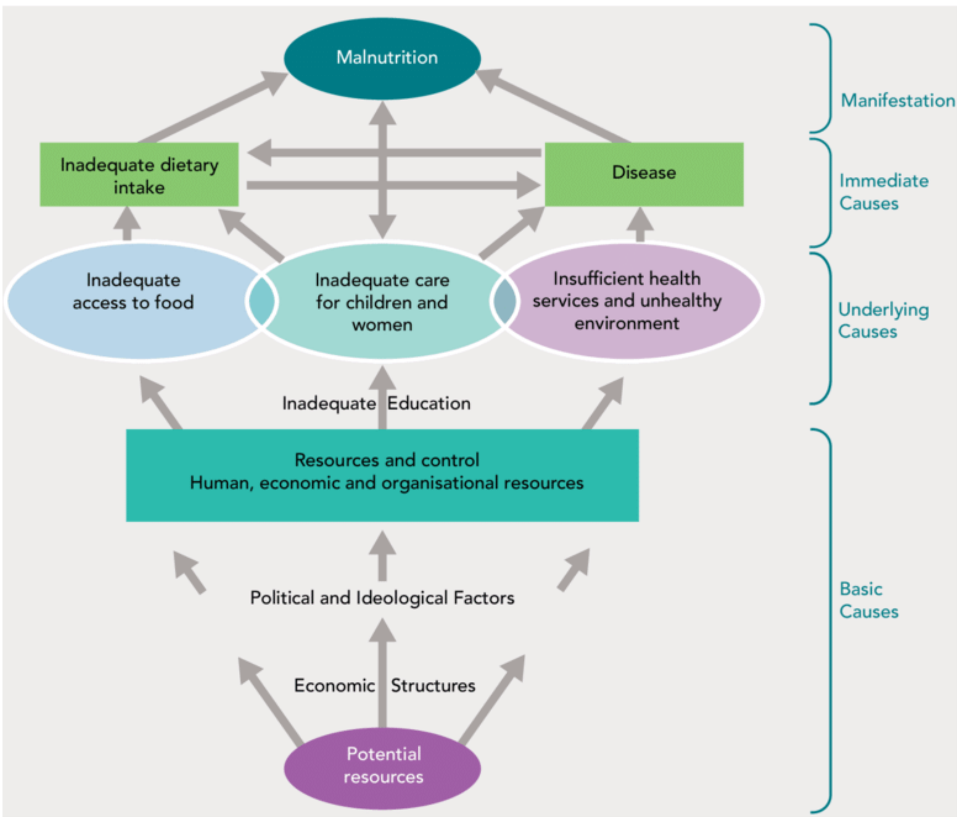


Figure 1.4 UNICEF conceptual framework (UNICEF, 1991)

In many cases, malnutrition is the result of both insufficient dietary intake and the presence of pathogens, particularly infectious diseases that impact nutrient utilization. These immediate causes are influenced by underlying factors, which can be grouped into three main clusters: household food security, maternal and child care and access to basic health services and a healthy environment. Among these factors, household food security and access to basic health services are crucial for ensuring adequate dietary intake and controlling common diseases. However, it is also necessary to have a system in place that health services for the well-being of children and women. Additionally, education, water and environmental sanitation, and housing can all influence the outcomes. All these underlying factors highlight the multisectoral nature of malnutrition. Furthermore, the root/basic causes of malnutrition can be attributed to both the historical background of a society and external factors. Numerous other adaptations of the UNICEF framework have been developed over the years, most notably by the Lancet Maternal and Child Nutrition Series to serve a variety of purposes (Black et al., 2008; Black et al., 2013).

Building on the UNICEF framework (1991) on the causes of malnutrition (UNICEF, 1991), the WHO conceptual framework on Childhood Stunting: Context, Causes and Consequences (presented in Figure 1.5) specifically focuses on the chronic form of malnutrition, stunting. For this WHO (2013) framework ‘stunted growth’ and ‘development’ are coupled at the core of the framework in recognition of the fact that they share common causes. Factors that influence stunting at the household and family level include maternal health and nutritional status during pregnancy (or prior to pregnancy) alongside home environmental factors that may exert a transgenerational influence on offspring growth and development. The contextual layer (community and societal factors) expands on the underlying and basic causes of malnutrition as illustrated in the UNICEF framework. The underlying causes of stunting are therefore influenced by different contextual factors. This implies that for programmes to be effective in preventing or reducing stunting, they should reach across disciplinary boundaries.

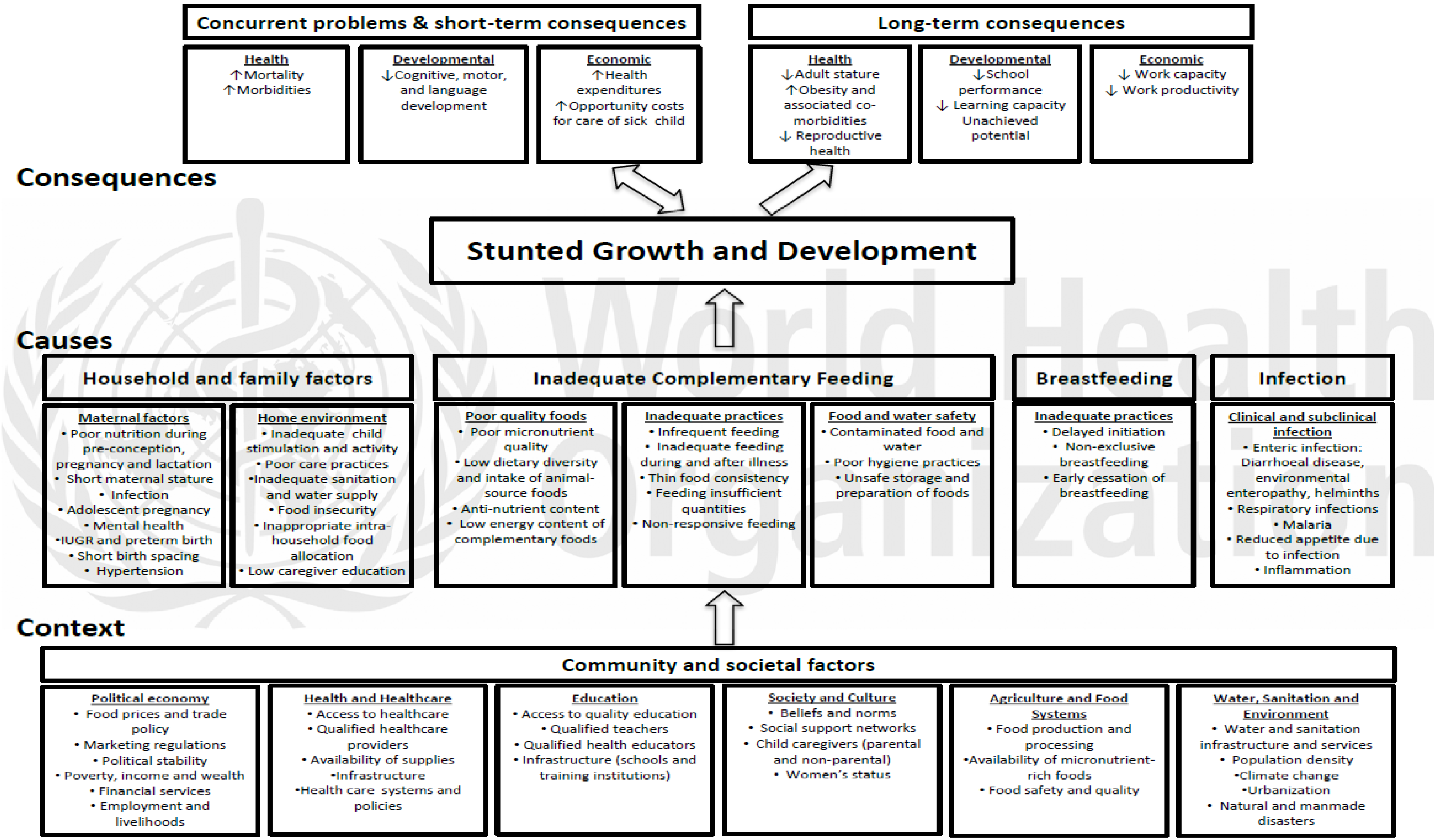


Figure 1.5 The WHO conceptual framework on Childhood Stunting: Context, Causes and Consequences (Stewart et al., 2013)

On the other hand, a bioecological framework called the 6Cs model for mapping the determinants of stunting has allowed for the visualization of potential interrelated factors (Veiga et al., 2022). Focusing on childhood stunting as the central concern (Figure 1.6), the immediate or proximal determinants are presented by two spheres: the cellular level and the individual child level. Common determinants in these two spheres include: the child's age (>12 months) (Torlesse et al., 2016), gender (boys are more vulnerable compared than girls because of their generally greater nutritional requirements) (Victora et al., 2022; Wamani et al., 2007), being born with foetal growth retardation or LBW or small gestational age (SGA) (Aguayo et al., 2016; Argaw et al., 2019; Danaei et al., 2016; Victora et al., 2021), high morbidity (Checkley et al., 2008; Fink & Rockers, 2014), suffering from other form of malnutrition, e.g., wasting (Victora et al., 2021), and insufficient dietary diversity or nutrient-rich foods (Ara et al., 2022; Dewey, 2016; Rah et al., 2010).

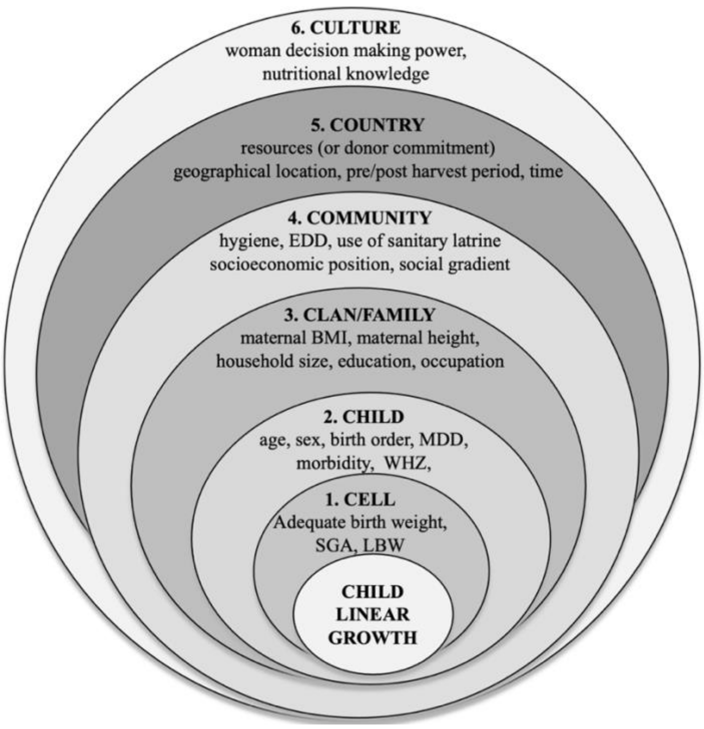


Figure 1.6 The 6Cs model for mapping the determinants of stunting, adopted from (Veiga et al., 2022)

In the third sphere, clan/family (maternal/household) related factors are highlighted, such as maternal low stature and undernutrition (Bhowmik & Das, 2017; Danaei et al., 2016; Kim et al., 2017; Victora et al., 2021), inadequate maternal diet before and during pregnancy, and low levels of maternal education (Huda et al., 2017; Semba et al., 2008), and absence of psychosocial stimulation (Hamadani et al., 2006; Iannotti et al., 2017; Niere et al., 2020). Maternal short stature and offspring stunting confirmed a robust intergenerational linkage (Katoch, 2022; Khatun et al., 2019). These determinants (child individual, maternal/family factors) are influenced by factors presented in subsequent spheres. For example, the causes of LBW or SGA are diverse and can result from congenital factors, placental insufficiency, or maternal factors (Bogin, 2020) (page 82). LBW or SGA are also highly associated with structural determinants, e.g., social stratification [the socioeconomic position (SEP) of the mother]. The possible mechanism of this relationship is due to the attitudes and behaviours of mothers and their opportunities for improving their living conditions, education, occupation, and their social status (Bogin, 2020) (page 82). The community related determinants presented in the 4th sphere include health services such as antenatal care (ANC), place of residence (urbanization) (Argaw et al., 2019), detrimental environmental factors including poor water and sanitation (Argaw et al., 2019; Danaei et al., 2016), enteropathy (Lin et al., 2013), poverty (Alao et al., 2021) and inequalities (Black et al., 2013; Huda et al., 2017; Krishna et al., 2018; Kumar et al., 2021; Nguyen et al., 2017; Rabbani et al., 2016; Torlesse et al., 2016). Large disparities in the prevalence of stunting exist across and within LMIC (Mohsena et al., 2015; Saha & van Wesenbeeck, 2022; Ssentongo et al., 2021). Seasonal fluctuations in nutritional status are also important and are closely associated with food insecurity, particularly during pre-harvest times when food shortages are prevalent (Mohsena et al., 2018). Woman's decision-making power, a mother's nutritional knowledge, policy makers' and donors' priorities/behaviours surrounding malnutrition are shaped by overarching cultural and social norms (Harrison et al., 2011). For instance, intra-household food distribution, or eating less food during pregnancy are largely shaped by cultural beliefs.

The aforementioned frameworks recognise the significance of underlying factors that contribute to inequalities. Therefore, a nutrition equity framework (Nisbett et al., 2022), which is also based on UNICEF framework (1991), highlights that malnutrition arise from unfair structural processes occurring at different times and in various geographical contexts (Figure 1.7). In summary, moving left to right on the diagram, the framework begins with the broad structural determinants and interactions of nutrition inequity, through socio-political contexts and social stratification, linked by an 'engine of inequity' comprising unfairness, injustice and exclusion. The intermediate determinants of malnutrition are on the right side of the diagram and depict the way in which structural causes are experienced in everyday conditions and environments.

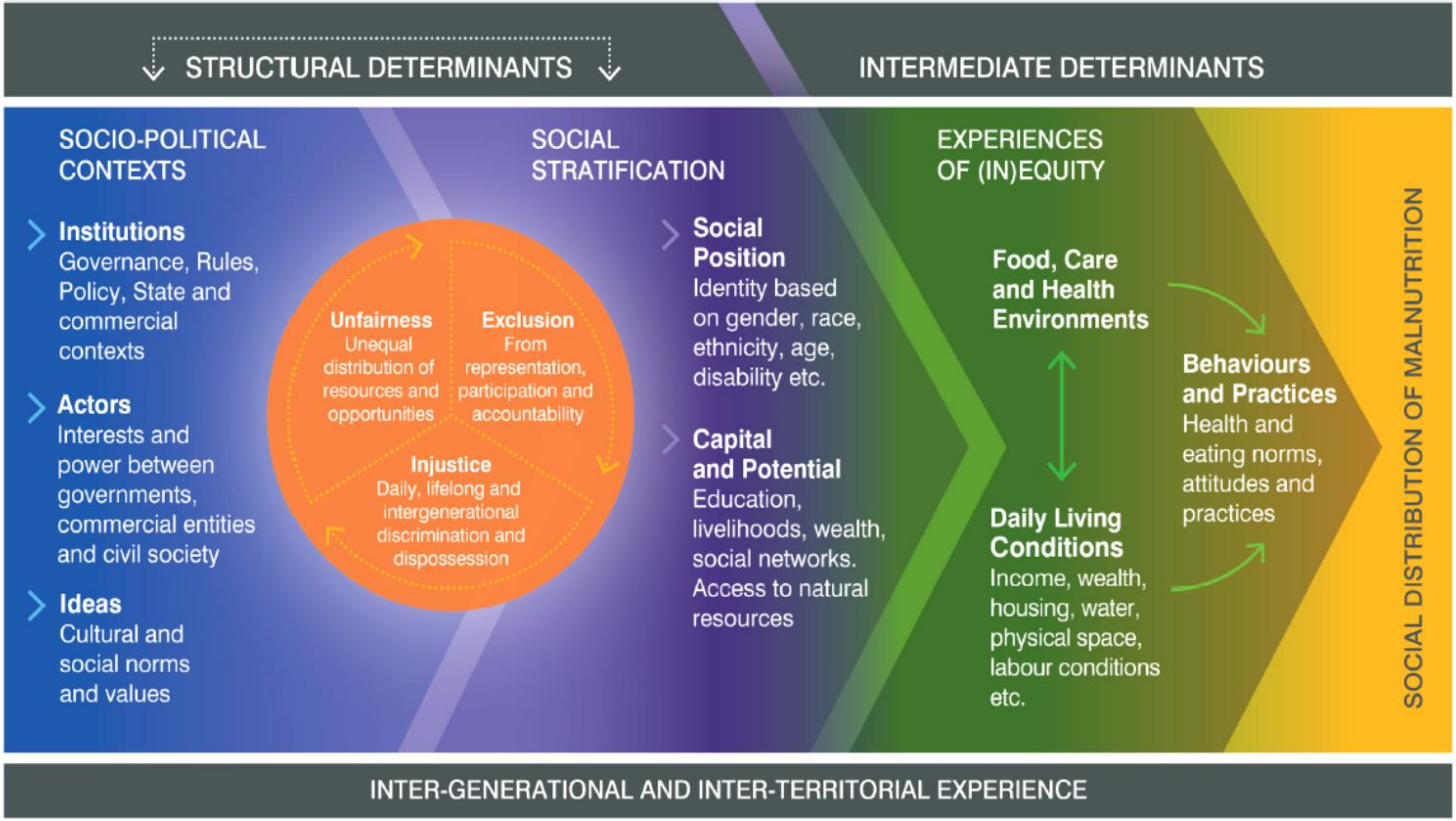


Figure 1.7 Nutrition Equity Framework (Nisbett et al., 2022)

Although the UNICEF, Lancet, bioecological, and equity frameworks were effective in identifying factors associated with stunting, there was a recognized need for a framework specifically focused on nutritional intervention. The nutrition action framework could help guide decisions on how, where, and with whom to intervene in order to effectively reduce stunting. Therefore, a statistically modelled framework was proposed by Lancet series (2013) (Figure 1.8), where for the first instance nutrition sensitive interventions were included along with nutrition specific interventions for optimal child growth (Black et al., 2013). Nutrition specific interventions directly address the immediate causes of child undernutrition, whereas nutrition-sensitive interventions address the underlying causes include household food insecurity, poor quality of caring practices for mothers and children, and unhealthy living environments (Smith & Haddad, 2014). This Lancet framework (2013) triggered multisectoral planning in many countries, at the same time, it posed challenges in terms of coordination and affixing responsibility for nutrition oversight.

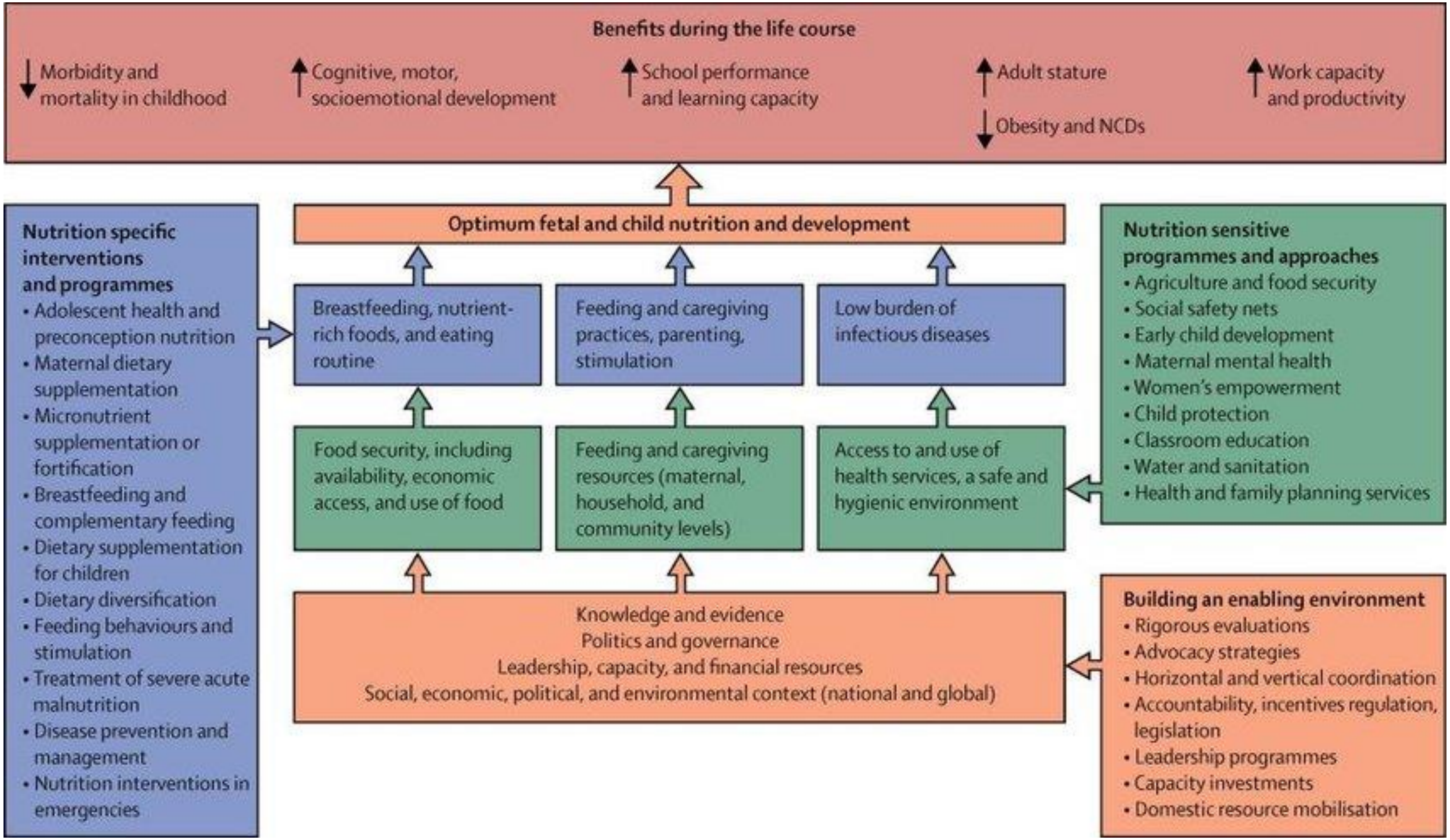


Figure 1.8 Nutrition action framework (Black et al., 2013)

Therefore, a revised framework (Figure 1.9) was produced in 2021 where nutrition actions were categorised into: i) direct health, ii) indirect health, iii) non-health care sector interventions, and iv) cross-cutting strategies. This new framework has strengthened the effectiveness of antenatal multiple micronutrient supplementation in reducing the risks of still births, LBW, SGA. Moreover, the use of a small quantity of lipid-based nutrient supplements has been proposed as a potential strategy for reducing childhood stunting (Keats et al., 2021).

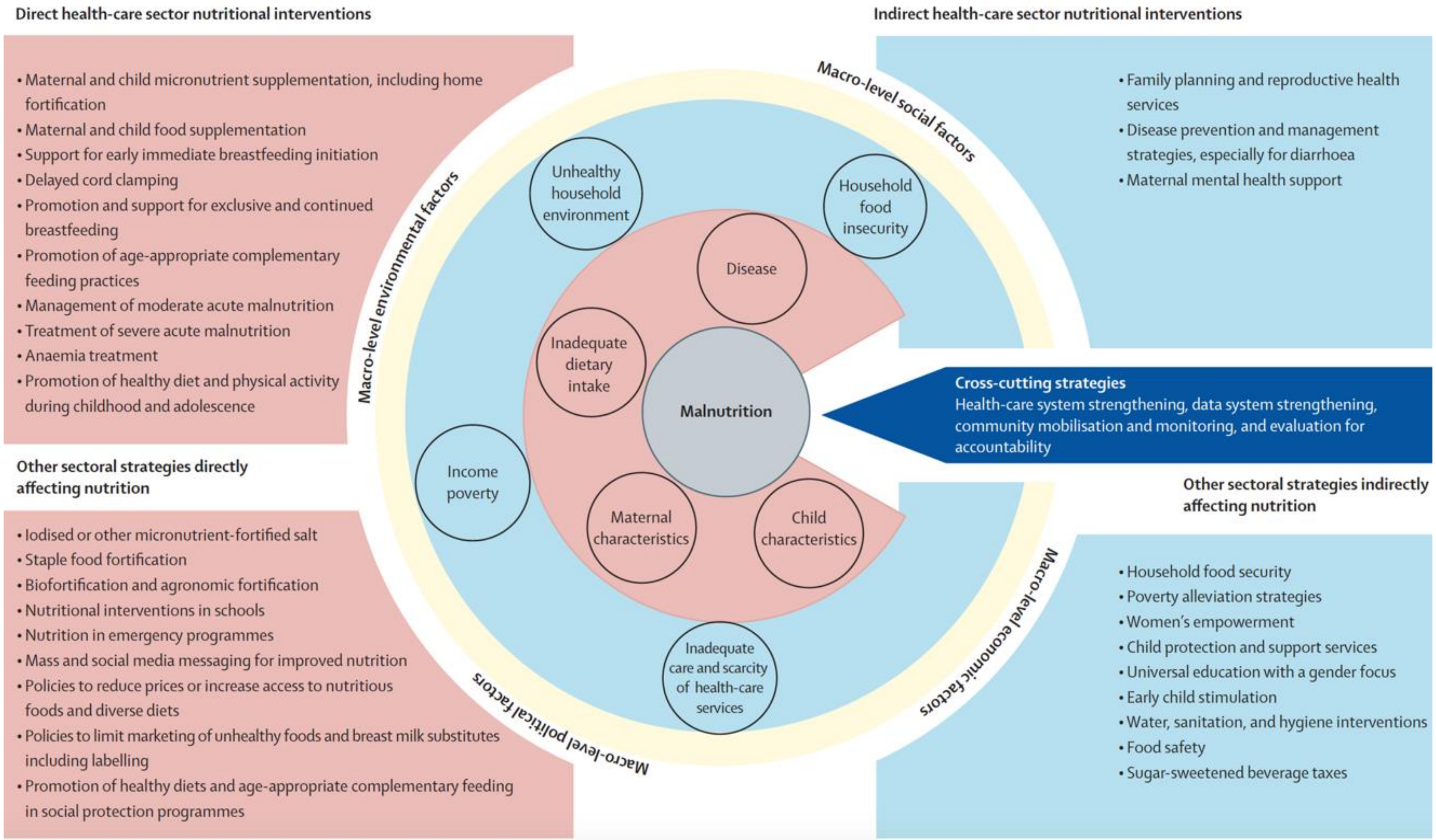


Figure 1.9 Nutrition action framework (Keats et al., 2021)

Global initiative to reduce stunting

As part of supporting the UN SDG, in 2012 the World Health Assembly (WHA), the decision-making body of the WHO, declared as its first global nutrition target a '40% reduction by 2025 in the number of children <5 years old who are stunted' (De Onis et al., 2013). In order to achieve this SDG target, unprecedented attention has been given to childhood malnutrition in the last decade. Nutrition for Growth (N4G) is a global initiative that brings together governments, donors, philanthropies, businesses, NGOs, and others with a shared commitment to addressing malnutrition and to achieve their goals. Their focus is not limited to their own countries but extends to supporting nutrition efforts worldwide and closing the financing gap. In support of the fight against malnutrition, 13 donors have promised over US$26.3 billion funds to spend between 2020 and 2030. It has been estimated that an additional average annual investment of US$10.8 billion is required between 2022 and 2030 to achieve four global nutrition targets related to stunting, wasting, anaemia, and breastfeeding, which are particularly relevant in LMIC. Under this N4G commitment, donors are not solely focused on mobilising funding but also strengthening the policy influence and partnerships to address poor diets and malnutrition in LMIC (GNR, 2021). However, it is not known yet whether N4G is on target.

A critical window of growth — 1000 days

Global nutrition considers the first 1000 days of a child's life (from conception to the child's second birthday) as a critical window or a 'window of opportunity', because this is when improvements in nutrition can have the greatest impact on populations with poor nutrition (Martorell, 2017). This claim comes from several follow-up studies, carried out in Guatemala by the Institute of Nutrition of Central America and Panama (1969–1977). These studies among women and young children have shown long term effects on adult skills, that eventually can be used to create economic value (Martorell et al., 1995). The first 1000 days is a time of very rapid growth and development extending to all organ systems (Martorell, 2017). Linear growth reflects growth of bone, muscle, and fat. In foetal life, body length grows fast until the twentieth week of gestation, when it attains maximum velocity (~10 cm/4 weeks), and then starts to decelerate including through the post-natal period (Martorell, 2017). In the neonatal period, linear growth is approximately 24 cm per year, but falls to <10 cm by two years of age. Growth velocities continue to be higher during the first two years of life compared to middle childhood (aged 5-9). Growth velocities only begin to accelerate again during adolescence (Martorell, 2017).

Intervention findings: interventions which aim to reduce stunting

Programme-implementing agencies, supported by donors, are actively engaged in implementing nutritional interventions based on the framework presented in the Lancet series, described above, with the aim of reducing the prevalence of stunting. Extensive research has established the critical role of adequate and nutrient-rich complementary feeding in supporting optimal physical growth and brain development, thereby preventing stunting (Aguayo et al., 2016; Dewey, 2016; Kim et al., 2017). Central to all nutritional interventions is the core assumption that enhancing the diet will result in a reduction of stunting (Mumm & Scheffler, 2019). Accordingly, a significant portion of nutritional interventions has focused on improving stunting status through dietary improvements or the provision of food supplementation (Haque et al., 2023; Nguyen et al., 2017; Richter et al., 2011).

A review paper examining 12 intervention studies on information, education, and counselling (IEC) interventions in South Asia found that IEC interventions had limited impact on improving child dietary diversity, especially in terms of consuming animal source foods. This could be attributed to challenges related to acceptability, availability, and affordability of such foods (Aguayo, 2017).

In contrast, food supplements demonstrated small positive effects on linear growth for households experiencing food insecurity, regardless of whether they received educational interventions or not (Panjwani & Heidkamp, 2017). A systematic review and meta-analysis (with 15 randomised controlled trials) indicated that food-based interventions can help to improve linear growth (mean difference in HAZ: 0.20, 95% CI: 0.04 to 0.35) among children under five years (Mamun et al., 2023). In a review of 22 nutritional interventions with children in slums, Goudet et al. (2017) found that only 7 studies reported a reduction in stunting (Goudet et al., 2017). A ‘network meta-analysis’, based on 79 randomised controlled trials (96 papers) involving 81,786 children, reported that MNP supplementations, and an iron folic acid (IFA) improve HAZ (MNP supplementation mean difference =0.08; 95% CI: 0.01, 0.15; IFA mean difference=0.03; 95% Cl: -0.02, 0.08) (Park et al., 2020).

In research conducted in Ecuador, focusing on children with a high prevalence of stunting, provision of one egg per day for six months during the early complementary feeding period for the children resulted in a substantial increase in HAZ of 0.63 (95% CI: 0.38, 0.88), and the prevalence of stunting decreased by 47% (Iannotti et al., 2017). Similarly, in a randomised controlled trial in rural Bangladesh Ara et al. (2022) provided one egg plus milk with multiple micronutrient powder (MNP) to young children (< 2 years) for 12 months, and found that length for age (LAZ) score increased by 0.37 (CI 0.24, 0.51, $p < 0.001$) (Ara et al., 2022). However, Stewart (2019) found that the provision of one egg per day for six months to young children had no effect on linear growth in a rural Malawian context. The author suggested that the study population had a diet rich in animal source foods and a low prevalence of stunting at baseline, which might have limited the potential impact (Stewart et al., 2019).

Dangour et al. (2013) in a meta-analysis of 14 water and sanitation intervention studies (specifically, solar disinfection of water, provision of soap, and improvement of water quality), reported a slight but significant change in child height (Dangour et al., 2013). New evidence around 'Environmental Enteric Dysfunction (EED)', a condition that was earlier known as tropical enteropathy observed in LMIC countries, for the causes of poor growth suggests these might be due to subclinical inflammation and environmental enteric dysfunction (EED) (Victora et al., 2021). EED received attention considering this as one of the major causes for stunting (Crane et al., 2015; Lin et al., 2013), which is a condition characterised by gut inflammation, nutrient malabsorption, and consequent chronic undernutrition, and is caused by chronic exposure to pathogenic bacteria, such as faecal coliforms, that can colonise the small intestine of children. Safe disposal of stools and handwashing with soap are considered a primary intervention to protect children from contamination (Humphrey, 2009). Water and sanitation interventions in a randomised control trial in Bangladesh and Kenya did not find any significant positive changes to stunting (Cumming et al., 2019; Luby et al., 2018). In a recent paper, Lin et al. (Lin et al., 2020) did not support the decades-long hypothesis that EED is a main contributor to stunting.

Hossain et al. (2017), in a systematic review of 18 papers concerning 14 programmes in LMIC, identified interventions which were effective to reduce stunting. The author found that only seven of those interventions (39%), of which three integrated nutrition sensitive (indirect) and nutrition specific (direct) interventions, showed any significant effect (>3% annual reduction) on rates of stunting (Hossain et al., 2017). The author also reported that those programmes which appeared most successful were where strong political commitment and multi-sectoral collaboration between government, non-government, national and international organisations existed and where programmes were delivered through community service delivery platforms with active community engagement (Hossain et al., 2017).

While small-scale research or review papers may demonstrate an impact on stunting reduction, policymakers consistently seek evidence from large scale interventions that are scalable and sustainable. For instance, a large scale nutrition programme, Alive & Thrive (A&T), was implemented in Bangladesh, Vietnam and Ethiopia (Menon et al., 2013) from 2010 to 2014, and was targeted at children under 2 years to reduce stunting. The approaches of A&T included improved counselling by frontline health workers during home visits, community mobilization, mass media campaigns with mothers, fathers and religious leaders, and policy advocacy. These approaches led to rapid and significant improvements in key practices related to breastfeeding and infant and young child feeding (IYCF) practices. For evaluation purposes to see the real impact of the programme, however, they assessed children >24 months at endline. The project did not achieve any positive changes in stunting in Bangladesh (Menon et al., 2016).

In the context where nutritional interventions do not yield significant positive results in terms of effectiveness, Mumm and Scheffler (2019) challenged the commonly held notion that "nutrition influences height". They tested the hypothesis that "nutrition does not affect height in children and adolescents", utilising data from the "Young Lives" study conducted in Ethiopia, India, Peru, and Vietnam. The study was longitudinal in design. The first cohort started with 1-year-olds (± 6 months) children (n = 2000, 1000 boys and 1000 girls). Boys and girls of the second cohort (n = 1 000, 500 boys, 500 girls) were 8 years old (± 6 months) at the first measurement. For each cohort, height (in cm) and weight (in kg) were measured over the course of 15 years in four rounds of data collection (2002, 2006, 2009, 2013). Children from the first cohort were 1, 5, 8 and 12 years' old during different rounds of measurement. Boys and girls from the second cohort were 8, 12, 15, and 19 years' old at the data collection. Furthermore, information on consumed food e.g. pasta/rice, meat, fish, milk, vegetables/fruits, cheese, sweets, etc., per household was only collected for Rounds 2 to 4. Nutritional factors were assessed based on macronutrient consumption and adherence to nutritional recommendations, including proteins, carbohydrates, fats, sweets, vegetables, fruits, and processed food. Linear mixed effect models and structural equation modelling (SEM) were employed, and both provided evidence that there was no significant association between nutrition (food intake) and height in children and adolescents from LMIC (Mumm & Scheffler, 2019). Although children from the Young Lives Study were suffering from poverty, no association was found between nutrition and height. The author also suggested to review critically all the modern nutritional interventions which are based on 'diet'.

Likewise, a study conducted in Germany examined the direct relationship between diet and height in preschool children and adolescents, and no significant association was observed (Pospisil et al., 2017). Additionally, Scheffler et al. (2018) investigated the impact of skinfold thickness (as an indirect indicator of nutritional status) on height of Indian and Indonesian children (aged 6.0–13.2 years). The study found no significant association between height and skinfold thickness (taken as an indicator of nutritional status) (Scheffler et al., 2018). Hermanussen and Scheffler (2016), Hermanussen and Wit (2017), and Bogin et. al (2015, 2017) proposed a new theory that suggests social inequalities within human societies play a significant role in explaining the prevalence and persistence of stunting worldwide. They proposed that, similar to social dominance observed in other species, social inequalities within human groups may impact growth through the hypothalamic-pituitary-adrenal (HPA) axis and the hormone IGF-1 (insulin-like growth factor-1) during childhood and adolescence (Bogin et al., 2015; Bogin et al., 2017; Hermanussen & Scheffler, 2016; Hermanussen & Wit, 2017). Same authors also highlight the importance of nutrition, health, living conditions, and caregiving for achieving optimal height, while emphasising that social interactions and group behaviours can influence and interact with height.

A major question therefore remains unanswered, namely, why all these large-scale interventions and billions of dollars spent to reduce stunting have so far not translated into a better outcome and understanding of the causes of stunting. One possibility is consideration of the structural determinants and issues relating to social inequality examined by different research groups (Nisbett et al., 2022).

The importance of inequalities in stunting

Three main types of factors have been documented to account for health inequalities: materialist, psychosocial, and behavioural/cultural inequalities (Bartley, 2016). Materialist factors include income, employment, level of education, poor quality housing, crime, and pollution (Bartley, 2016). Psychosocial explanations of health inequalities introduce the concept of relative deprivation. It is related to how people experience inequalities and their emotional response to it, which can eventually increase both acute and chronic levels of stress (Mattheys et al., 2016; Wilkinson & Pickett, 2010). Behavioural factors contributing to health inequalities refer to the effects of individual behaviours that are damaging to health, such as smoking, alcohol, poor diet, and lack of exercise which have all been noticed as more prevalent among people from disadvantaged areas (Mattheys et al., 2016).

While Nisbett et al. (2022) has more recently specifically discussed stunting inequalities (Nisbett et al., 2022), several researchers investigated the impact of inequalities more broadly on life expectancy and healthy life expectancy and showed a dominant influence of structural inequalities. S*ocioeconomic inequality* has therefore emerged as a significant focus in recent research on health across the life course, as it is closely associated with health disparities (Eikemo & Øversveen, 2019; Marmot, 2005). Health-related issues are more prevalent in socioeconomically deprived areas, and they tend to be more pronounced in societies with higher levels of inequality (Wilkinson & Pickett, 2010). The steeper the social gradient within society, the more strongly it will be related to inequality. Previous studies, primarily conducted in developed countries, have predominantly examined life expectancy, child wellbeing, and obesity in relation to social gradients (Wilkinson & Pickett, 2010). While studies on stunting inequality have more recently been investigated in LMIC, overweight and obesity have historically been more common in richer households from higher-income countries. However, overweight and obesity have become more prevalent in poorer households in higher-income countries and also in better-off households in lower-income countries related to the increasing availability of energy-dense, cheap foods (Alao et al., 2021).

Although inequality can be measured by simply comparing the status of richest against the poorest, commonly used economic metrics to describe economic inequalities in health outcome (malnutrition, including stunting) are concentration curves (CCs) and concentration index (CIX). A CC plots cumulative distribution of health against a variable capturing living standards (e.g., socioeconomic status) (Wagstaff et al., 1991). The straight diagonal 45° line from the origin (as in the figure 1.10 below) running from the bottom left corner to the top right-hand corner is considered the line of equality. The CIX is estimated as twice the area between the CC, and the line of equality. A CIX will be zero when there is no socioeconomic inequality. The CIX with negative value means that higher percentage of poorer have ill-health, and the CC then lies above the line of equality. The larger the area between the curve and the line, the more negative the index value will be. For positive values of CIX , the concentration curve lies below the line of equality; and the larger the area between the curve and the line, the more positive is the index value. In Figure 1.10, CIXs are negative (2014: -0.164 and 2004: -0.094), the CCs lie above the line of equality and 2014 is furthest from the 2004 implying that inequality increased in 2014 compared to 2004.

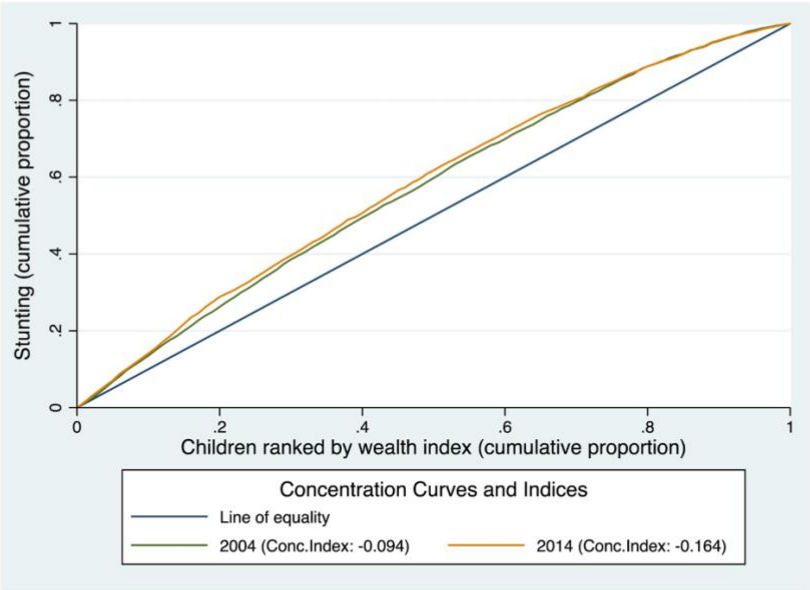


Figure 1.10 An example of concentration curve, concentration index, Source: (Huda et al., 2017)

Another common measure of income inequality is the Gini coefficients (Alao et al., 2021; De Maio, 2007). Gini coefficients are calculated using Lorenz curves, which are like CCs but they show economic inequality instead of health inequality. Instead of representing a health outcome, they plot the cumulative proportion of economic status against the cumulative proportion of a population ranked by its economic status. Similar to CC and CIX, the Gini coefficient is twice the area between the Lorenz curve and the 45° line of equality. Values closer to 0 indicate lower inequality and values closer to 1 indicates higher inequality. The difference between Lorenz curves and CC is that the Lorenz curves are always below the line of equality, while the CC can be above or below it. This means that Gini coefficients ranges from 0 to 1, whereas CIX are bounded by −1 and +1 (Alao et al., 2021).

The association of *income inequality* (as expressed by the Gini coefficient) and stunting is reported by a systematic review paper by Alao et al. (Alao et al., 2021). Their systematic review reported that childhood stunting is concentrated in poor households (by economic status) regardless of region, whereas concentration of overweight and obesity by economic status depends on region (Alao et al., 2021). An analysis for the Lancet Nutrition Series, incorporating data from 79 countries, showed that stunting prevalence was 2.47 (range 1.00–7.64) times higher in the poorest than in the richest quintile (Black et al., 2013). More recently, research on socioeconomic inequalities related to stunting and its effect on stunting in south Asian countries has been attracting attention and several researchers examined the role of inequalities on changes of stunting prevalence (Angdembe et al., 2019; Argaw et al., 2019; da Silva et al., 2018; Huda et al., 2017; Krishna et al., 2018; Rabbani et al., 2016; Sarker et al., 2020).

For example, Argaw and colleagues (2019) conducted an extensive investigation into various independent factors associated with stunting in 14 LMIC using mixed effects models to unpack the associations (Argaw et al., 2019). The authors employed three separate multivariable regression models for each group of indicators: distal, intermediate, and proximal indicators, where each model only specifically included variables for the specific group (e.g., distal) without adjusting for the other groups (e.g., intermediate and proximal). The significant distal indicators that explained the trend of stunting over time were changes in income inequality, urbanization, and women's decision-making power; while the intermediate service related factors were changes in household access to improved sanitation facilities and improved drinking water sources, the child immunization rate for basic vaccinations. Finally for the proximal factors were changes in the prevalence of reported LBW and early initiation of breastfeeding. Although they justified this choice of model as an intention to avoid over estimation, however, in real life, factors interact and coexists simultaneously. Hence, these models could not provide the full picture of realistic scenario explanation and need careful interpretation. Notably, maternal factors were not included in any of the models in this study (Argaw et al., 2019). Similarly, Krishna et al. (2017) investigated a wide range of factors related to stunting in Nepal, India, Bangladesh, and Pakistan. Their adjusted models using pooled data revealed higher rates of stunting among children with poor diets, mothers with low educational attainment, or those living in poor households (Krishna et al., 2018). Da Silva et al. (2018) reported that poor-rich gaps are stable in middle-income countries but slightly increasing in low-income countries (da Silva et al., 2018). These studies on a selective set of risk factors for stunting trends are valuable for assessing the role of specific determinants, but do not allow an examination of the relative importance of multiple factors on child linear growth (Argaw et al., 2019; da Silva et al., 2018; Krishna et al., 2018).

A decomposition analysis, in relation to changes in stunting over time, was commonly used by several researchers, for example Headey et. al. (2016); Huda et. al. (2017), Rabbani et. al. (2016); Sarker et al (2020), to measure the most important factor which is responsible for changes in stunting over time. The decomposition analysis entails multiplying observed changes in the means of each explanatory variable by its regression coefficient (Headey et al., 2016). These studies have identified that wealth and maternal factors such as their mothers' schooling and short stature can play a significant role in moderating the effect of socioeconomic inequalities on childhood stunting and changes in stunting prevalence over time (Table 1.1) (Headey et al., 2016; Huda et al., 2017; Rabbani et al., 2016; Sarker et al., 2020).

Using population attributable fraction (PAF), Danaei et. al., (2016) identified the most important risk factors as: foetal growth restriction/preterm birth, environmental factors (unimproved sanitation, water), and maternal nutrition (short stature, underweight, malaria), (Table 1.1) (Danaei et al., 2016). While a wealth index was not included in Danaei et. al. (2016) analysis, environmental factors such as unimproved water and sanitation status may serve as indicators of social status. In contrast, logistic regression models conducted by Kim et.al. (2017) examined the relative significance of each correlated factors with stunting and ordered those based on their magnitude. The study found that mother's short stature was the most influential factor to affect stunting followed by wealth status (Kim et al., 2017). Furthermore, Bhowmik and Das (2017) employed multiple classification analysis (MCA) and identified wealth status as one of the top-ranked factors associated with stunting (Bhowmik & Das, 2017).

Table 1.1 The top five ranked factors associated with stunting from existing literature

Literature	Country	1st rank	2nd rank	3rd rank	4th rank	5th rank
(Headey et al., 2016)	Bangladesh, India, Nepal, Pakistan	**Wealth status**	Maternal education	Paternal schooling	Being born in a medical facility	Open defecation
(Huda et al., 2017)	Bangladesh	**Wealth status**	Maternal education	Paternal schooling	Access to health services	Mother's short stature
(Rabbani et al., 2016)	Bangladesh	Maternal education	**Wealth status**	Child age	Being born in a medical facility	ANC from a trained provider
(Sarker et al., 2020)	Bangladesh	**Wealth status**	Maternal education	Access to media	Place of residence (urban)	Birth order
(Danaei et al., 2016)	137 developing countries	Foetal growth restriction/ preterm birth	Environmental factor (un-improved sanitation, water)	Maternal nutrition (short stature, under-weight, malaria)	Child nutrition (diarrhoea, zinc deficiency, non-breastfeeding)	Teenage motherhood /short birth intervals
(Bhowmik & Das, 2017)	Bangladesh	**Wealth status**	Child's age	Maternal education	Maternal nutrition (low BMI)	Birth intervals
(Kim et al., 2017)	Afghanistan, Bangladesh, India, Nepal, and Pakistan	Mother's short stature	**Wealth status**	Maternal nutrition (low BMI)	Inadequate dietary diversity (child's)	Maternal education

Despite many frameworks acknowledging the importance of factors such as socioeconomic conditions, maternal factors, and child feeding practices in determining optimal growth in early childhood, there remains a lack of research that compares and *ranks* the relative significance of two factors: socioeconomic inequality vs. nutritional factors (NF) for child stunting at the national level.

Country context: Bangladesh

Bangladesh is located in south Asia and is surrounded on three sides by India (with a narrow border with Burma in the southeast of the country), and with the Bay of Bengal in the south (Figure 1.11). The main language of the country is Bengali.

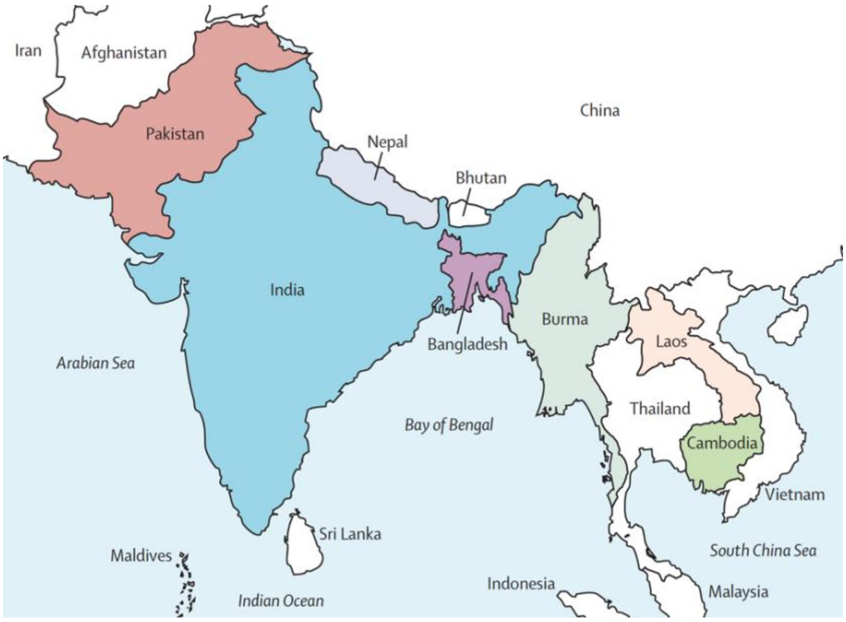


Figure 1.11 Bangladesh and neighbouring Asian countries; source: (Chowdhury et al., 2013)

Approximately 90% of Bangladesh's population is Muslim while Hindus make up around 8%, and the remaining minority comprises Buddhists and Christians (NIPORT/MOHFW/ICF, 2023). The presence of Muslims in this region can be traced back to the 7th century Christian Era (CE) when Arab traders and preachers arrived, followed by Mughal rulers (Chowdhury et al., 2013). British colonial rule began in 1757, and at that time, the region that is now Bangladesh was known as East Bengal, the other part being West Bengal, with its capital in

Kolkata. Since Kolkata was the capital city of the area, the British administration focused primarily on West Bengal, resulting in economic and political decline in East Bengal.

Until 1947, most government positions in East Bengal were occupied by officials from outside the area. The weak educational system and systematic discrimination prevented Bangladeshis from competing effectively for government jobs (Chowdhury et al., 2013). In 1947, East Bengal became part of the western Indian subcontinent to form East Pakistan despite being physically separated from West Pakistan. However, the exploitation of Bengalis by non-Bengalis in West Pakistan continued. The neglect of East Bengal and later East Pakistan resulted in poor organization of the civil and military bureaucracy. Finally, Bangladesh gained independence in 1971 after a liberation war that resulted in the displacement and loss of lives of millions of Bengali people. The newly formed government faced the challenges of establishing an effective civil service and addressing other significant tasks. NGOs emerged shortly after the war, initiated by enterprising individuals, and played a vital role in the country's development, contributing to the establishment of a pluralistic health system in Bangladesh (Chowdhury et al., 2013).

Bangladesh now has eight administrative divisions: Barishal, Chattogram, Dhaka, Mymensingh, Khulna, Rajshahi, Rangpur and Sylhet. These divisions are divided into 64 districts which are further divided into sub-districts or *upazilas*, then *unions* (for rural area), and then villages in descending order of size. The government is responsible for building health facilities in both urban and rural areas. The health sector is a pluralistic system with four key actors that define the structure and function of the system: government, private sector, NGOs, and donor agencies. This pluralistic health system has generated impressive health outputs. For example, outreach and coverage of vaccination and oral rehydration therapy programmes are exemplary compared with neighbouring South Asian countries (Chowdhury et al., 2013). The health care system primarily falls under the control of the Ministry of Health and Family Planning (MoHFW). The MoHFW, through the two Directorates General of Health Services (DGHS) and Family Planning (DGFP), manages a dual system of general health and family planning services through district hospitals (~250 bed capacities), *Upazila* Health Complexes at the subdistrict level (with an inpatient capacity of 30–50 beds), *Union* Health and Family Welfare Centres at the *union* level, and community clinics at the village level (Parvez, 2021) (Figure 1.12).

a. A typical district hospital in Bangladesh

b. A typical sub-district (*upazila*) health complex in Bangladesh

c. *Union* Health and Family Welfare Centres

d. A community clinic (village/community level)

Figure 1.12 Health care service centres at different tiers in Bangladesh, Source: Internet

Nutrition context in Bangladesh

The Government of Bangladesh is aligned with the WHA six priority global nutrition targets (six priority global nutrition target: wasting, anaemia, low birth weight, stunting, breastfeeding and overweight) to be achieved by 2025 (MoHFW, 2017) that includes the reduction of stunting and has set a national nutrition target, to reduce the prevalence of stunting among children aged under five. The Government of Bangladesh has made substantial investments in the nutrition sector since 1996 by implementing the Bangladesh Integrated Nutrition Programme (BINP) (1996-2002), (Hossain et al., 2005) and later the National Nutrition Programme (NNP) (2006 to 2011). A range of community-based nutrition specific services were provided through contracted NGOs. BINP and NNP both were more vertical in design without any links with the national level (mainstream) health system. Unfortunately, the BINP Programme did not demonstrate any significant change in the prevalence of stunting in Bangladesh (Hossain et al., 2005). Later, the National Nutrition Service (NNS), an operational plan, came up with a more holistic approach. The government is now implementing NNS, a mainstream, comprehensive package of nutrition services (primarily food related interventions supporting infant and young child feeding, micronutrient supplementation, food supplementation and other health interventions), and is trying to develop and strengthen coordination mechanisms with other sectors to ensure a multisectoral response to malnutrition (Billah et al., 2017). All of the major milestones related to the nutrition programmes in Bangladesh can be found in Appendix file A1.

Trends of stunting in Bangladesh

Previously, Bangladesh had the highest rates of stunting in South Asia, even with notable economic progress in recent times (Biswas et al., 2016). However, findings from Bangladesh demographic health survey (BDHS) shows that there is a notable reduction in stunting rates, declining from 51% in 2004 to 24% in 2022 (Figure 1.14). While this progress is commendable, it is important to note that a stunting prevalence ranging from 20% to <30% is still considered a high public health concern. Despite the overall improvement, currently (in 2022) most deprived population (poorest) continue to face significantly higher stunting prevalence at 35%, which remains of utmost public health significance. Furthermore, this group has only seen a marginal 5% reduction compared to the 40% prevalence reported in 2019 (Figure 1.13). In one study, it was reported (in 2014) that the stunting rate reduction annually was 2.7% (Ahmed et al., 2016). Another study (Krishna et al., 2018) reported a slightly higher rate of reduction (2.9% between 1991 and 2014), while a third reported a lower rate of reduction of 1.2% between 1996/7 and 2014 (Rabbani et al., 2016). Moreover, a significant proportion of the country's population still lives with food insecurity (FAO/WFP/IFAD, 2012; NIPORT/ICF, 2019).

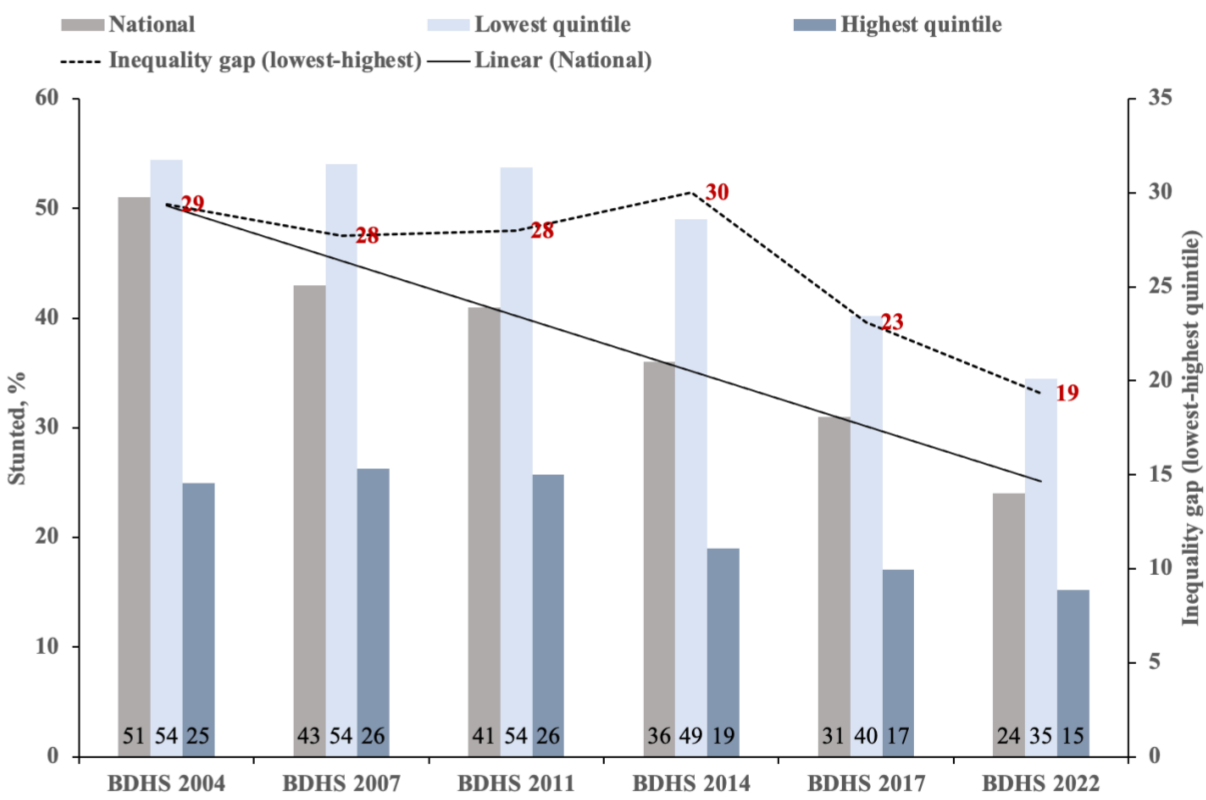


Figure 1.13 Stunting prevalence at the national level with linear trends, showing stunting prevalence in the lowest and highest quintiles, and the inequality gap among children aged <5 years in Bangladesh: results taken from Bangladesh Demographic Health Surveys (BDHS), 2004–2022. (NIPORT/MOHFW/ICF, 2023)

However, national data depict that there is still huge variability across regions (Figure 1.14) (NIPORT/ICF, 2019). Sylhet, the north eastern division of Bangladesh, currently has the highest rate of stunting (34%) compared with any other division. A Household Income Expenditure Survey (HIES) in 2010 and 2016 also captured that poverty remained almost unchanged in Sylhet division between 2010 and 2005 (20.7% and 20.8, respectively) (HIES/BBS, 2011). These numbers reveal a compelling story of geographical inequality, with the Sylhet division of Bangladesh being most affected.

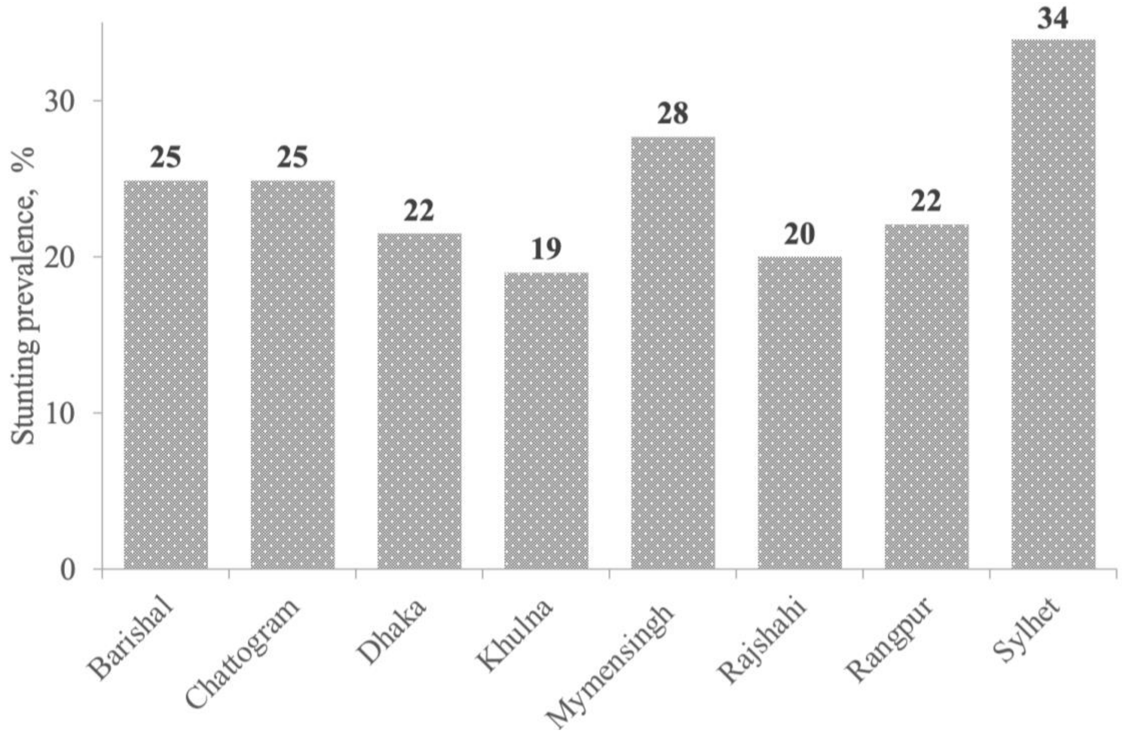


Figure 1.14 Prevalence of stunting among children under five years in eight divisions of Bangladesh: results of the Bangladesh demographic health surveys (2022) (NIPORT/MOHFW/ICF, 2023)

Bangladesh is also committed to the 2030 Agenda for Sustainable Development adopted by the UN General Assembly, which includes as its second goal ‘to end hunger, achieve food security and improved nutrition and promote sustainable agriculture’. This Goal includes the specific target to be reached by 2030, as: “… *end all forms of malnutrition, including achieving by 2025 the internationally agreed targets on stunting and wasting in children under 5 years of age and address the nutritional needs of adolescent girls, pregnant and lactating women and older persons*” (MoHFW, 2017).

Study Goals

My PhD research aims to address the knowledge gap regarding the comparative role of socioeconomic inequalities and nutritional factors on child linear growth. To achieve this, I utilised national surveillance data from the Food Security and Nutritional Surveillance Project (FSNSP) in Bangladesh. The FSNSP, which focused on food security and nutrition among children aged <5 years and their mothers, was a European Union (EU)-funded project aimed at monitoring malnutrition at national and regional level, alongside examining its underlying factors. The project collected data three times a year over a span of four years (2010–2014) across the entire country (HKI/JPG-SPH, 2016). Additionally, I analysed data from an evaluation programme called 'Suchana', a Bengali word indicating “new beginning’, which was an initiative aimed at addressing undernutrition in Bangladesh funded by the EU and the Foreign, Commonwealth and Development Office (FCDO). Suchana specifically targeted vulnerable households in northeast Bangladesh with the goal of reducing stunting among children aged under 2 years.

Using these two datasets, this study has aimed to answer two main research questions:

i) Assessment of the relative importance of socioeconomic inequalities compared to nutritional factors in terms of explaining variabilities in child linear growth at the national level: What is the relative importance of socioeconomic inequalities compared to nutritional factors in explaining variabilities in child linear growth at the national level;

ii) Assessment of the relative importance of socioeconomic inequalities compared to nutritional factors in terms of explaining variabilities in child linear growth, among the poor and poorest socioeconomic status households in Sylhet division (with existing high prevalence of malnutrition), in northeast region of Bangladesh: What is the relative importance of socioeconomic inequalities compared to nutritional factors in explaining variabilities in child linear growth in a programmatic context?

In terms of the structure of the dissertation, in the second chapter, I provide an overview of the data sources which I used for my PhD research, a brief description of these data, and the kinds of methods I used to analyse the data. The third chapter focuses specifically on how I constructed a socioeconomic position (SEP) index for my research. Chapters 4 and 5 addresses the two research questions respectively using first the FSNSP data and secondly, Suchana data. These have been written as publishable papers to be submitted to peer-reviewed journals. Finally, in Chapter 6, I present some overarching conclusions that can be drawn from my research.

2. CHAPTER 2

DESCRIPTION OF DATA

In a pursuit of answering my research questions i) how nutritional factors and socioeconomic inequality rank in terms of importance in explaining variabilities in stunting among under-five children in rural Bangladesh; and ii) how nutritional factors and socioeconomic inequality rank in terms of importance in explaining variabilities in stunting among under-two children within the context of a nutrition intervention in areas with high levels of malnutrition, I used data from a nationally representative surveillance system 'Food Security and Nutrition Surveillance Project (FSNSP)' (for Research Question 1), and another data collected in Sylhet, northeast Bangladesh that evaluated an intervention 'Suchana, Ending the cycle of chronic malnutrition' (for Research Question 2) in my PhD thesis.

Dataset #1: Food Security and Nutrition Surveillance Project (FSNSP)

FSNSP was the only active nutritional and food security surveillance project in Bangladesh operational during 2010 to 2014, where nationally representative data were collected from children, adolescent girls, and women to assess food insecurity and nutritional status. (HKI/JPG-SPH, 2016). The major domain of the FSNSP was primarily assessment of child nutrition and factors associated with malnutrition, as well as assessing household food security status. FSNSP carried out a multistage repeated cross-sectional survey in both urban and rural areas, where each survey covered one of three seasons a year in Bangladesh: i) post-*aman* (one of the major annual rice crops); ii) the crop harvest period (January–April), the height of the monsoon (May–August); and iii) post-*aus* (another major type of rice crop) crop harvest season (September–December) (HKI/JPG-SPH, 2016).

The FSNSP provides data that are representative of Bangladesh as a whole, as well as at level of divisions, agroecological zones, adolescent girls, women, and children. Beginning in 2011, from Round-4 onwards, FSNSP used a three-stage sampling design: in the first stage, the country was divided into 13 strata where six corresponds to ‘vulnerable zones’ (coastal belt, eastern hills, *haor*, Padma chars, northern chars, northwest) and remaining seven strata corresponds to ‘divisions’- administrative units (Barishal, Chattogram, Dhaka, Khulna, Rajshahi, Rangpur, Sylhet) (Figure 2.1) and sample of *upazila* (sub-districts) in those divisions which were not included within the six zones. Within each zone, 12 *upazila* (sub-districts) were selected in each round; whereas 22 *upazila* were contributed by the divisions. Again, from each *upazila*, villages (*mohollas*) were then selected. For the last stage of sample selection, households were selected at specific field sites (HKI/JPG-SPH, 2016).

For surveillance purposes, a household was eligible for inclusion if it included any of the three target groups: children less than 5 years of age, adolescent girls (aged 10 to 18 years), non-pregnant women (aged 19 to 49 years). A random selection was then taken for anthropometric measurements and a household questionnaire survey was administered. All anthropometric measurements (height, weight, Mid-Upper-Arm-Circumference) for children aged <5 years from those sampled households were collected. Along with that, data on feeding practices of the youngest child were collected if there was more than one child in one household.

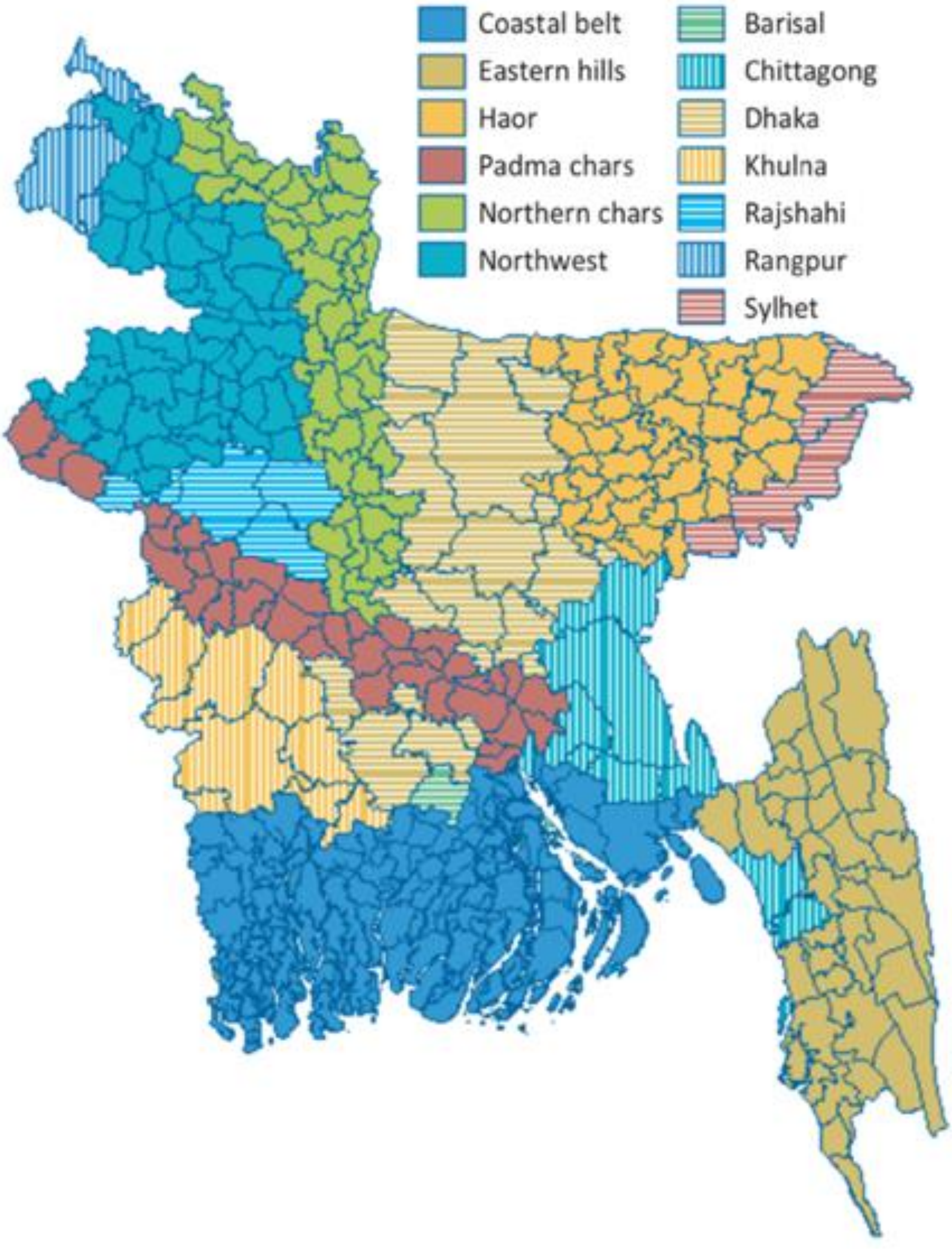


Figure 2.1 FSNSP surveillance data collection areas; Source (HKI/JPG-SPH, 2016)

The FSNSP system was designed to obtain representative prevalence estimates for indicators of food insecurity and children’s and women's undernutrition by surveillance zone. Sample size calculations were based on the estimated prevalence of eight key indicators: 1) acute childhood undernutrition 2) child underweight 3) chronic childhood undernutrition 4) proportion of women with chronic energy deficiency 5) proportion of women who are overweight 6) proportion of households with food insecurity 7) proportion of households with "food deficits" and 8) proportion of households with poor or borderline food consumption patterns.

The largest sample size required by these indicators was the number of households needed to estimate food deficits seasonally, which was calculated as 1,152 households per zone per round. This requirement was met by including 12 *upazila* in each zone and interviewing 96 households per *upazila* (24 households in each of four *communities*). Community was defined where the villages in all selected *upazila* were divided into equal-sized *community* clusters of households. From that list of equal-sized community clusters, four *communities* were selected from each selected *upazila*, *using* a random draw. In keeping with these minimum requirements, the final sample size was 1,152 households per surveillance zone, per round. The total target sample size per round was 9,024 households. The survey thus included 111,978 households’ comprising information from 12 rounds of data collection (Rounds 4–15). Among 111,978 households from which data were collected, not all of them had children. Since my research question was related to children data, I selected only those households where children (<5 years) were present. To keep a harmonised data set that will have dietary data collected using consistent set of variables, data for children less than six months who are more likely to be exclusively breasted and have not started complementary food were excluded from my analyses. As the FSNSP sampling methods were refined over time, most notably between the first, second and third rounds of data collection in 2010 (round 1–3), and there were changes in some variables, I analysed data from Rounds 4–15, which were collected from February 2011 to December 2014, and specifically utilised data for 6–59 month-old children, accounting for 37,929 children with anthropometric measurement, socioeconomic indicators and feeding data.

Variables

To address *my first research question* (What is the relative importance of social inequalities vs. nutritional factors in terms of explaining variabilities in linear growth of under-five years children in Bangladesh), along with presenting descriptive results to depict population characteristics, regression models were used where the HAZ score, reflecting the linear growth of children, was considered as the outcome variable. The variables of interests (socioeconomic position and nutritional factors), alongside demographic and other confounding variables were utilised in the model to explain variabilities in linear growth. HAZ score was calculated by subtracting the individual's observed height from an age-and sex-appropriate median value from a standard population and dividing this by the standard deviation of the reference population (WHO, 2006). Height, age, and sex were used to calculate HAZ for each child. Whereas, in practice length is measured for children below 2 years (laid down), and standing height is measured for children 2-5years old, the term HAZ is used here interchangeably to keep it simple. A standard training protocol was used to check intra- and inter-observer reliability and staff were retrained until they passed the threshold for acceptable measurement (WHO, 1995). On top of ensuring that all data collectors passed the threshold of acceptable measurement in training, the FSNSP data collection used a quality control system which randomly collected part of the data twice to cross-check for any variation and necessary adjustment (HKI/JPG-SPH, 2016). Globally, children are defined as stunted if their length/

height-for-age Z-score (L/HAZ) is <-2 standard deviations from the median of WHO child growth standards (WHO, 2006). Stunting (percentage with HAZ <-2SD), although not used as an outcome in the regression model, was used for descriptive analysis (presented as %) to reflect how prevalent linear growth retardation was in this population group.

Table 2.1 Key variables of interest for descriptive results and regression models, FSNSP data

Variables (Outcome)	Source: FSNSP 2011–2014 data	Type	Analysed
Stunted	0= not stunted 1=stunted	Binary	Descriptive
Height-for-age Z-score (HAZ)		Continuous	Regression models

Nutritional factor (NF): To uncover the relationship between nutritional factors and the linear growth of children, the UNICEF framework was adopted in my analyses by including two nutritional factor components in the analyses, namely, 'inadequate dietary intake' and 'morbidity' (UNICEF, 1991) and the framework considered these two as 'immediate causes' contributing to low nutritional status. Infectious diseases such as diarrhoea, malaria, pneumonia, and acute respiratory illnesses among children can diminish the absorption capacities of vital nutrients leading to malnutrition (Brown, 2003).

NF variable 1, inadequate dietary intake: Following WHO guidelines, inadequate dietary intake was measured using information for child minimum dietary diversity (MDD) for the last 24 hours among children aged 6–23 months (WHO, 2010). In the list-based recall method, the interviewer reads out a list of foods to the respondent. The interviewer first explained that they would read out a list of food groups and that the respondent should indicate which were consumed by the reference child during the last 24 hours (previous day and night). The respondent was also instructed to consider main ingredients from mixed dishes (e.g. chicken curry with potato/vegetables) the child consumed when they responded. The interviewer then read out a list of foods organized in groups, giving multiple examples for each group. The interviewer filled in responses for each food group on the list according to the respondent's answer (i.e. "yes", "no", or "don't know") (WHO/UNICEF, 2021).

This assessment of dietary diversity uses seven food groups as a proxy of diet quality: 1) grains, roots and tubers, 2) legumes and nuts, 3) dairy products, 4) meat/fish, 5) eggs, 6) vitamin A-rich fruits and vegetables, and 7) other fruits and vegetables. A dietary diversity score was obtained by summing the intake from all seven food groups which ranged from 0 to 7, where 0 represented non-consumption of food items from any of the food groups and 7 represented consumption from each of the listed food groups in the last 24 hours, the highest level of dietary diversification. Children who took $\geq$4 food groups in the last 24 hours before the interview were considered to have achieved an adequate minimum dietary diversity (MDD). A binary variable was then created to represent whether children had an inadequate (0), or adequate (1) MDD (Rakotonirainy et al., 2018; WHO, 2010; Woldegebriel et al., 2020) (Table 2.2). The most recent WHO/UNICEF (2021) guidelines for the assessment of infant and young child feeding (IYCF) practices for those aged <2 year (WHO/UNICEF, 2021), suggest including eight food groups, including breast milk. However, since data collection was guided by the previous WHO guidelines/indicators available at that time (WHO, 2010), which recommended using seven food groups, this research could not utilize the most recent guidelines in place.

Table 2.2: Variables for nutritional factor (NF) included in the regression models, FSNSP data

Variables (Nutritional factors)	Source: FSNSP data, 2011–2014	Type
Minimum Dietary Diversity (MDD)	0=Not achieved 1=MDD achieved	Binary
Morbidity	0–5 (Fever, runny nose, difficult breathing, diarrhoea, other diseases)	Continuous

NF variable 2, morbidity: Morbidity histories were collected for two weeks preceding the data collection day during the survey based on maternal recall. Data were available for: fever, runny nose, difficulty breathing, diarrhoea, and other diseases (here 'other' was not recorded specifically). Each of the positive responses of morbidity was scored as 1, and the total morbidity score ranged between 0–5 where 0 meant no morbidity, and 5 was the maximum number of recorded morbidities (Table 2.2).

Socioeconomic position (SEP): To measure socioeconomic inequality, in terms of differences in the outcome HAZ between those considered to have richest and poorest socioeconomic position (SEP), variables which related to social class, social status (prestige) and material assets were chosen to utilise correlated variables indicating social status and create a statistically weighted composite index, the methods for which are described further in Chapter 3. The variables utilised for SEP index (Table 2.3) were:

i. Occupation: household head's occupation with three categories being labourer, farmer, and professional/landlord.

ii. Educational level: highest level of education for both the mother and household head were categorised as no education, primary, and secondary and above.

iii. Material assets: A list of household assets: ownership of agricultural land, radio/television, telephone/cell phone, fan, wardrobe, table/chair, watch/clock. Other material assets that reflected housing condition for the house they live in and associated facilities, such as: the number of rooms in the house (count); materials used in constructing the floor (sand, cement); type of latrine (unimproved, pit latrine with or without slab, safe/sanitary); type of drinking water (high risk of contamination where household used tap water/tube well with shared facilities, low risk when household used tube well owned/protected well/ rain water), were also included.

Table 2.3: Variables included in the calculation of SEP index, FSNSP data

Variables (SEP index)	Source: FSNSP data, 2011–2014	Type
Occupation	1=labourer 2=farmer 3=professional/landlord	Ordinal
Education	0= no education 1= primary 2= secondary and above	Ordinal
Ownership of agricultural land	0= No land, 1= <50 decimals* of land 2= ≥50 decimals of land	Ordinal
Radio/television	0=No 1=Yes	Binary
Telephone/cell phone	0=No 1=Yes	Binary
Fan	0=No 1=Yes	Binary
Wardrobe	0=No 1=Yes	Binary
Table/chair	0=No 1=Yes	Binary
Watch/clock	0=No 1=Yes	Binary
Number of rooms	1–7	Continuous
Materials used in constructing floor	1=sand 2=cemented	Categorical
Type of latrine	1=unimproved 2=pit latrine with/without slab 3=safe/sanitary	Ordinal
Type of drinking water	0= not low risk of contamination 1= low risk of contamination	Binary

*1 decimal=435.6 square feet

Several other demographic indicators with established associations with stunting were included in the statistical models examining the comparative effect of nutritional factors and SEP on stunting (Table 2.4). Since nutritional status generally varies by age and sex (Baig-Ansari et al., 2006; Reinbold, 2011; Shrimpton et al., 2001; Victora et al., 2010), these two variables were included. Child age was categorised as 6–11, 12–23, 24–35 and 36–59 months.

Table 2.4 Demographic variables included in the regression model explaining HAZ as an outcome, FSNSP data

Variables (demographic)	Source: FSNSP data, 2011–2014	Type
Age	1=6–11 months 2=12–23 months 3=24–35 months 4=36–59 months	Ordinal
Gender	0=Girl 1=Boy	Binary

Other confounding variables: Several other indicators of maternal and child nutritional status, household size, administrative divisions, time (years), and seasons data collected, which are known to have established association with HAZ, were included in the regression model due to the fact that they can influence the association of HAZ with NF and SEP (Table 2.5). Short maternal stature (low height) was found to be associated with lower HAZ and weight-for-height Z-score (WHZ) for children at the age of 24 months (Victoria 2021). Researchers have used different cut-offs for defining 'short maternal stature'. For this study, I used the latest Lancet reference defining <145 cm as short maternal stature and ≥145cm as normal maternal height (Victoria 2021).

Maternal nutritional status, indicated by the Body Mass Index (BMI) to group mothers as undernourished (those with BMI<18.5 kg/m2) were used for descriptive results, whereas BMI in its original form (as a continuous variable) was included in the final full model utilised for regression. Moreover, WHZ as a continuous form, [which measure the occurrence of wasting (<-2 WHZ), a form of acute malnutrition], was also included in the analyses. Household size (number of people eating from the same cooking pot) were grouped as a categorical variable: 2-4=0, and ≥5=1, and similarly another categorical variable for child birth order (1st, 2nd, 3rd and 4^{th} +) was also included in regression model. Divisional boundaries changed somewhat following data collection of the FSNSP rounds. When the data were collected for FSNSP, there were only seven divisions (Mymensingh, later become a separate division, which was then considered to be part of Dhaka division); I have therefore presented my results using seven divisions. Moreover, the variables 'time' and 'season' were calculated, which corresponded to the years 2011-2014, and seasons in Bangladesh, respectively; which were then used to present descriptive results of changes in HAZ score, and also included in full final model for regression.

Table 2.5 Other confounding variables included in the regression model explaining HAZ as an outcome, FSNSP data

Variables (Other confounders)	Source: FSNSP data, 2011–2014	Type
Short maternal stature	0= ≥145cm 1= <145 cm	Binary
Maternal BMI	Continuous	Continuous
Weight-for-height Z-score (WHZ)	Continuous	Continuous
Household size	0=2-4 members 1=≥5 members	Binary
Child birth order	1 2 3 4+	Ordinal
Geographical area, divisions	1= Rajshahi 2= Khulna 3= Barishal 4= Dhaka 5= Sylhet 6= Chattogram 7= Rangpur	Categorical
Time	1=2011 (round 4–6) 2=2012 (round 7–9) 3=2013 (round 10–12) 4=2014 (round 13–15)	Categorical
Harvest seasons	1=post-*aman* crop (Jan–Apr) 2=height of the monsoon (May–Aug) 3=post-*aus* crop (Sep–Dec)	Categorical

The seven divisions and six vulnerable areas (total 13) was considered as 'strata' and adjusted for in all analysis yielding a national or divisional estimate. For all comparisons, differences were estimated using chi-square tests for categorical variables and ANOVA and t-tests for quantitative variables, when assumptions of parametric tests were satisfied. Linear regressions were used to calculate the relationships between SEP, nutritional factor (NF) and linear growth (HAZ) where, the beta coefficient indicated the association between HAZ and explanatory variables, described using their original units (i.e., one unit change in explanatory variable 'X' will be related to one unit change in HAZ). In contrast, the standardised beta coefficient indicated the same associations expressed using standard deviations. All analyses were performed using Stata 16 and the significance level was set at $p<0.05$. The R^2 value to determine the proportion of variance in HAZ that could be explained by SEP and NF.

Dataset #2. Suchana, ending the cycle of chronic malnutrition

Suchana, Ending the Cycle of Undernutrition in Bangladesh, is a multisectoral nutrition programme, that has aimed to reduce the incidence of stunting among children <2 years by breaking the intergenerational cycles of malnutrition in Sylhet and Moulvibazar districts (2 out of 4 districts in Sylhet division), from a total of 64 districts in Bangladesh (see Figure 2.2). The Suchana consortium is comprised of Save the Children as the lead agency, three other technical partners (Hellen Keller International, World Fish Centre, and International Development Enterprise), three implementing partners (Friends in Village Development Bangladesh, Rangpur Dinajpur Rural Services and Centre for Natural Resource Studies); and a research partner, icddr,b (formerly known as International Centre for Diarrheal Disease Research, Bangladesh).

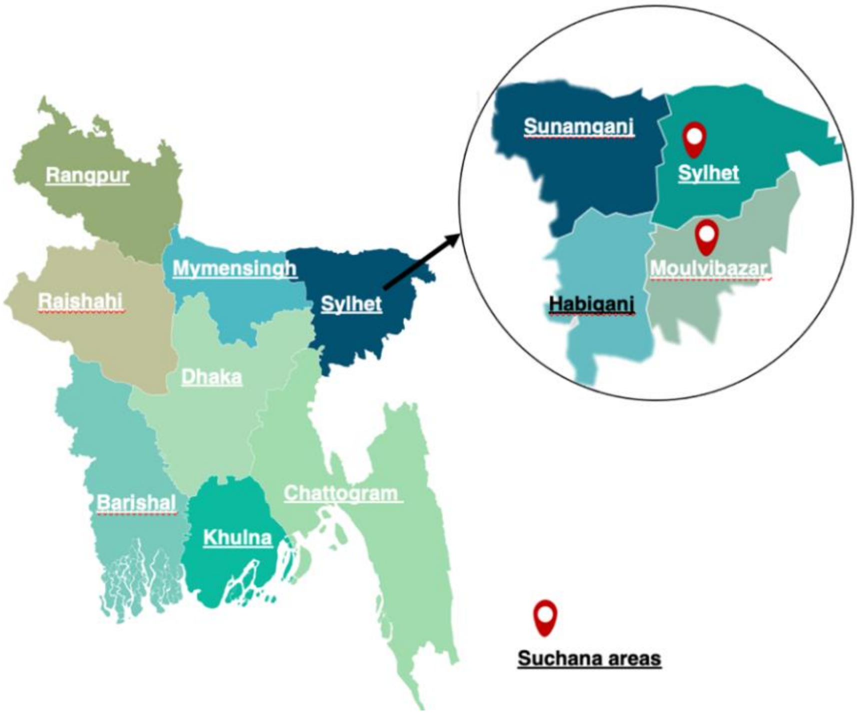


Figure 2.2 Suchana programme areas

For over six years, Suchana has been working with the two lowest segments of the population, namely, poor and very poor households, implementing the delivery of integrated nutrition-specific and nutrition-sensitive interventions in partnership with the Government of Bangladesh (GoB), non-government organizations (NGOs) and the private sector in Sylhet and Moulvibazar districts of Sylhet division. The total number of beneficiaries for Suchana were 235,500 households. To identify the most vulnerable households to be targeted in each community, Suchana used a combination of a participatory rural approach, e.g., a wealth-ranking method from a series of focus group discussions and individual interviews with local people of different socioeconomic backgrounds, and then a wealth ranking list was prepared from each village. Following a consensus of the Suchana consortium, the lowest 40% of households from the wealth ranking list were classified as very poor, while the remaining 60% of households were classified as poor. All households rated as poor or very poor in the wealth-ranking lists were included for further verification at the household level where they were selected and enrolled to the programme if they had any of the following four groups: i) a married women aged between 15 to 45 years, ii) a pregnant women (including divorcees and widows), iii) at least one child <2 years old, and iv) at least one female adolescent aged between 15 to 19 years. Intervention households also had to meet any one of the following five conditions (Haque et al., 2020): i) unable to have three full meals a day throughout the year, ii) a monthly income < 7500 BDT Taka (1 US dollar=108.05 BDT; dated 4 July 2023), iii) total assets worth <15,000 BDT (excluding the price of household land including a pond or dyke), iv) have homestead land < 10 decimals (1 decimal = 435.6 square feet), and iv) have cultivable land < 50 decimals (excluding homestead land together with a pond or dyke).

From the inception of Suchana, a total of 157 unions in the districts of Sylhet and Moulvibazar, were randomly assigned to 4 phases of the programme, that followed a step-wedge design

(Figure 2.3). Since the unions were assigned randomly, it was expected that characteristics from their individual 4 phases would not differ significantly from others had they been sampled at that same time. Moreover, implementation was carried out in a phased manner, where the beneficiaries in the last phase, (the last 40 unions), acted as an untreated control group until they joined the programme, while the beneficiaries from the first 40 unions from in the first phase received the interventions over a period of time sufficient to lead to a difference in outcome measures.

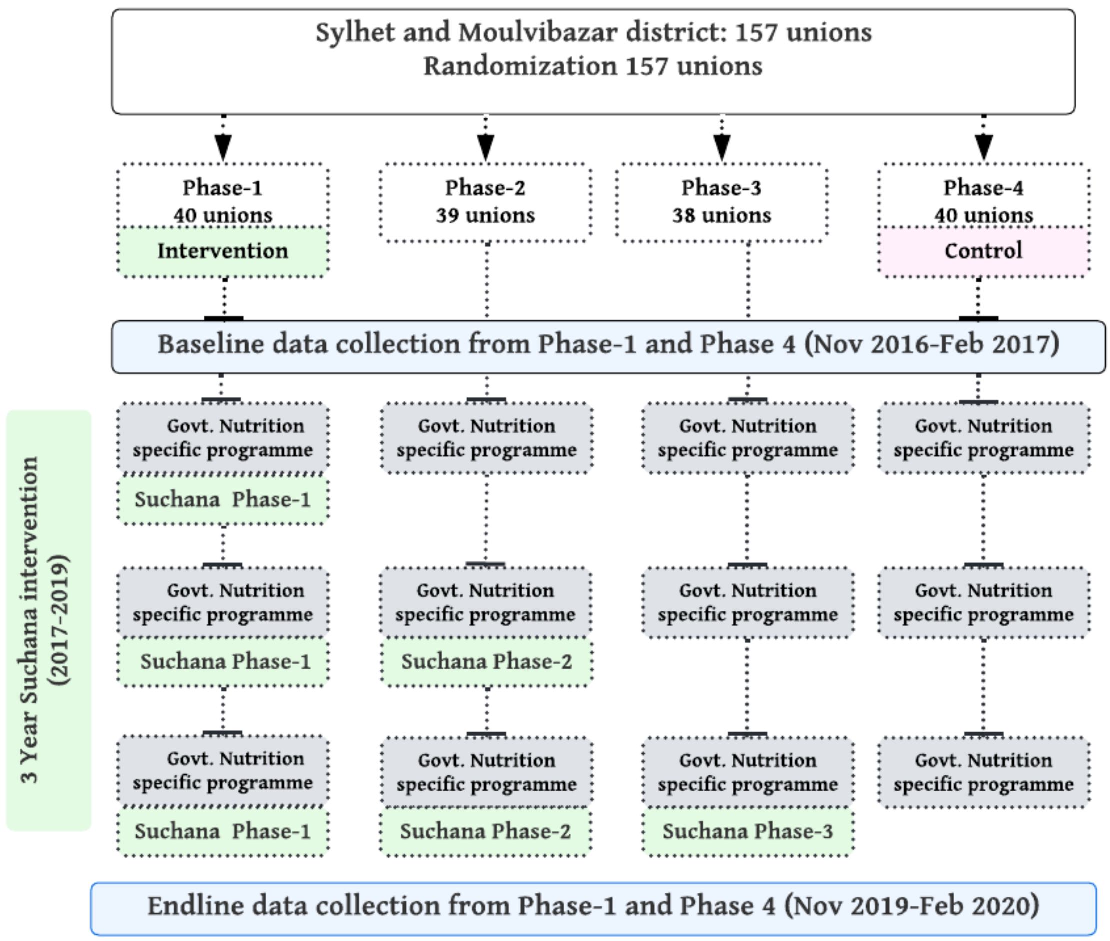


Figure 2.3 Suchana programme implementation phase and data collection time for Suchana evaluation

Suchana programme encouraged Suchana beneficiaries to keep receiving existing government nutrition-specific services which included: vitamin A capsule for mother and children, participation of mothers in observation of ‘nutrition week’ (the 'nutrition week' is observed nationally in June), participation of mothers in observation of ‘breastfeeding week’ ('breastfeeding week' takes place in August), participation in a nutrition group, a community nutrition education session, counselling at the household level, observations of infant and young child feeding practices and maternal and child health nutrition practices, a cooking and feeding demonstration, growth monitoring promotion services, severe acute malnutrition screening and referral, nutrition information sharing with religious leader and influential, capacity building for service providers, nutrition education/awareness through mass media, and nutrition education for adolescents.

Apart from regular government nutritional services, there were several nutrition sensitive generic interventions for all Suchana beneficiaries, which included: gender awareness, mother’s participation in household decision making and woman empowerment by involving into income generating activities. There were two other tailored Suchana intervention (nutrition sensitive) packages, separate packages for ‘poor’ and ‘very poor’ Suchana beneficiary households: poor or very poor households. The poor households received training on skills development and provided the links with government/non-government facilities; whereas the very poor households received assets, equivalent of a maximum of Bangladeshi Taka (BDT) 8000, (1 US dollar=108.05 BDT; dated 4 July 2023), either goat or fish or poultry along with training and government links during the programme.

For evaluation purposes of Suchana, two cross sectional surveys, conducted three years apart, formed the baseline survey (in 2016) and the endline survey (in 2019). Since the whole district was brought under the intervention targeting households with under-2 years age children, Suchana beneficiary households were selected for inclusion if the beneficiary household had children aged <2 years during baseline, and the same criteria was followed at endline. Data collection therefore followed children by age group rather than as individuals (i.e., it was cross-sectional rather than longitudinal). Mother of the child was the respondent for the questionnaire survey. Samples were collected from three distinct age groups: 3,120 samples were drawn from children aged 0–5 months to assess breastfeeding status, 3,600 samples were drawn from children aged 6–11 months to estimate IYCF (infant and young child feeding) practices, and 9,600 samples were drawn from children aged 12–23 months to measure stunting. However, for my PhD research, purposively I have used data if the child age is ranged between 6–23 months old (Figure 2.4), which would allow having a comparable age group and set of indicators as was used for FSNSP but the context here would be utilising data for evaluating an intervention.

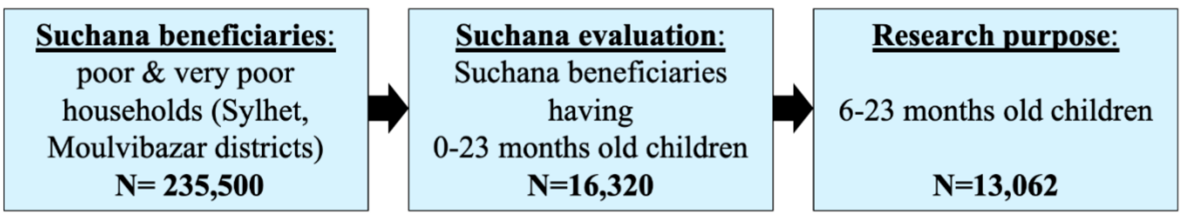


Figure 2.4 Suchana sample used for research purpose

Variables

Similar to the FSNPS data, the outcome variable here was L/HAZ. Children were defined as stunted if their length/height-for-age Z-score (L/HAZ) was <-2 standard deviations of the median of WHO child growth standards (Table 2.6) (WHO, 2006). A standard training protocol was used to check inter and inter-observer reliability and staff were retrained until they passed the threshold for acceptable measurement (WHO, 1995). A SECA Infantometer (Model SECA

416) with a precision of 0.1 cm was used to measure child length. Suchana data collectors measured participants twice for length/height measurement, and a third measurement was taken if the first two consecutive measurements differed by >2 cm. The averages of the anthropometric measurements were used during the analyses of Suchana data.

Table 2.6 Key variables of interest for descriptive results and regression models, Suchana data

Variables (Outcome)	Source: Suchana 2016 and 2019 data	Type	Analysed
Stunted	0= not stunted 1=stunted	Binary	Descriptive
Height-for-age Z-score (HAZ)		Continuous	Regression models

Nutritional factors (NF), Suchana: For grouping variables under the domain of nutritional factor (NF), two independent indicators: minimum dietary diversity (MDD), and morbidity were included (Table 2.7) and expected to explain variabilities in the outcome HAZ for regression models.

NF variable 1, MDD: Children who took $\geq$4 food groups in the last 24 hours before the interview were considered to have achieved minimum dietary diversity (MDD), similar to the protocols for FSNSP above.

NF variable 2, morbidity: Morbidity history was collected for 2 weeks preceding the data collection day during the survey. Data were available for: fever, runny nose, difficulty breathing and diarrhoea.

Table 2.7 Variables for nutritional factor (NF) included in the regression models, Suchana data

Variables (Nutritional factors)	Source: Suchana 2016 and 2019 data	Type
Minimum Dietary Diversity (MDD)	0=Not achieved 1=MDD achieved	Binary
Morbidity	0–4 (fever, runny nose, difficulty breathing, diarrhoea)	Continuous

To measure SEP, the variables which related to social class, social status (prestige) and material assets were chosen for inclusion (Table 2.8).

The following variables, similar to FSNSP variables (except for occupation, which was not suitable for inclusion here) were selected:

i. Educational status of the mother and household head: categorised into three groups: no education, primary, secondary and above.

ii. Material assets: television, telephone, fan, showcase, table, chair, sofa, ceremonial saree and materials used for household floor, type of toilet.

Table 2.8 Variables included in the calculation of SEP index , Suchana data

Variables (SEP index)	Source: Suchana data, 2016 and 2019	Type
Education	0= no education 1=primary 2=secondary and above	Ordinal
Television	0=No 1=Yes	Binary
Fan	0=No 1=Yes	Binary
Showcase	0=No 1=Yes	Binary
Chair	0=No 1=Yes	Binary
Table	0=No 1=Yes	Binary
Sofa	0=No 1=Yes	Binary
Ceremonial saree	0=No 1=Yes	Binary
Materials used in constructing floor	1=sand 2=cemented	Binary
Type of latrine	1=unimproved 2=pit latrine without slab 3= pit latrine with slab 4= safe/sanitary	Ordinal

Several other demographic indicators with established associations with stunting were included in the statistical models examining the comparative effect of nutritional factors and SEP on stunting (Table 2.9). Child age was categorised as 6–11, and 12–23 months. Gender was also included as a binary variable.

Table 2.9 Demographic variables included in the regression model explaining HAZ as an outcome, Suchana data

Variables (demographic)	Source: Suchana data, 2016 and 2019	Type
Age	1=6–11 months 2=12–23 months	Ordinal
Gender	0=Girl 1=Boy	Binary

Several other predictors (Table 2.10) with established associations with linear growth were included in the statistical models examining the comparative effect of nutritional factors and SEP on linear growth. Consistent with FSNSP models, here maternal height was also categorised as <145cm and ≥145cm (Victora et al., 2021) reflecting short and normal stature; and mother's BMI (as a continuous form) was also included in the regression model. Household size (2-4=0, and ≥5=1), and child birth order (1^{st}, 2^{nd}, 3^{rd} and 4^{th} +) were also included. The hygiene status was assessed by using spot-check observations on two items; i.e., cleanliness of the hands and fingers of the mother and her child; which was not available for FSNSP data set. Each item was given a score of 1 when it was found clean, or 0 when it was dirty, and the sum was used as the hygiene score which ranged between 0-2. This variable was used as a continuous variable for both descriptive results, and regression model.

Table 2.10 Other confounding variables included in the regression model explaining HAZ as an outcome, Suchana data

Variables (Other confounders)*	Source: Suchana data, 2016 and 2019	Type
Wasting [weight-for-height Z-score (WHZ) <-2]	0=not wasted 1=wasted	Binary
Maternal short stature	0= ≥145cm 1= <145 cm	Binary
Maternal BMI	Continuous	Continuous
Household size	0=2-4 members 1=≥5 members	Binary
Child birth order	1 2 3 4+	Ordinal
Nutritional knowledge	0–7	Continuous
Hygiene score	0–2	Continuous
Woman dietary diversity	0=No 1=Yes	Binary
Mother received at least 4 antenatal care services during her last pregnancy from a skilled provider	0=No 1=Yes	Binary
Mother received postnatal care services in her last child birth	0=No 1=Yes	Binary
Mother participated in taking decision on household matter	0–6	Continuous
Time	0=2016 (Baseline) 1=2019 (Endline)	Binary
Intervention	0=control 1=Intervention	Binary

*Morbidity is included in Table 2.7 as one of the independent variables

Moreover, the variable 'time' was considered to reflect baseline (2016) and endline (2019) periods. Since the Suchana data covered both intervention and control areas, an 'intervention' variable was also included. Given that the Suchana programme intended to change a mother's participation in household decision making, their dietary diversity status, nutritional knowledge, and their antenatal and postnatal care practices were also included in the analysis. The variable 'women having decision-making power' was measured for six dimensions: i) food purchases, ii) major household purchases, iii) food preparation, iv) children's healthcare, v) their own healthcare, and vi) their ability to visit family and relatives. Each variable had four options, such as: (a) mainly the mother, (b) mother and husband jointly, (c) mainly husband, and (d) others. All outcomes were treated as binary variables, indicating: yes (1) if the woman had the ability to make decisions herself (or jointly with her husband), and no (0) if only the husband or the other family members made decisions. Moreover, I created a composite variable score that encompassed all six dimensions of decision-making, (ranging from 0-6, where 0 meant the mother did not have any decision-making power, and 6 where she had extensive decision-making autonomy).

For all comparisons, differences were estimated using chi-square tests for categorical variables and ANOVA and t-tests for continuous variables, subject to meeting assumptions of para metric tests. Linear regressions were used to calculate the relationships between SEP, NF and stunting (HAZ) where, the beta coefficient indicated the association between HAZ and explanatory variables, described using their original units. In contrast, the standardised beta coefficient indicated the same associations expressed using standard deviations. All analyses were performed using Stata 16 and the significance level was set at $p<0.05$. The R^2 value was used to determine the proportion of variance in HAZ that could be explained by SEP and NF.

Ethical issues

The FSNSP project was led by the BRAC James P. Grant-School of Public Health (JPG-SPH), BRAC University, Dhaka, Bangladesh which owns the data. FSNSP obtained ethical clearance from the European Union (Study number FOOD/2008/145-720). Verbal informed consent was taken from study participants. Data access was possible following a standard application procedure detailing the research objectives and analytical approaches. Oral informed consent was obtained at all levels of access during the primary questionnaire data collection. The approval of secondary analyses of this dataset were obtained through ethical approval from the Department of Anthropology Ethics Committee, Durham University, UK (Reference number: ANTH-2021-07-30T13:26:50-czfz39).

For Suchana, the study was approved by the Research Review Committee and Ethical Review Committee (Appendix A2.1, A2.2, A2.3), the two obligatory components of the institutional review board of icddr,b (formerly known as International Centre for Diarrhoeal Disease Research, Bangladesh) (Grant number: 01116). The evaluation was registered at the Registry for International Development Impact Evaluations (RIDIE-STUDY-ID-5d5678361809b) on 16/08/2019, before starting the end-line survey. Informed written consent was taken from study participants. There was no compensation or monetary equivalent paid to participants. Participants were informed in advance about the study purpose and if there was any risk.

3. CHAPTER 3

CONSTRUCTION OF SOCIOECONOMIC INDEX

Title: Creating a composite measure of socioeconomic position using nationally representative surveillance and programme data to assess inequalities in child growth in Bangladesh

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Abstract

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Background: Assessing socioeconomic inequalities in health and nutrition in developing countries receives much attention from both researchers and policymakers. However, the assessment of socioeconomic position (SEP) is not straightforward. Researchers have either used a single proxy indicator or have applied principal component analysis (PCA) -a dimension reduction technique -to create an index from a range of indicators reflecting household SEP. PCA creates components from correlated variables where the first component is usually used as a proxy for SEP and primarily relies on linear associations between continuous variables. The Demographic and Health Survey (DHS) commonly uses the Filmer-Pritchett PCA (FP-PCA) for ordinal and continuous variables which converts the former to dummy variables in order to create a wealth index. Researchers have found that these dummy variables can produce spurious correlations. Polychoric PCA (pPCA) is methodologically advanced, can handle dichotomous, ordinal and continuous variables, and is beginning to gain recognition in public health studies as an improvement over FP-PCA. This study used both FP-PCA and pPCA for two different data sets to assess their respective performance.

Methods: Two datasets from Bangladesh were used: 1) a nationally representative, Food Security Nutrition Surveillance Project (FSNSP) that ran from 2011–14, and 2) a large-scale, cross-sectional intervention and evaluation project called Suchana that operated its survey in 2016 and 2019.

Results: A total of 14 and 11 correlated variables were used from FSNSP and Suchana, respectively, to create a socioeconomic index applying both FP-PCA and pPCA. Variables, such as parental education, occupation, ownership of land, assets and other household characteristics were used. The eigenvalue, representing the total variance explained by the first principal component was higher for pPCA than FP-PCA [FSNSP: 6.4 vs. 5.2 (21% to 45% improvement); Suchana: 4.5 vs. 3.5 (18% to 40% improvement)]. The Cronbach's alpha was >0.7 for both data sets, reflecting that the indices generated had good reliability.

Conclusions: The pPCA is methodologically advanced and suitable for continuous, categorical and ordinal data. The SES index created by applying pPCA was reliable and explained larger variabilities in SES for both nationally representative surveillance and survey data in Bangladesh. The pPCA-generated SEP index can be useful for assessing socioeconomic inequalities in public health nutrition contexts.

Introduction

Assessing socioeconomic inequalities in health and nutrition in developing countries receives great attention from both researchers and policymakers. Socioeconomic inequalities are sometimes referred to as ‘social class’, ‘social status/position’, or ‘socioeconomic status (SES)’ with the three terms used interchangeably (Bartley, 2016; Marmot, 2015; Pickett & Wilkinson, 2010). Bartley has preferred to include social class, social status (prestige) and material assets and proposed the broader term of socioeconomic position (SEP) (Bartley, 2016). However, constructing SEP is not a simple task. Standard indicators used to measure SEP typically rely on household income, expenditure, or consumption data. Collecting accurate income and expenditure data from households is always challenging, particularly in low income countries and in the contexts where households draw income from multiple sources e.g., formal, informal, in-kind and remittances. Alternatively, consumption data might be easier to collect compared to household income data but this is extensive and costly because it requires a lot of time and specialised skills and resources (Amek et al., 2015; Filmer & Pritchett, 2001). Due to limitations of obtaining complete and accurate data on income and expenditure to measure SEP, alternative methods for measuring it have been developed (Amek et al., 2015).

Specifically, the use of proxies of living standards, are widely used by researchers and policy makers. Proxies of living standards include 10–20 characteristics such as household ownership of assets (television, radio, car among others), access to clean water, electricity, sanitation facilities, household characteristics and so forth. Thus, an index of household assets is created by following a standardised method (Kolenikov & Angeles, 2004). Popular methods for aggregating variables include: (i) applying equal weights to assets, (ii) applying weights based on a consensus of experts, (iii) applying weights based on prices of items, or (iv) using statistical techniques to weight assets included in the indices (Akhter, 2013; Falkingham &

Namazie, 2001; Wagstaff & Watanabe, 2003). Weighting asset variables might appear simple but is quite subjective as two assets may not have equal significance and thus the index may not be useful. Moreover, the weighting process involves difficult and subjective judgements which are subject to errors (Akhter, 2013). Therefore, researchers have commonly applied a statistical technique, principal component analysis (PCA), to create an index from a range of indicators reflecting household SEP.

PCA is a statistical, data-reduction procedure, which uses a number of variables and employs multivariate techniques to reduce dimensions by grouping relevant variables together (Howe et al., 2008a; Vyas & Kumaranayake, 2006). The procedure attempts to retain as much variance in the original dataset as possible by constructing new features (principal components) as linear combinations (Pearson's correlations) derived from the original variables. PCA assigns weights to the variables in the model based on the correlation matrix between them (Howe et al., 2008b) and assigns higher weights for more unequally distributed variables (Vyas & Kumaranayake, 2006). Ideally, PCA generates several components and among these the first component explains the largest degree of variabilities and is considered a proxy of SES. This first component, derived from PCA, is therefore used to disaggregate a population of interest into wealth groups for potential further analyses (Akhter, 2013; Houweling et al., 2003; Wagstaff et al., 2007).

One of the most common methods for the construction of socioeconomic indices for PCA was developed by Filmer and Pritchett (Filmer & Pritchett, 2001) who used data on household assets, type of access to hygienic facilities, number of rooms in a dwelling, and construction materials used in the dwelling (Kolenikov & Angeles, 2009). Their methodology has been endorsed by the World Bank and the Demographic and Health Survey (DHS) to assess household SES (Bellows et al., 2020; Filmer & Pritchett, 2001; Kolenikov & Angeles, 2004).

Filmer-Pritchett (2011) incorporated both discrete and continuous variables in their method. Some variables included multiple response categories, e.g., "roof materials" with responses being: thatched (1), leaves (2), and tin (3). In cases of discrete variables (ordinal variables including ordered response categories, or nominal variables with no ordering of response categories) with more than two categories, Filmer and Pritchett (2001) suggested that the variable should be broken down into a number of dummy variables based on the number of categories. These dummy variables were then used for each category of the discrete variable (e.g., the variable "source of drinking water" with categories for: lake or stream (1), tube well (2), pipe outside the dwelling (3), and the pipe inside the dwelling (4), represented by 4 dummy variables (Kolenikov & Angeles, 2004).

PCA is an inherently numerical measure and not suitable for nominal categorical, or ordinal categorical and sequential data (IBM, 2021). The Filmer-Pritchett procedure, using dummy variables instead of ordinal variables, means that dummy variables are treated as independent variables which then lose all of the ordinal information (Kolenikov & Angeles, 2009). Since, PCA assumes linear associations between variables, using binary dummy variables in place of ordinal categorical variables, violates this assumption. The use of dummy variables can also introduce spurious correlations. This can deteriorate post-estimation measures (to test model accuracy) because of noise in the covariance matrix. Difficulties of using binary dummy variables has also been reported elsewhere (Kolenikov & Angeles, 2009). Unlike the Filmer-Pritchett approach, a tetrachoric correlation uses ordinal variables in their original form (Kolenikov & Angeles, 2004, 2009), but is used when there are only two ordinal categories (Andre, 2020; IBM, 2021). Some literature also refers to this method as categorical PCA (CATPCA).

In contrast, polychoric PCA (pPCA) treats variables as ordinals for each category and can handle more than two categories. Kolenikov and Angeles (2005) have described this form of PCA as an improvement over Filmer-Pritchett. Until now, the use of polychoric correlations in economic publications has been limited (Kolenikov & Angeles, 2009), but the method has gained recognition in public health studies to measure socioeconomic inequalities (Kolenikov & Angeles, 2009). Given the methodological problems described above, this paper describes how to create an index measuring SEP using pPCA, and also compares pPCA performance with the more traditional FP-PCA.

Methods

Source data: Two independent SEP indices were evaluated using two data sets: (1) a nationally representative surveillance data from Bangladesh, named the 'Food Security and Nutrition Surveillance Project (FSNSP)' and (2) an evaluation programme , called *Suchana*, which is a large scale multisectoral nutrition programme to reduce stunting in Bangladesh. These two datasets contain comprehensive information on nutritional and health indicators for the Bangladeshi population where having an accurate measure of SEP would be very valuable. Table 3.1 describes the major features of these two data sets.

Table 3.1 Description of source data

Description		Surveillance data FSNSP	Survey data Suchana
1.	Surveillance/survey	Surveillance data, 12 rounds data	Survey data (Programme evaluation), 2 cross sectional survey data
2.	Data collection time and place	2011–2014, Bangladesh	2016 and 2019, Bangladesh
3.	Household selection criteria for surveillance/ survey for questionnaire survey	Household was selected for questionnaire survey if there was any reproductive aged woman with/without child from all over Bangladesh	Household was selected for questionnaire survey if there was any reproductive aged woman with/without child among Suchana beneficiaries households (lowest two segments of poverty scale)
4.	Coverage	Surveillance covered all over the country regardless of their socioeconomic status	Suchana programme targeted the lowest two segments of poverty scale in two districts, Sylhet and Moulvibazar under Sylhet division of Bangladesh
5.	Data collection for surveillance/survey	Nutrition and health related data (demographic information, dietary diversity, maternal and child nutrition, anthropometric data) from <5 children and their caregiver/mothers	Nutrition and health related data (demographic information, dietary diversity, maternal and child nutrition, anthropometric data) from <2 children and their mother from two districts under Sylhet division
6.	Included in analysis for this paper	Complete available data from mother-child dyad (children 6–59 months) from rural area	Complete available data from mother-child dyad (children 6–23 months) from Suchana area
7.	Total sample	N=37,929	N=13,064

PCA variable selection: While screening the variables, careful attention was paid to ensure that the ones selected provided relevant information related to SEP. The frequency distributions for each variable was checked within each dataset. I considered 5% as the minimum frequency for inclusion, i.e., a minimum 5% of households should own any item in question that might be included. Furthermore, to check whether candidate indicators (likely to reflect social position in rural Bangladesh) were good predictors of social status they were first assessed against an established indicator of socioeconomic status for this population (e.g., land ownership, educational qualifications) (Akhter, 2013). Table 3.2 shows the distribution of candidate variables for FSNSP data against categories of landownership. This table listed variables which were selected for inclusion in the PCA for FSNSP. The frequencies of these candidate variables were checked against agricultural land ownership (recoded as an ordinal variable) since land ownership is a well-known indicator of social status (Akhter, 2013). This variable was recoded as: i) no land, ii) <50 decimals of land, and iii) ≥ 50 decimals of land (where 1 decimal= 435.6 square feet). The variables included in the PCA were therefore chosen based on their association with land ownership. For instance, households with no land were expected to have a lower proportion of TV ownership, while households with a significant amount of agricultural land were expected to have a higher proportion of TV ownership (Akhter, 2013).

Table 3.2 Percentage/mean of assets that were included in the PCA for FSNSP by agricultural land ownership categories (n =37,929)

Indicators	No land	≤50 decimal	>50 decimal	Total
Radio/Television,	22.4	30.5	46.7	28.8
Mobile	73.5	81.4	91.1	78.4
Fan	33.4	44.8	58.9	40.5
Almirah (Wardrobe)	46.1	61.4	79.2	55.4
Table/chair	67.9	84.7	92.8	75.7
Watch	31.3	42.9	60.4	39.2
Floor, *pacca*	7.3	10.7	21.0	10.7
Toilet, safe	7.7	11.9	24.2	11.8
Low contaminated water	13.6	25.2	37.1	20.3
Number of living room				
1	37.8	22.0	8.2	29.1
2	32.4	33.3	22.2	30.4
3	18.4	23.6	26.7	20.9
4	7.7	12.5	20.1	11.0
5	2.3	5.1	12.4	4.90
6	0.7	1.9	5.5	1.9
7	0.4	1.2	4.7	1.4
Household head’s education				
No education	48.5	38.6	30.7	43.2
Primary	29.5	28.7	26.0	28.6
Secondary and above	21.9	32.6	43.2	28.1
Maternal education				
No education	28.5	18.9	13.1	23.7
Primary	36.4	32.7	23.9	33.2
Secondary and above	35.0	48.3	62.9	42.9
Household head’s occupation				
labour	56.5	41.7	8.5	44.1
farming	18.5	31.1	53.0	27.7
Professional/business/salary	24.8	27.1	38.3	28.0
Agricultural land	-	-	-	-

The list of variables selected for inclusion in the PCA for Suchana is presented in Table 3.3. Candidate indicators from Suchana (likely to reflect social status especially in the context of extreme poor households in Bangladesh) were selected and their directions checked against the household head's educational status (recoded as an ordinal variable) as this is a well-known indicator of social status. Household education was recoded as: i) no formal education, ii) primary and iii) secondary or above. Variables selected for inclusion in the PCA were ones that had higher frequencies for higher ordered categories of the established indicator.

Table 3.3 Percentage/mean of owning assets that are included in PCA for Suchana, by household head's educational level categories (n =13,064)

Indicators	No education	Primary	Secondary+	Total
Have television	13.1	19.6	26.7	17.8
Fan	67.6	78.2	86.0	74.6
Showcase	43.9	50.5	52.5	47.9
Chair	74.6	80.4	86.9	78.8
Table	59.3	70.5	80.2	67.0
Sofa	5.6	11.0	23.0	10.4
Ceremonial saree	59.7	72.9	79.2	68.0
Floor material, *pacca*	15.6	21.7	30.8	20.3
Toilet				
Open defecation	15.0	7.8	5.6	10.7
Ring without slab	51.0	48.0	40.1	48.2
Ring with slab	26.3	30.4	32.9	28.9
Sanitary latrine with septic tank	7.7	13.8	21.5	12.2
Household head's education	-	-	-	-
Maternal education				
No education	30.2	11.1	6.0	18.8
primary	48.0	54.5	32.6	48.4
Secondary+	21.8	34.5	61.5	32.8

After screening for variables whether they show a gradient similar to categories of an established indicator (as in Table 3.2, and Table 3.3.), correlation between established indicator and candidate variables were done using a correlation matrix. Variables that were only weakly or not at all related to each other, those variables were excluded from the analysis. If any two variables presented very high correlations (r>0.8), then one of the two variables was excluded to avoid multicollinearity and redundancy (Akhter, 2013). A pair of variables with very high correlations suggest that each reflect the same dimension of social status and therefore are interchangeable (e.g., owning a fan and having access to electricity).

Before running the PCA, I converted categorical variables into sets of binary (dummy) variables following DHS procedures. I then compared FP-PCA with the pPCA index in terms of their eigenvalues which determine the amount of variance explained by each principal component.

The PCAs were run in Stata to generate the SEP indices when the following conditions for a satisfactory PC were met:

a. The determinant statistics of the correlation matrix, which should be a low value to be acceptable (close to zero is desirable) (Field, 2013).

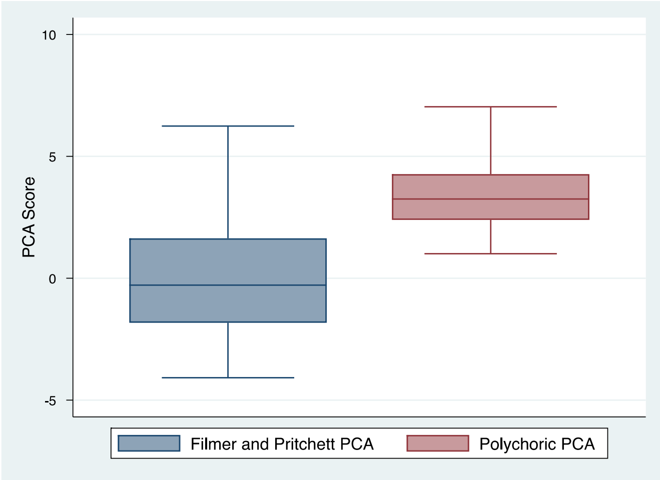
b. Kaiser-Meyer-Olkin (KMO) and Bartlett's test: adequacy of sample size was assessed by the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy, for which values between 0.8 and 0.9 are considered good, and values above 0.9 are considered excellent. The Bartlett's test of sphericity is a measure of factorability, which tests the null hypothesis that the correlation matrix is an identity matrix. In an identity matrix, all variables are completely independent to one another (Field, 2013). The significance value <0.05 here indicates that the correlation matrix was not an identity matrix and the relationship between variables were factorable.

c. Variability, reliability and factor loadings: several PCAs were run for both datasets (FSNSP and Suchana), and the final PCAs were chosen as the ones which explained the highest variability (Kolenikov & Angeles, 2004) and generated a reliable scale. Cronbach's Alpha is a measure of internal consistency. It indicates how closely related a set of variables are as a group. A higher value (closer to 1) suggests stronger interrelatedness among the variables. For PCA, Chronbach's alpha needs to have a value of 0.7 or higher to be acceptable (Field, 2013). Loading of each variable was estimated by 'factor loadings' which were calculated by Eigenvectors*√Eigenvalues. This factor loadings indicates how much each variable contributed to the PCA.

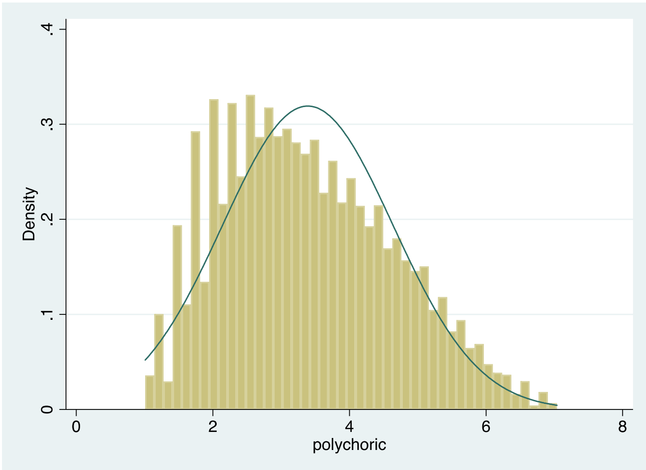
Result

FSNSP

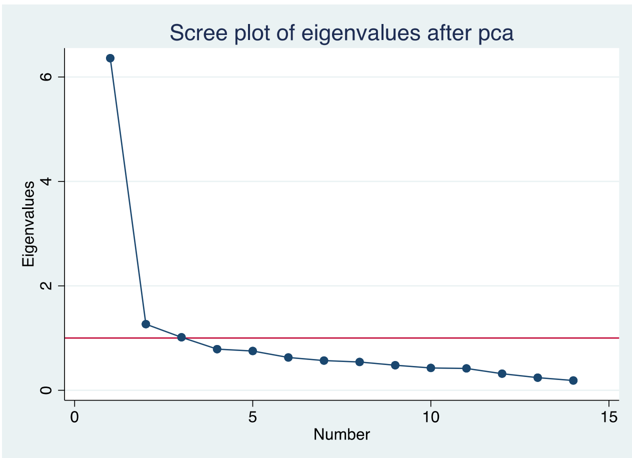
The distribution of asset indices obtained from FP-PCA, and pPCA are presented with box-and-whisker plots (Figure 3.1a). The central line of each plot shows the median of the data while the boundaries of the boxes are the lower and upper quartiles. The length of the whisker for FP-PCA (with dummy variables) was longer than the distance between the median and the corresponding quartile. The asset index derived from FSNSP (using pPCA) is presented in Figure 3.1b and was normally distributed. The eigen value from FP-PCA from the first component was 5.2 and captured only 22% of the total variance. Using pPCA, the eigen value increased to 46%. The scree plot (Figure 3.1c.) shows that the first component (derived from pPCA FSNSP) is highly significant.



a. Social position indices obtained from FSNSP data: FP-PCA and pPCA



b. Social position index derived from pPCA score, FSNSP data



c. Scree plot of eigenvalues after a pPCA, FSNSP data

Figure 3.1 FSNSP pPCA performance

The factor loadings for each variable are presented in Table 3.4, where high factors loading scores would indicate higher ability to distinguish socioeconomic status than those with low factor loading scores. The variables that indicated whether the household's floor type is cemented, or if they had an *almirah* (a wardrobe), or a fan, all of which were highly ranked items that can distinguish socioeconomic position. The top five ranked variables from FSNSP dataset are marked with bold font in Table 3.4.

Table 3.4 Factor loadings for variables for the pPCA of FSNSP

Variables	**FSNSP**
Cemented floor	**0.80**
Almirah (Wardrobe)	**0.80**
Fan	**0.80**
Television	**0.79**
Table/chair	**0.75**
Mobile	0.72
Watch	0.68
Maternal education	0.64
Toilet	0.63
Number of rooms	0.60
Agricultural land	0.57
Household head's education	0.55
Household head's occupation	0.52
Water source	0.47

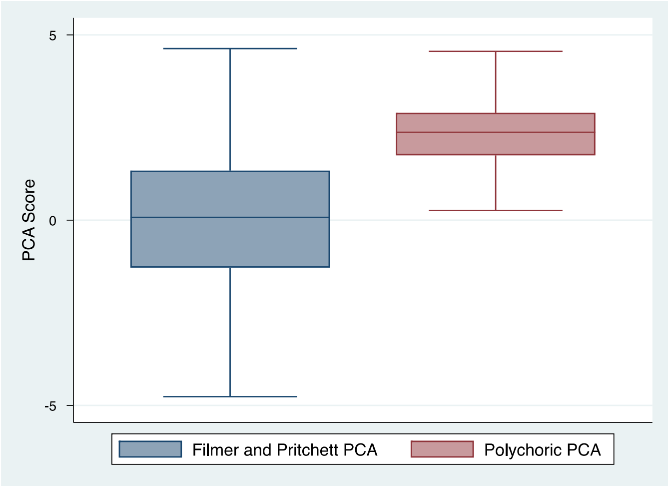
The Cronbach’s alpha was found to be ≥0.7 (Table 3.5) in FSNSP data. Determinant statistics of the correlation matrix was 0.05, KMO statistic was 0.91 and the Bartlett’s test result was highly significant (<0.001).

Table 3.5 Characteristics of the FSNSP indices

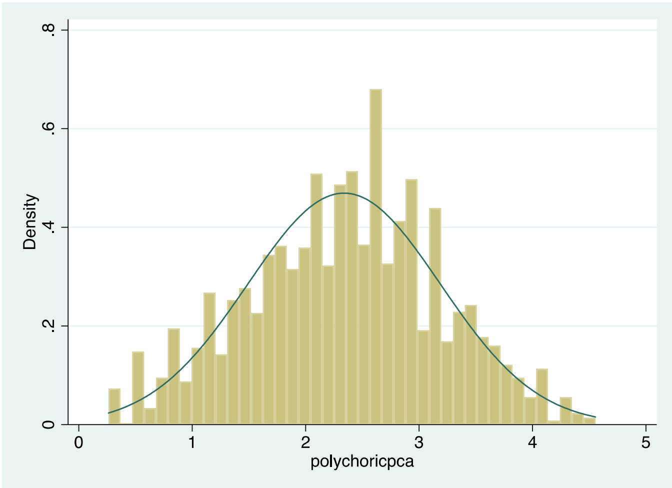
Postestimation test	Polychoric PCA from FSNSP data
Cronbach's Alpha	0.78
The determinant statistics of the correlation matrix	0.05
Kaiser-Meyer-Olkin	0.91
Bartlett test of sphericity p-value	<0.001
Collinearity Diagnostics	1.3
# of variables	14

Suchana

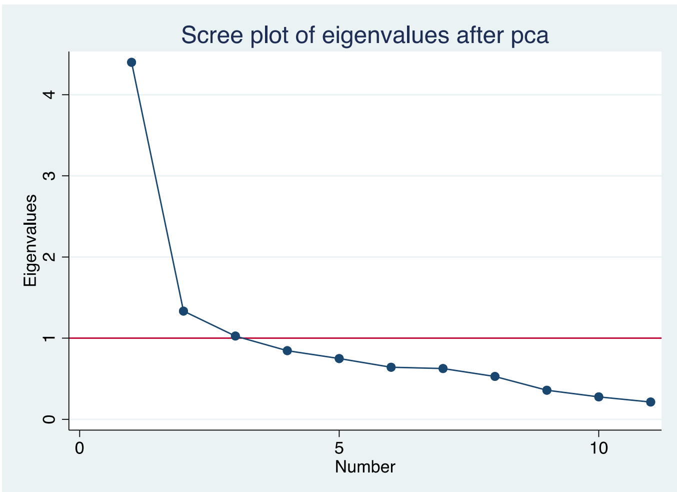
The distribution of asset indices which was obtained from the two different procedures (FP-PCA, and pPCA) are presented with box-and-whisker plots (Figure 3.2a). The SEP index derived from Suchana (using pPCA) was normally distributed (Figure 3.2b). The eigenvalue from the first component was 3.5 which captured only 18% of the total variance when using FP-PCA, but this increased to 41% (4.5/11; the eigenvalue of the first principal component was 4.5) using pPCA. The scree plot for the pPCA (Figure 3.2c) shows that the first component is very high, and the first principal component captures 40% of the total variance or total information.



a. Social position indices obtained from Suchana data: FP-PCA and pPCA



b. Social position index derived from pPCA score, Suchana data



c. Scree plot of eigenvalues after a pPCA, Suchana data

Figure 3.2 Suchana pPCA performance

Factor loadings for each variable included in PCA for Suchana data are presented in Table 3.6. Among the variables for which the PCA assigned a high weight, having a sofa and a table were highest. The top five ranked variables are marked with bold font in Table 3.6.

Table 3.6 Factor loadings for variables for the pPCA of Suchana

Variables	Suchana
Sofa	**0.81**
Table	**0.78**
Chair	**0.72**
Fan	**0.69**
Ceremonial saree	**0.65**
Television	0.63
Maternal education	0.62
Toilet	0.55
Cemented floor	0.51
Showcase	0.42
Household head's education	0.46

The Cronbach's alpha (reliability estimate) of the SEP index was 0.70 (Table 3.7). Determinant statistics of the correlation matrix was 0.24 (desired value should be >0.0001), and KMO statistic was 0.80. The Bartlett's test result was highly significant (<0.001).

Table 3.7 Characteristics of the Suchana SEP indices

Postestimation test	Polychoric PCA from Suchana data
Cronbach's Alpha	0.70
The determinant statistics of the correlation matrix	0.24
Kaiser-Meyer-Olkin	0.80
Bartlett test of sphericity p-value	<0.001
Collinearity Diagnostics	1.2
# of variables	11

Discussion

The discussion includes the characteristics of the two PCAs (FP-PCA, and pPCA) conducted and the indices generated from the two datasets: FSNSP and Suchana. I have shown that the pPCA method can be easily applied for surveillance and survey data. The pPCA approach appears to produce more credible distributions of wealth than the more commonly used FP-PCA.

The two important determinants of performance of PCA are the proportion of variance explained and number of variables used (Kolenikov & Angeles, 2009). The percentage of variability in the dataset explained by the pPCA-based asset indices of FSNSP and Suchana were 46% and 40% respectively. The variability explained by pPCAs of household data from FSNSP and Suchana was higher and better than what was reported by other studies where the highest was 23% (Hargreaves et al., 2007), or 15% (El Arifeen et al., 2008) (See Appendix A3 for findings from other study).

The PCAs conducted on both the FSNSP and Suchana data had adequate cases, as the KMO statistics for sampling adequacy reflected (Field, 2013). In the literature it was suggested that the sample size for PCA should be ≥100 (Shaukat et al., 2016). Therefore, both the FSNSP and Suchana data sample sizes (37,929 and 13,064 respectively) were reassuringly adequate to conduct PCA on these datasets. The PCAs conducted on both datasets were also internally consistent as the indices had high reliability scores (Cronbach's alpha ≥0.7).

One of the significant observations made during the study pertains to the choice of variables. Although the data from FSNSP and Suchana were selected only from rural areas, I found that the same set of variables used for FSNSP could not be applied to the Suchana data, which is understandable as one refers to the range of household characteristic in relation to the SEP status, whereas households in the Suchana data refers to the poor and poorest SEP groups (as described in Chapter 2). For example, mobile phone and ownership of agricultural land, they were included in FSNSP but not in Suchana. For mobile phone: the data collection period for FSNSP ranged between 2010 and 2014, whereas the data for Suchana was collected between 2016 and 2019. This time gap highlighted a significant change in the use of mobile phones across SEP groups. The widespread adoption of mobile phones during this period rendered it a universal variable, irrespective of socioeconomic status. Therefore, I excluded mobile phone ownership from the PCA for Suchana data to ensure the analysis accurately represented the wealth. Secondly, the ownership of agricultural land is generally considered as a social status indicator when considered on a national level and also applied for FSNSP data. However, it was observed that the beneficiaries of the Suchana programme were among the poorest of the poor, and consequently, very few households owned any agricultural land. Due to this lack of variation within the Suchana dataset, including agricultural land as a variable in the PCA would not have yielded meaningful results. Therefore, I decided to exclude it from the analysis to avoid misleading interpretations. The primary reason for this discrepancy is that the Suchana population represents a distinct group that differs significantly from the national scenario. It is well known that for making a composite index, the choice of indicators influence the magnitude of the observed health inequalities (Darin-Mattsson et al., 2017). Therefore, it is important to consider local contexts, socioeconomic conditions, cultural factors, and other relevant aspects when selecting variables to assess inequalities.

Moreover, there are some common variables which used in both data sets, but variables had quite different factor loadings assigned by the two datasets (e.g., factor loadings in FSNSP, Suchana: floor 0.80, 0.51; showcase 0.80, 0.42 respectively). The weight assigned to a particular variable is relative for a specific data set (in relation to correlation of all variables included in the PCA). Prakongsai also had similar findings of PCA assigning different weight to the same variable when data from a different period was used (Prakongsai, 2006).

My present work could be useful in future when researchers might use DHS, surveillance or survey data for selecting SEP indicators that suit a particular context. For those designing new surveys intending to measure inequalities in developing countries, I advise including items that poor households are likely to own and that are indicators of social status in rural areas. In policy oriented applications, these measures can also be utilised to make decisions regarding the allocation of projects that are to benefit the poor.

Conclusions

While public health researchers increasingly becoming interested in measuring inequalities, valid assessments requires reliable measures of socioeconomic status. In this research, I have demonstrated an example of analysing surveillance and survey data using pPCA, a method capable of handling ordinal variables. The application of pPCA in this context allows for more robust and accurate evaluations of inequality, specific to each context, thereby contributing to the advancement of research and policy efforts aimed at addressing socioeconomic disparities in health and nutrition outcomes.

4. CHAPTER 4

MANUSCRIPT#1 FSNSP DATA

[International Journal of Epidemiology]

Relative effects of socioeconomic inequalities and nutritional factors on the linear growth of children

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Abstract

Background: Millions of dollars have been spent attempting to improve children's linear growth measured through height-for-age Z-score (HAZ) and thereby reducing the prevalence of stunting, although evaluations of nutritional interventions show little progress. While nutrition is essential, an individual's socioeconomic position (SEP) within hierarchical societies can play an important role in determining adequate child growth. This study assesses the relative effects of SEP inequalities vs. nutritional factors (NF) on linear growth of Bangladeshi children.

Methods: Mother-child dyads were studied using a nationally representative 'Food Security Nutrition Surveillance Project (FSNSP)' (2011–2014, n=37,929, children <5 years). Applying polychoric principal component analysis (pPCA), a composite SEP scale was constructed utilising parental education, occupation, land ownership, assets, and other household characteristics. Comparisons of HAZ between the "richest" (highest quintile) vs. "poorest" (lowest quintile) of SEP groups formed the inequalities assessment. NF included child's minimum dietary diversity (MDD) and morbidity status. Multiple linear regression models with HAZ as an outcome and SEP group and NF as main variables of interest controlling for covariates (child age, sex, birth order, wasting, maternal short stature, BMI, household size) were performed. Standardised beta coefficient estimates allowed a comparison of relative effects of SEP and NF.

Results: While SEP and MDD were both statistically significantly associated with HAZ, morbidity was not associated. SEP inequalities had a larger effect (0.22 SD units difference between poorest vs. richest, 95% CI: 0.19,0.25), whereas the effect of achieving MDD was much less (0.06 SD units, 95% CI: 0.03,0.09).

Conclusions: Socioeconomic inequalities have a much larger effect on HAZ than NF, raising questions about international development priorities that focus solely on nutrition. Optimal linear growth for children may not be achieved until wider issue of social inequalities are addressed.

Introduction

Despite recent improvements, worldwide 149 million children under five years suffer from stunting, i.e., low height for age, which limits their physical and cognitive potential (GNR, 2021). Sub-Saharan Africa (35%) and South Asia (32%) contribute the highest proportion of such children (GNR, 2021). Following the WHO (2020) definition, stunting is referred to as 'suboptimal nutrition, inadequate care and repeated infections' (WHO, 2020). Stunting is significant not only as an outcome, but also as an indicator of various adverse consequences, for example, reduced cognitive function (Black et al., 2013; Prendergast & Humphrey, 2014), decreased learning capacity (Martorell et al., 2010), and lower productivity (Hoddinott et al., 2013), increased morbidity and mortality (Aguayo & Menon, 2016; Black et al., 2008; Özaltin et al., 2010), long-term health problems, e.g., chronic diseases (Gluckman et al., 2007; Hoddinott et al., 2013) such as cardio-metabolic diseases, particularly overweight (Barker, 2007), an increased risk of cephalopelvic disproportion leading to dystocia (Wells, 2017), and poor birth outcomes [e.g., low birth weight (LBW) or small gestational age (SGA)] in the next generation (Black et al., 2013). To support the UN Sustainable Development Goals (SDG), in 2012 the World Health Assembly (WHA), the decision-making body of the WHO, declared a '40% reduction by 2025 in the number of children <5 years old who are stunted' as its first global nutrition target (De Onis et al., 2013).

In order to achieve the WHA target, in the last decade, unprecedented attention has been given to childhood malnutrition by implementing both nutrition-*specific* (interventions to address the immediate determinants of child growth and development) and nutrition-*sensitive* (addressing the underlying determinants of foetal/child nutrition and development) interventions. Victora et al. (2021) reviewed progress on reducing undernutrition using data from 2000 to 2015 from 50 low-to-middle income countries (LMIC) and found that the prevalence of childhood stunting had fallen from 33% in 2000 to 22% in 2017 (Victora et al., 2021). While stunting had declined, the current trend (11% reduction in 17 years) in many LMIC is still insufficient to reach the WHA target for 2025 (Argaw et al., 2019).

Planning interventions and allocating resources to reduce stunting requires understanding the dynamics of determinants and linkages. To this end, a number of observational studies and randomised trials have identified the complex determinants and risk factors for stunting (Argaw et al., 2019; Chirande et al., 2015; Danaei et al., 2016; Dewey et al., 2017; Headey et al., 2016; Huda et al., 2017; Krishna et al., 2018; Kumar et al., 2021; Torlesse et al., 2016). It is well established that adequate and nutrient-rich complementary feeding is critical to support optimal physical growth and brain development for children and to prevent stunting (Aguayo et al., 2016; Dewey, 2016; Kim et al., 2017). Modest effects of dietary interventions to prevent stunting (Hossain et al., 2017; Nguyen et al., 2017) may reflect an incomplete understanding of the optimal way and time to intervene. Other common determinants of childhood stunting are: maternal low stature (Bhowmik & Das, 2017; Danaei et al., 2016; Katoch, 2022; Kim et al., 2017; Victora et al., 2021), maternal undernutrition (Victora et al., 2021), poor maternal diet before and during pregnancy, low levels of maternal education (Huda et al., 2017; Semba et al., 2008), foetal growth retardation or LBW (Aguayo et al., 2016; Danaei et al., 2016), child age (Torlesse et al., 2016), detrimental environmental factors including poor sanitation (Danaei et al., 2016), enteropathy (Lin et al., 2013), poverty and inequalities (Black et al., 2013; Huda et al., 2017; Krishna et al., 2018; Kumar et al., 2021; Nguyen et al., 2017; Rabbani et al., 2016; Torlesse et al., 2016).

Wilkinson and Picket (2010) have pointed out that growing income and wealth inequalities are recognised as the greatest social threats to health in rich countries (WHO, 2008). The vast majority of people in many affluent countries are now suffering as a result of growing inequalities (Dorling, 2019). There is always a gap in health between those living in more advantaged situations than those living in less advantage situations. This inequality is primarily due to structural determinants, e.g., governance, rules, policy, social position, human capital and potential (Nisbett et al., 2022) and is present across the social gradient (Marmot, 2015). Health (e.g., life expectancy), social problems (e.g., drug use), mental illness and child wellbeing are worse in more unequal countries (Wilkinson & Pickett, 2010). Similarly, the importance of socioeconomic inequalities for stunting have been reported by several researchers, mostly in LMICs (da Silva et al., 2018), and more specifically in South Asian countries, e.g., Nepal (Angdembe et al., 2019), Bangladesh (Huda et al., 2017; Kumar et al., 2021; Rabbani et al., 2016; Sarker et al., 2020) and for a mix of Bangladesh, Nepal, India, Pakistan, Afghanistan (Headey et al., 2016; Kim et al., 2017; Krishna et al., 2018).

Furthermore, improvements in relative social status and its effect on health has garnered increasing attention in anthropology and public health (Bogin et al., 2015; Bogin et al., 2017; Hermanussen & Scheffler, 2016; Hermanussen & Wit, 2017). Hermanussen and colleagues have suggested in their many papers, for example, that relative social inequalities explain HAZ far more than just nutritional factors. They have also suggested that, similar to the effects of social dominance and subordinance observed in other species, these effects within human groups might be mediated through the hypothalamic-pituitary-adrenal (HPA) axis and also via the role of the hormone IGF-1 (insulin-like growth factor-1) during childhood and adolescence (Bogin et al., 2015; Bogin et al., 2017; Hermanussen & Scheffler, 2016; Hermanussen & Wit, 2017).

In Bangladesh, the existence of socioeconomic inequalities in stunting prevalence has been recognised by several authors but most of them have only focused on establishing the association between stunting and inequalities between two specific time points, e.g., 2004 and 2014 (Huda et al., 2017; Sarker et al., 2020), 1996 and 2014 (Rabbani et al., 2016), 2004 and 2017 (Kumar et al., 2021) to determine the factors driving these changes. These studies examined change in stunting over time and factors associated with stunting trends, but did not use longitudinal data sets or measured growth hormones to explain that (Huda et al., 2017; Kumar et al., 2021; Rabbani et al., 2016; Sarker et al., 2020). Cross-sectional studies are important to uncover the determinants of stunting and its trends but have also been limited due to the absence of data on several nutrition-related determinants. For example, data on child's diet was not available in some cases (Huda et al., 2017; Kumar et al., 2021; Rabbani et al., 2016; Sarker et al., 2020) or morbidity in others (Huda et al., 2017; Kumar et al., 2021; Rabbani et al., 2016). Both socioeconomic inequalities and nutritional related determinants have sufficient evidence of their importance relating to stunting from these studies and others, but with little evidence to assess the relative contribution of each in an LMIC context. Although the significance of risk factors for stunting has been measured in south Asian countries (Kim et al., 2017; Svefors et al., 2019), the relative significance of the same set of risk factors may substantially vary by age of a child and region.

Understanding the relative contributions of socioeconomic inequalities and NF at the national level is vital in designing and prioritising more local and effective interventions that could foster greater equality and improve nutritional outcomes. This study aimed to utilise a set of nationally representative data to assess the relative contribution of socioeconomic inequalities and NF on the linear growth of children <5 years in rural Bangladesh and also to guide policy decisions.

Methods

I used data collected 2011 to 2014 from a nationally representative surveillance project in Bangladesh, namely the 'Food Security Nutrition and Surveillance Project (FSNSP)'. FSNSP carried out a repeated multistage, cross-sectional survey, comprising three rounds per year in both urban and rural areas, covering seven *divisions* and six *vulnerable areas*. "Divisions", the first layer of the multistage data collection (divisions are the first layer of administrative units in Bangladesh) namely: Barishal, Chattogram, Dhaka, Khulna, Rajshahi, Rangpur, and Sylhet. FSNSP sampling followed administrative layers, where samples for each divisions were divided into districts, which were further divided into sub-districts or *upazilas*, and then unions for rural areas. The sampling of households also covered some so-called vulnerable zones, the coastal belt, eastern hills, *haor* basin (wet land), the Padma *chars* (a *char* is a tract of land surrounded by river waters) northern *chars* (drought prone), and northwest (northern part), using a categorisation based on a risk profile for being affected by natural calamities such as cyclones in riverine and flood-prone areas in Bangladesh. FSNSP rounds coincided with three seasons in Bangladesh per year: i) the harvest period (January–April) ii) the height of the monsoon (May–August), and iii) the second harvest period (September–December).

For surveillance purposes, households were selected if there were any girls or women (aged 10 to 49 years of age) or children (<5 years) present in the households. One girl or woman from each household was randomly selected for a 'household questionnaire survey interview' focusing on dietary consumption and anthropometric measurements (height and weight). Anthropometry was carried out on children <5 years of age in the household (HKI/JPG-SPH, 2016). The weight of women and children was measured to the nearest 0.1 kg using a portable electronic weighing scale (TANITA Corporation Japan, model HD305). The height of women and children >2 years, and the recumbent length of children <2 years were measured to the nearest 0.1 cm using a locally made height and length board. All anthropometric measurements were performed according to FSNSP standard procedure (HKI/JPG-SPH, 2016).

For specific purposes of this paper, this research focuses solely on rural data due to the challenges associated with creating an index using same set of variables that could incorporate both urban and rural data when measuring inequalities, and to ensure simplicity and comparability with other rural data in Bangladesh. Similarly, the analyses focused on children aged 6–59 months old, so comparable dietary data are available across the groups. Infants <6 months old were excluded as recommendations suggest they should be exclusively breastfed and over 50% of the rural mothers practice exclusive breastfeeding for this age group (HKI/JPG-SPH, 2016). Unlike children aged 6–59 months, this group would not contribute data on dietary intake, an essential component for this study. Similarly, data from women who were not the mother of the reference child were excluded from all analyses to allow inclusion of maternal factors in the regression models. After these specific exclusions (urban households, infants <6 months old, non-mothers of target children), a total of 37,929 mother-child pairs, whose records were complete for the required individual and household-level variables, were included in the analyses (Figure 4.1).

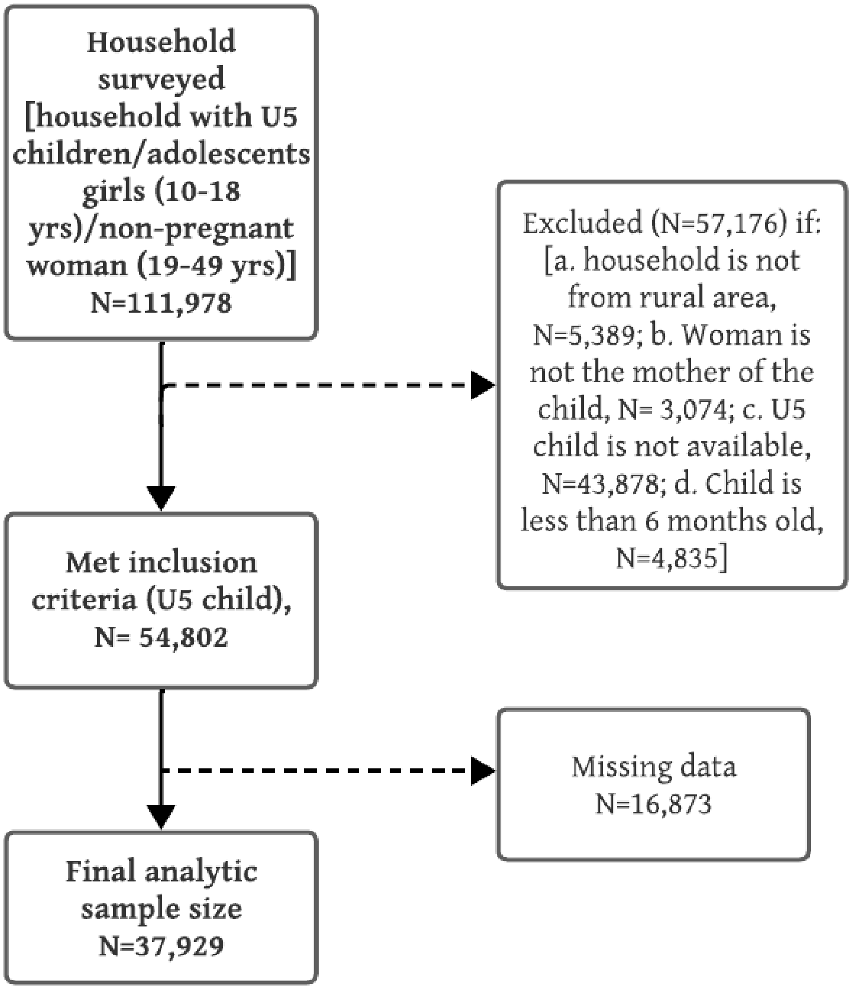

Figure 4.1 Flow chart for final analytic sample size, FSNSP data

Variables

The outcome variable was length/ height-for-age Z-score (L/HAZ) reflecting the linear growth of children and calculated using WHO criteria (WHO, 2006), where children are defined as stunted if their HAZ is <-2 standard deviations (SD) of the median of WHO child growth standards (Leroy & Frongillo, 2019). To uncover the relationship between NF and linear growth of children, two variables, 'inadequate dietary intake' and 'morbidity' were included in analyses (UNICEF, 1991). Following WHO (2010) guidelines, an inadequate dietary intake was measured using child dietary diversity information for the last 24 hours (WHO, 2010). This assessment of dietary diversity used 7 food groups: 1) grains, roots and tubers 2) legumes and nuts, 3) dairy products, 4) meat/fish, 5) eggs 6) vitamin A-rich fruits and vegetables and

7) other fruits and vegetables, reflecting data used in other studies (Rakotonirainy et al., 2018; Woldegebriel et al., 2020). Most recent WHO (2021) guidelines suggest including eight food groups, including breast milk, for the assessment of infant and young child feeding (IYCF) practices for those aged <2 years (WHO/UNICEF, 2021). Given that I have included data for children aged 6–59 months, relying on recall procedure for breast feeding data from their mothers could introduce recall bias. Therefore, I opted to use 'seven food groups' and to exclude breast milk (WHO, 2010).

A dietary diversity score was obtained by summing the intake from all seven food groups, ranging from 0 to 7, where 0 represented non-consumption of food items from any of the respective food groups and 7 represented consumption from each of the groups within the last 24 hours. Children who ate from ≥ 4 food groups in the last 24 hours of maternal interview were considered to have achieved an “adequate” minimum dietary diversity (MDD). A binary variable was then created to represent whether children had an adequate (≥ 4 food groups=1) or inadequate MDD (≤ 4 food groups=0) (Rakotonirainy et al., 2018; WHO, 2010; Woldegebriel et al., 2020).

FSNSP included data on morbidity history for two weeks preceding the date of interview during the survey including: occurrence of fever, runny nose, difficult breathing, diarrhoea, and other diseases (here ‘other’ was not recorded specifically). Each positive response for morbidity was scored as 1, and the total morbidity score was summed where 0 meant no morbidity, and 5 was the maximum possible recorded morbidity. However, for descriptive analyses in the graphs, morbidity was reported as a binary variable, where 0 indicates no morbidity, and ≥ 1 indicates the presence of morbidity.

To measure socioeconomic inequality, first a variable of socioeconomic position (SEP) index was calculated using variables which related to social class, social status (prestige) and household material assets (Table 4.1).

Table 4.1 The list of the variables to make an index by using polychoric PCA

Variables	Types	Categories
Household head's occupation	Ordinal	Labourer
		Farmer
		Professional/landlord
Maternal educational status	Ordinal	No education
		Primary
		Secondary and above
Household head's educational status	Ordinal	No education
		Primary
		Secondary and above
Material assets		
Agricultural land	Binary	Yes/No
Radio/television	Binary	Yes/No
Telephone/cell phone	Binary	Yes/No
Fan	Binary	Yes/No
Wardrobe	Binary	Yes/No
Table/chair	Binary	Yes/No
Watch/clock	Binary	Yes/No
Number of rooms in the house	Count variable	Count
Floor materials	Ordinal	Sand
		Cemented
Type of latrine	Ordinal	Unimproved
		Pit latrine with/without slab
		Safe/sanitary
Type of drinking water	Ordinal	High risk of contamination
		Low risk of contamination

To compute this SEP index, polychoric principal component analysis (pPCA) was conducted. The SEP index was then grouped into quintiles, where Quintile 1 represented the poorest segment of the population and Quintile 5, the richest. Comparisons between the richest and poorest SEP groups formed the assessment of relative socioeconomic inequalities.

Several other predictors with established associations with linear growth were included in the statistical models examining the comparative effect of NF and SEP. Since nutritional status generally varies by age and sex (Baig-Ansari et al., 2006; Reinbold, 2011; Shrimpton et al., 2001; Victora et al., 2010); these variables were included for the children in the models, for which age was categorised as 6–11, 12–23, 24–35 and 36–59 months. Wasting and stunting share common determinants *in utero* and infancy, with evidence that wasting increases the risk of subsequent stunting (Raiten & Bremer, 2020), suggesting that the body responds to weight faltering by slowing linear growth (Victora et al., 2021). Therefore, weight-for-height Z-score (WHZ) (<-2 WHZ score the cut-off for wasting), were also included in the analyses (Victora et al., 2021). Short maternal height is also associated with lower HAZ and WHZ for children at the age of 24 months (Victora et al., 2021). While researchers have used different cut-offs for defining short maternal stature (Huda et al., 2017), this study applied the latest Lancet reference, with <145 cm defined as short stature and ≥145cm as normal maternal height (Victora et al., 2021). Given that child nutrition, particularly stunting, is strongly associated with maternal nutritional status (Black et al., 2013; Goudet et al., 2017; Victora et al., 2021), maternal BMI was also included in our analyses as a continuous variable. Household size (number of people eating from the same cooking pot) were grouped as a categorical variable: 2-4=0, and ≥5=1, and similarly another categorical variable for child birth order (1st, 2nd, 3rd and 4^{th} +) was also included in regression model. Year was an additional variable corresponding to the sampling period 2011–2014, "season" represented a variable for the different seasons of data collection, and a variable for the 7 'divisions' was also included (Guha et al., 2022).

I accounted for the complex sampling method (i.e., stratification, clustering, and sample weights) in estimating summary statistics as well as inferential statistics for variables at the population level. All analyses were undertaken where '*zones*' (13 zones: 6 vulnerable areas and 7 divisions) were considered as 'strata' and the *upazilas* were considered as 'sampling units'/'clustering'. I used the Stata svy command to account for strata and clusters.

The FSNSP raw data consisted of individual Stata files by rounds (one for each season of each year), with data for children and households. Before merging files, the data were checked for any modifications in names of variables or categories across rounds and were excluded if there were inconsistencies which could have affected the analyses. WHO Anthro software (built into Stata) was used to compute the HAZ and WHZ (WHO, 2006). HAZ outliers (>6 or < –6) were excluded from the analyses (WHO, 2006). Age and sex were included in all models.

Descriptive statistics, summarising continuous data as mean ± SD and percentages for categorical responses were used to provide an overview of the population. For comparisons of categorical responses by groups chi-square tests were used. Similarly, ANOVA and t-tests for continuous variables, subject to meeting assumptions of parametric tests. Linear regressions were used to calculate the relationships between SEP, NF and stunting (HAZ) where, the beta coefficient indicated the association between HAZ and explanatory variables, described using their original units. In contrast, the standardised beta coefficient indicated the same associations expressed using standard deviations. All analyses were performed using Stata 16 and the significance level was set at $p<0.05$. The R^2 value was used to reflect the proportion of variance in HAZ that could be explained by SEP and NF in the different models.

Five models were then constructed for analyses. Model-1 was the base model, which included child age and sex as predictors for HAZ, while Models-2 and 3 added NF and then SEP, respectively, as additional explanatory variables. Model-4 included both NF and SEP together with child age and sex. Finally, Model-5 included HAZ as the dependent variable with NF and SEP as main explanatory variables along with additional covariates (child age, sex, child's birth order, child's WHZ, maternal BMI, maternal short stature, household size, season and data collection time). In the final model (Model-5), the beta coefficient, and standardised beta coefficients were then used to calculate the relative contribution of NF and SEP on HAZ.

Ethics

The FSNSP project was led by the BRAC James P. Grant-School of Public Health (JPG-SPH), BRAC University, Dhaka, Bangladesh which owns the data sets. Data access was possible following a standard application procedure detailing the research objectives and analytical approach. Verbal informed consent was obtained during the primary questionnaire by trained research assistants. The approval for secondary analyses of the dataset were obtained through ethical clearance from the Department of Anthropology Ethics Committee, Durham University, UK (Reference number: ANTH-2021-07-30T13:26:50-czfz39).

Results

Table 4.2 presents the distribution of household sociodemographic characteristics by stunting characteristics of children aged <5 years. Overall, a large proportion of households did not own any agricultural land (64%), nearly half of household heads were day labourers, and about one third had a secondary school or higher education. About 21% of households had cemented walls, 16% had a cemented floor, but only 6% had cemented roofs. Nearly 40% of children lived in household with <5 members (median), and about 60% were from larger households with 5 or more members.

Table 4.2 Sociodemographic characteristics of households with children <5 years by stunting status in rural Bangladesh, 2011–2014

Characteristics	Stunted % (n)	Not stunted % (n)	Total % (n)	*p* value
Ownership of agricultural land				
No agricultural land	68.0 (10455)	61.9 (13635)	64.4 (24090)	<0.001
Agricultural land ≤50 decimal	16.4 (2320)	15.8 (3515)	16.0 (5835)	
Agricultural land > 50 decimal	15.6 (2664)	22.3 (5340)	19.6 (8004)	
Household head's education				
No education	46.0 (7578)	36.5 (8848)	40.3 (16426)	<0.001
Primary (up to five class)	30.2 (4485)	26.7 (6388)	28.2 (10873)	
Secondary and above	23.8 (3376)	36.8 (7254)	31.5 (10630)	
Household head's occupation				
Day labourer	50.8 (7531)	42.2 (9200)	45.7 (16731)	<0.001
Farmer	22.9 (4112)	24.3 (6461)	23.7 (10573)	
Professional/salaried/landlord	26.3 (3796)	33.5 (6829)	30.6 (10625)	
Household size				
2–4 members	37.2 (5554)	39.3 (8661)	38.5 (14215)	0.028
≥5 members	62.8 (9885)	60.7 (13829)	61.5 (23714)	
Household assets:				
Radio/television				
No	74.4 (12114)	60.9 (14911)	66.3 (27025)	<0.001
Yes	25.6 (3325)	39.1 (7579)	33.7 (10904)	
Telephone/cell phone				
No	23.8 (4131)	16.1 (4125)	19.2 (8256)	<0.001
Yes	76.2 (11308)	83.9 (18365)	80.8 (29673)	
Fan				
No	60.2 (10447)	45.9 (12179)	51.7 (22626)	<0.001
Yes	39.8 (4992)	54.1 (10311)	48.3 (15303)	
Almirah (Wardrobe)				
No	46.8 (8004)	35.1 (9016)	39.8 (17020)	<0.001
Yes	53.2 (7435)	64.9 (13474)	60.2 (20909)	
Table/chair				
No	27.0 (4647)	17.7 (4688)	21.4 (9335)	<0.001
Yes	73.0 (10792)	82.3 (17802)	78.6 (28594)	
Watch/clock				
No	61.4 (10328)	52.7 (12808)	56.2 (23136)	<0.001
Yes	38.6 (5111)	47.3 (9682)	43.8 (14793)	
Household materials-wall				

Non-cemented	37.9 (6556)	31.1 (8155)	33.8 (14711)	<0.001
Half-cemented	47.0 (6982)	44.1 (10048)	45.3 (17030)	
Cemented	15.1 (1901)	24.8 (4287)	20.9 (6188)	
Household materials-roof				
Non-cemented	5.5 (1242)	3.7 (1352)	4.5 (2594)	<0.001
Half-cemented/tin	91.5 (13926)	88.7 (20197)	89.8 (34123)	
Cemented	3.0 (271)	7.6 (941)	5.7 (1212)	
Household materials- floor				
Non-cemented	90.3 (14444)	80.3 (19399)	84.3 (33843)	<0.001
Cemented	9.7 (995)	19.7 (3091)	15.7 (4086)	
Number of living room				
one room	32.7 (5043)	26.3 (6020)	28.9 (11063)	<0.001
two rooms	31.2 (4969)	28.4 (6559)	29.5 (11528)	
≥3 rooms	36.1 (5427)	45.3 (9911)	41.6 (15338)	
Type of toilet				
Hanging/bush/open	15.6 (3488)	11.4 (3985)	13.1 (7473)	<0.001
Pit/slab	72.4 (10723)	67.3 (15225)	69.4 (25948)	
Safe sanitary	12.0 (1228)	21.3 (3280)	17.5 (4508)	
Water source with relatively low contamination risk				
Relatively high contamination risk (tap water/tube well (shared)	19.3 (2569)	26.0 (5121)	23.3 (7690)	<0.001
Relatively low contamination risk (protected well/rainwater/tube well (owned))	80.7 (12870)	74.0 (17369)	76.7 (30239)	
N	15439	22490	37929	

Table 4.3 illustrates child and maternal characteristics by child stunting status. Among the surveyed children, 53% were boys and 47% were girls of whom nearly 33% were first born. The majority (45%) were between 36–59 months with a mean age of 28 months (not presented in the table). Overall, 43% of children had achieved MDD, but the proportion was significantly lower among stunted children (39%) compared with non–stunted (45%). Overall, 66% of children reported some kind of morbidity, and this was very similar between stunted and non–stunted children (*p*=0.198), the most commonly cited being cough/runny nose (50%), fever (47%), and diarrhoea (13%) (data not presented). Nearly half of the mothers (48%) were educated up to secondary school or higher, and a majority were housewives (60%). About 13% of the mothers were short-statured, one third (31%) were undernourished (BMI $<18.5 kg/m^2$), while 58% had a normal BMI.

Table 4.3 Child and maternal characteristics for the studied population in rural Bangladesh, 2011–2014

Characteristics	Stunted % (n)	Not stunted % (n)	Total % (n)	*p* value
Child characteristics				
Age group, % (n)				
6–11 month	6.1 (1034)	15.2 (3348)	11.6 (4382)	<0.001
12–23 month	23.2 (3528)	22.1 (4960)	22.5 (8488)	
24–35 month	23.8 (3735)	19.9 (4725)	21.5 (8460)	
36–59 month	46.9 (7142)	42.8 (9457)	44.4 (16599)	
Gender, % (n)				
Boy	53.4 (8007)	52.6 (11496)	53.0 (19503)	0.521
Girl	46.6 (7432)	47.4 (10994)	47.0 (18426)	
WHZ score, mean±SD	-1.0± 1.0	-0.8±1.0	-0.9±1.0	<0.001
Birth order, % (n)				
1	29.6 (4615)	35.0 (7867)	32.8 (12482)	<0.001
2	28.6 (4316)	31.8 (6960)	30.5 (11276)	
3	17.6 (2785)	17.3 (3867)	17.4 (6652)	
4 or more	24.2 (3723)	15.9 (3796)	19.3 (7519)	
Minimum Dietary Diversity achieved (MDD) , % (n)				
No	61.4 (9924)	54.9 (13248)	57.5 (23172)	<0.001
Yes	38.6 (5515)	45.1 (9242)	42.5 (14757)	
Morbidity reported, mean±SD	1.1±1.0	1.1±1.0	1.1±1.0	0.051
Maternal characteristics				
Mother's education, % (n)				
No education	24.8 (4595)	15.8 (4523)	19.5 (9118)	<0.001
Primary (up to five)	36.3 (5662)	30.0 (6973)	32.5 (12635)	
Secondary and above	38.9 (5182)	54.2 (10994)	48.0 (16176)	
Mother's occupation, % (n)				
Housewife	66.4 (9852)	62.6 (13298)	64.2 (23150)	<0.001
Day labourer	5.2 (783)	4.5 (1017)	4.8 (1800)	
Farmer	10.2 (1892)	9.1 (2603)	9.5 (4495)	
Business/salaried/professional	18.2 (2912)	23.8 (5572)	21.5 (8484)	
Maternal height, % (n)				
Short stature (<145cm)	20.0 (3176)	8.7 (2099)	13.2 (5275)	<0.001
Normal (≥145cm)	80.0 (12263)	91.3 (20391)	86.8 (32654)	
Maternal BMI, % (n)				
Undernourished	35 (5385)	27.5 (5942)	30.5 (11327)	<0.001
Normal	57.5 (8981)	58.5 (13673)	58.1 (22654)	
Overweight and obese	7.5 (1073)	14.0 (2875)	11.4 (3948)	
N	15439	22490	37929	

All values are percent (n), unless otherwise indicated

The mean HAZ was 0.8 units lower for children in the poorest households versus the richest (Figure 4.2 a). Similarly, a large and significant difference existed for prevalence of stunting between the poorest (53% for the poorest) and richest (25% for the richest) households. The percentage of children with adequate dietary diversity followed a steep gradient, again with a stark difference (28%) in the prevalence of MDD between the poorest and richest households (Figure 4.2 b). However, the difference was less pronounced for morbidity status (Figure 4.2 c).

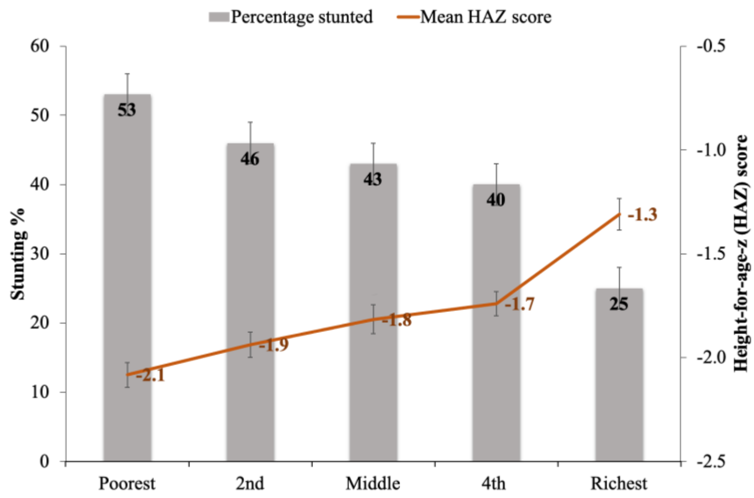

Figure 4.2a : Prevalence of stunting and mean HAZ across the SEP categories

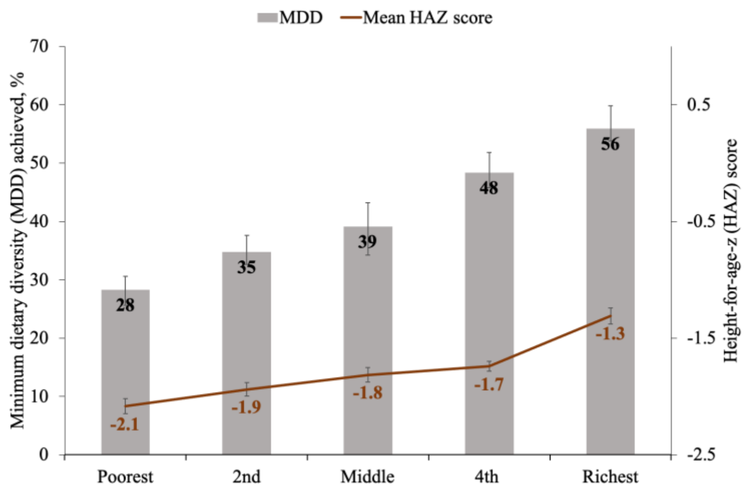

Figure 4.2b: Percentage children with MDD and mean HAZ across the SEP categories

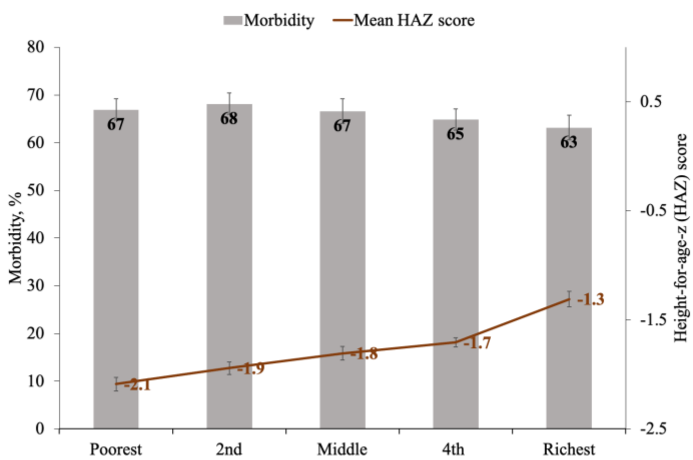

Figure 4.2c: Mean HAZ and morbidity prevalence across the SEP categories

Figure 4.2 Prevalence of stunting, MDD, morbidity and mean HAZ across the SEP categories

Table 4.4 presents results for the four different regression models that were used to assess the relative contribution of SEP and nutritional factors in relation to explaining variabilities in HAZ. Model-1 with the demographic variables accounted for 4% (R^2*100) of the variability in HAZ. When NF (Model-2) were added to the base model, the model explainibility remained same (5%), which indicated that addition of NF do not provide further explainibility in linear growth variation. However, when SEP was added to the base model (Model-3), the proportion of variability in HAZ explained by the model increased to 9%, meaning SEP explained 4% additional variability. Model-4, that included NF in addition to the base model and SEP (Model-3) was able to explain an additional 1% variability, over and above what the Model-3 could explain. These comparisons of models revealed that addition of NF in a model could explain much less variability in HAZ compared to the addition of SEP would do.

Table 4.4 Models examining the association of HAZ with nutritional factors and SEP among children aged <5 years in rural Bangladesh, 2011–2014

Variables		Model-1 Base (CI: Low, High)	Model-2 Base+Nutrition (CI: Low, High)	Model-3 Base+SEP (CI: Low, High)	Model-4 Base+ +SEP + Nutrition (CI: Low, High)
Child age group					
	6-11mo	Reference	Reference	Reference	Reference
	12-23mo	-0.65 (-0.75, -0.54)	-0.72 (-0.82, -0.61)	-0.62 (-0.72, -0.53)	-0.67 (-0.77, -0.57)
	34-35mo	-0.69 (-0.79, -0.59)	-0.79 (-0.88, -0.70)	-0.66 (-0.75, -0.56)	-0.73 (-0.81, -0.64)
	36-59mo	-0.68 (-0.75, -0.60)	-0.79 (-0.87, -0.70)	-0.64 (-0.70, -0.57)	-0.71 (-0.78, -0.64)
Child sex					
	Girl	Reference	Reference	Reference	Reference
	Boy	0.01 (-0.04, 0.06)	0.01 (-0.04, 0.06)	0.00 (-0.05, 0.05)	0.00 (-0.04, 0.05)
MDD					
	<4 food groups	-	Reference	-	Reference
	≥4 food groups	-	0.28 (0.21, 0.34)	-	0.18 (0.12, 0.25)
Morbidity		-	-0.05 (-.07, -.03)	-	-0.04 (-.06, -.02)
Socioeconomic position Index					
	Quintile-1 Poorest	-	-	Reference	Reference
	2nd	-	-	0.15 (0.06, 0.23)	0.14 (0.05, 0.21)
	Middle	-	-	0.26 (0.18, 0.34)	0.24 (0.16, 0.32)
	4th	-	-	0.33 (0.28, 0.39)	0.30 (0.24, 0.35)
	Quintile-5 Richest	-	-	0.75 (0.66, 0.83)	0.69 (0.61, 0.77)
R^2		0.05	0.05	0.09	0.10

All values in the table are unstandardised beta coefficients. CI= Confidence interval; MDD=minimum dietary diversity
Model-1 included child age, sex; Model-2 additionally included nutritional factors (Diet and morbidity variables). Model-3 included age, sex, and SEP categories; and Model–4 included age, sex, nutritional factors (dietary diversity and morbidity), and SEP categories.

Table 4.5 presented the final full model, namely Model-5, for multiple linear regression examining association of HAZ that included demographic, NF, SEP, and additional covariates. The Model-5 (column 5a: unstandardised coefficients) results showed that children in the richest household would have a 0.57 unit higher HAZ compared to that of children in the poorest households. The standardised units of SD (Model-5, column 5b) allows comparable across different variables and reflected a 0.22 SD increase (95% CI: 0.19, 0.25) in mean HAZ for the children in richest households, compared to children in the poorest. The same model (Model-5; column 5b) results found that the difference that can be achieved in mean HAZ with having MDD was only 0.06 SD (95% CI: 0.03, 0.09). Morbidity had no significant association with HAZ. Apart from confirming the established growth pattern by age, Model-5 also showed that maternal stature (coefficient: 0.15, 0.13, 0.17) and child WHZ (coefficient: 0.12, CI 0.09, 0.14) were relatively strong predictors of HAZ (Figure 4.2).

Table 4.5 Final full model for multiple linear regression examining association of HAZ with nutritional factors and SEP categories among children <5 years in rural Bangladesh, 2011–2014

Variables	Model-5: Final Full model based estimates		*p*–value
	5a Unstandardised coefficient (95% CIs: low, high)	**5b** Standardised coefficient (95% CIs: low, high)	
Demographic			
Child age			
6–11mo	Reference	Reference	
12–23mo	-0.61 (-0.71, -0.51)	-0.23 (-0.26, -0.19)	<0.001
24–35mo	-0.66 (-0.74, -0.58)	-0.24 (-0.27, -0.21)	<0.001
36–59mo	-0.64 (-0.72, -0.56)	-0.29 (-0.32, -0.25)	<0.001
Child sex			
Girl	Reference	Reference	
Boy	-0.00 (-0.05, 0.05)	-0.00 (-0.02, 0.02)	0.903
Nutritional factors (Child)			
Minimum Dietary Diversity			
<4 food groups	Reference	Reference	
≥4 food groups	0.14 (0.08, 0.19)	0.06 (0.03, 0.09)	<0.001
Morbidity	-0.02 (-0.04, -0.00)	-0.02 (-0.04, -0.00)	0.089
Socioeconomic position categories			
Quintile-1 Poorest	Reference	Reference	
2nd	0.12 (0.04, 0.19)	0.04 (0.02, 0.07)	0.001
Middle	0.17 (0.09, 0.25)	0.06 (0.03, 0.09)	<0.001
4th	0.22 (0.15, 0.3)	0.08 (0.05, 0.11)	<0.001
Quintile-5 Richest	0.57 (0.49, 0.65)	0.22 (0.19, 0.25)	<0.001
Other covariates			
Maternal BMI	0.02 (0.01, 0.03)	0.06 (0.04, 0.08)	<0.001
Maternal height			
<145cm	Reference	Reference	
≥145cm	0.49 (0.43, 0.55)	0.15 (0.13, 0.17)	<0.001
Household size			
2–4 member	Reference	Reference	
5+ member	-0.07 (-0.1, -0.03)	-0.03 (-0.05, -0.01)	0.031

Child birth order			
1	Reference	Reference	
2	0.02 (-0.06, 0.09)	0.01 (-0.02, 0.04)	0.588
3	0.00 (-0.07, 0.07)	0.00 (-0.03, 0.02)	0.977
4+	-0.12 (-0.22, -0.03)	-0.04 (-0.08, -0.01)	0.005
Child WHZ	0.13 (0.1, 0.16)	0.12 (0.09, 0.14)	<0.001
Divisions (Administrative unit)			
Dhaka	Reference	Reference	
Rajshahi	0.02 (-0.05, 0.1)	0.01 (-0.02, 0.03)	0.619
Khulna	-0.01 (-0.09, 0.08)	0 (-0.02, 0.02)	0.891
Barisal	-0.06 (-0.15, 0.03)	-0.01 (-0.03, 0.01)	0.147
Sylhet	-0.31 (-0.42, -0.21)	-0.08 (-0.1, -0.05)	<0.001
Chattogram	-0.21 (-0.3, -0.12)	-0.08 (-0.11, -0.05)	<0.001
Rangpur	-0.05 (-0.12, 0.03)	-0.01 (-0.04, 0.01)	0.115
Seasons			
Monsoon	Reference	Reference	
Post Aus	-0.08 (-0.13, -0.03)	-0.03 (-0.05, -0.01)	0.007
Post Aman	-0.1 (-0.14, -0.05)	-0.04 (-0.06, -0.02)	0.001
Year data collected			
Year 2011	Reference	Reference	
Year-2012	0.04 (-0.03, 0.1)	0.02 (-0.01, 0.05)	0.207
Year-2013	0.09 (0.04, 0.14)	0.03 (0.01, 0.04)	0.001
Year-2014	0.09 (0.04, 0.15)	0.03 (0.01, 0.05)	0.001
R^2	0.1636		

┼The estimates are the regression coefficient estimates, where 5a reflects Unstandardised mean differences in HAZ and 5b reflects Standardised mean differences.

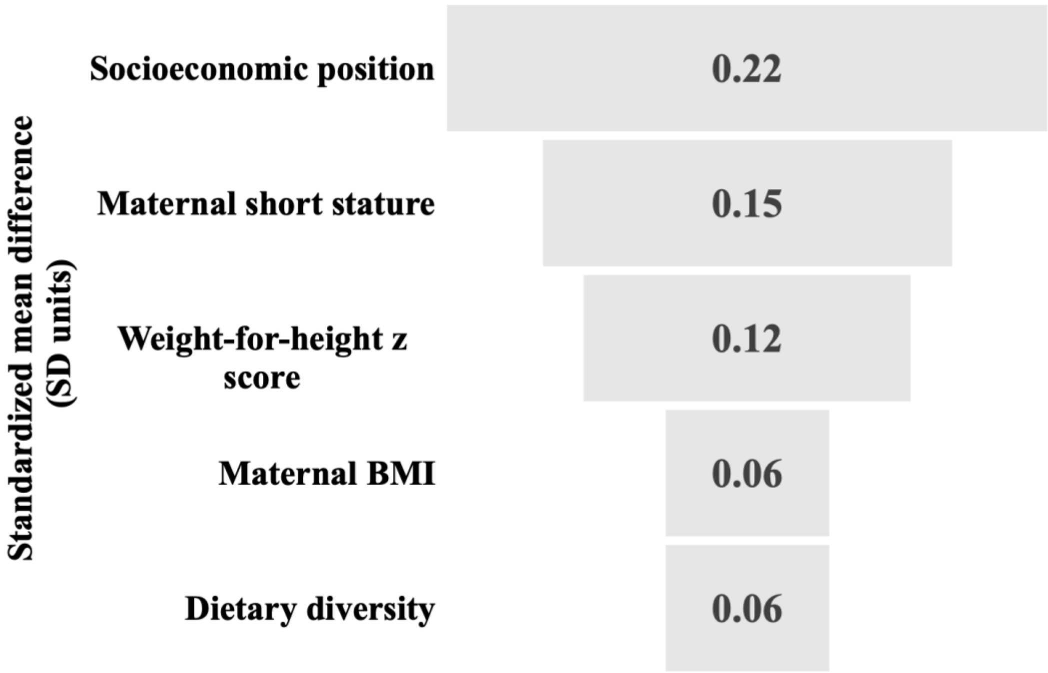

Figure 4.3 Top five ranked associated factors with HAZ among children 6-59 months in Bangladesh (FSNSP data).

Figure data did not consider directionality, but extent of standardised mean difference are presented as coefficient.

Discussion

Determining which factors contribute to improve linear growth among children is critical if policies aimed at reducing stunting are to succeed in the future. In this paper, I have presented a comprehensive analysis of factors associated with linear growth among children aged <5 years in Bangladesh to assess whether socioeconomic inequalities can help to explain higher variability in growth compared to more traditional views that predominantly focused on dietary intake (Arimond & Ruel, 2004). I found that the effect of SEP can contribute to the largest difference in growth among Bangladeshi children compared to the effect of NF or other independent variables included in the models. In terms of the strength of association with HAZ, the top five ranked associated factors in rank order were SEP, mother's short stature, wasting, mother's BMI and MDD.

Our approach differs from previous work in several ways. First, most of the existing literature has focused on discussing change in stunting prevalence within a country or across South Asia. They have used two different time points to examine changes in stunting trends to determine the factors driving these changes (Angdembe et al., 2019; Huda et al., 2017; Rabbani et al., 2016). These empirical studies on a selective set of risk factors for stunting trends are valuable for assessing the role of specific determinants, but do not allow examination of the relative importance of multiple factors on children's health and nutritional outcomes. In comparison, our analysis has allowed us to conduct a relative comparison of factors at the national level and could allow priorities to be set for valid intervention to reduce stunting in LMIC.

Additionally, instead of using multiple statistical models, I employed a single linear regression model that incorporated all relevant indicators (i.e., distal, intermediate, and proximal indicators using the UNICEF conceptual framework of malnutrition). This contrasts with earlier papers (e.g., Argaw et al. 2019) which utilised three separate models i.e., distal, intermediate, and proximal indicators to avoid 'over-adjustment' but did not consider maternal factors. Similarly, Danaei et al. (2016) identified risk factors for stunting using five major themes: i) maternal nutrition and infection, ii) teenage motherhood and short interbirth intervals, iii) foetal growth restriction and preterm birth, iv) child nutrition and infection, and v) environmental factors. These authors used five separate statistical models, but did not include SEP factors. Milman et al. (2005) ran nine multiple linear regression models to find the most important factors relating to stunting while Kim (2017) proposed two different models per child age group (6–8 months and 9–23 months) (Kim et al., 2017). Therefore, our approach was more pertinent to our research question.

Morbidity status in our study, however, did not show any significant effect on stunting status when all other variables were included in the model, although multi-country, pooled cohort studies have indicated that diarrhoea increased the risk of stunting (Checkley et al., 2008). A possible reason for the disparity between our findings and earlier ones could be attributed to the impressive achievement of Bangladesh in attaining the highest global coverage of oral rehydration therapy for diarrhoea (El Arifeen et al., 2013). This success might have contributed to a decrease in adverse effects on linear growth. Another contributing factor is the widespread immunization coverage in Bangladesh (89% of children are fully immunised and 91% received the measles vaccine at 9 months) (WHO, 2021). This has significantly reduced or partially eliminated the occurrence of preventable illnesses and their subsequent impact on growth. Svefors and colleagues (2019), who examined the relative comparison of factors associated with HAZ, provide additional support for the limited impact of child morbidity on linear growth that I have observed in our sample. Moreover, stunting reflects long-term deprivation, whereas acute illness is a short-term measure of health status and therefore, might have limited effects.

Low MDD was found to be a significant factor for lower HAZ, but its effect size was not as high as SEP. This finding (diet and HAZ) aligns with prior randomised controlled trials (Ara et al., 2022; Christian et al., 2015), a systematic review with 14 papers (Lassi et al., 2020), and a meta-analysis with 15 papers (Mamun et al., 2023) where the authors suggested that dietary intervention with or without MNP had a modest effect on HAZ. Our data indicates that more than 40% of children aged 6–59 months in rural Bangladesh are given diets that meet MDD. This result (MDD 40%) is high, however, compared to national estimates of 25–35% from Bangladesh and other Asian countries such as Afghanistan, India, Nepal and Pakistan (Aguayo & Menon, 2016; NIPORT/ICF, 2019). Dietary diversity is indeed important for overall nutritional status and micronutrient intake, but its direct impact on linear growth may not be as significant as the quantity of food consumed. Nguyen et al.'s (2017) intervention study found child dietary diversity was not significant contributors to HAZ changes, perhaps because dietary diversity was already very high (88%) in their study sample at baseline (Nguyen et al., 2017). However, another aspect to consider is the significant wealth and education based inequalities in MDD among Bangladeshi children aged 6–23 months as highlighted in the study by Kundu et. al (2022) (Kundu et al., 2022). These inequalities might play a crucial role in determining the overall impact of dietary diversity on linear growth outcomes in this population. Furthermore, in Model-5, child wasting and maternal nutritional status were found as important predictors of HAZ. The possible reasons might be the mother's nutritional status before and during pregnancy, as well as during breastfeeding, which could have an impact on the availability and quality of nutrients which the child receives (Victora et al., 2021).

Our results highlight maternal short stature as an important determinant of lower HAZ. The impact of maternal factors on child stunting aligns with previous work (Angdembe et al., 2019; Argaw et al., 2019; Black et al., 2013; da Silva et al., 2018; Huda et al., 2017; Kumar et al., 2021; Nguyen et al., 2017). Maternal stunting influences child's HAZ by affecting foetal growth (Martorell & Zongrone, 2012) reflecting the large body of work in the Developmental Origins of Health and Disease (DOHaD) (Gluckman et al., 2016). Genetic input also likely plays a role (Svefors et al., 2019; Ulijaszek, 2020), although this has been refuted by Bogin (2021) based on current knowledge about the complex nature of interactions between the genome, epigenome, physical environment, and socioeconomic factors (Bogin, 2021).

The influence of maternal early life nutritional status on foetal growth, together with the prevailing low status of women highlights the role of intergenerational transfer of growth deficits between mothers and their children, and intergenerational continuity in differences in childhood living conditions (Katoch, 2022; Khatun et al., 2019; Subramanian et al., 2011). Differences in adult height of mothers in South Asian countries and SGA infants between poorest and richest wealth quintiles (Keats et al., 2021) underscore the importance of socioeconomic inequalities. A mother with a low SEP might find it very difficult to raise her SEP and therefore there is a vicious cycle of poverty across the generations. It is not solely that higher or lower SEP itself directly impacts birth weight, instead, it is the attitudes, behaviours, living conditions, education, occupation, and social status associated with SEP that all play a role (Bogin, 2020).

Addressing the social gradient of childhood stunting is a complex and challenging task that extends beyond simply targeting the difference between poor and non-poor populations. Relying solely on a country's economic growth as the solution to societal challenges may not be sufficient. Economic models assume that there is an inherent mechanism to reduce both poverty and inequalities coincident with development, but this need not be true given current increases in global measures of social inequalities alongside strong investment in LMIC. In

Bangladesh, specifically, the country has been successful in poverty reduction in the past based on the cost of basic need (CBN) method, the poverty line decline from 35% in 2010 to 21% in 2022) (BBS, 2022). However, the Gini coefficient increased during the same period (0.499 in 2022 compared to 0.458 in 2010) (BBS, 2022). This shows that while one objective of economic growth namely, poverty reduction, has succeeded, the other (reducing inequalities) has not. Hence, to reduce social inequalities, the earlier literature has suggested that appropriate attention needs to be given to fostering strong political commitment on nutrition within a nation (Argaw et al., 2019; Keats et al., 2021).

National policies and priorities have a significant influence on health inequalities, and can often align with the priorities of donors in many cases. Policy research related to nutrition has had a strong global focus on technical interventions (such as food fortification or supplementation) with insufficient attention given to the political economy surrounding the implementation of these interventions (Biehl, 2016; Birn, 2014; Nisbett et al., 2022; Topp et al., 2021). For much of the time, global health has been characterised by a power dynamic (Topp et al., 2021) that has reflected the interests of the world's richest countries (Birn, 2014), where multilateral [i.e.,, United Nations, World Bank (WB), WHO], bilateral [i.e., United States Agency for International Development (USAID), Foreign, Commonwealth and Development Office (FCDO), Swedish International Development Cooperation Agency (SIDA)] or philanthropic [i.e., Bill and Melinda Gates Foundation (BMGF)] health organisations have designated how their contributions are to be spent (Birn, 2014). Their interests regarding nutrition primarily revolve around various areas, including but not limited to ending extreme poverty (a focus of FCDO), agriculture and nutrition programs (a focus of USAID), upstream research such as food fortification (a focus of BMGF), and data analysis and policy advice (a focus of WB). Understanding this power dynamic in global health research is an emerging issue to improve the depth and breadth of knowledge regarding the root causes of inequities in health (Nisbett et al., 2022). Therefore, a reassessment of resource allocations and shifting priorities may be necessary to address the social gradient of childhood stunting in Bangladesh more effectively rather than more target-oriented indicators.

However, in our study the variables were carefully chosen after an extensive literature review, the model was statistically rigorous and model assumptions were met (Supplementary file S1, and Figure S1 represents the Residuals graph). Additionally, I ensured that variables with multicollinearity were not included in the analysis (Supplementary file S2). Finally, instead of relying on one single indicator of SES, such as using income inequalities, I explored combinations of indicators, such as ownership of land and assets and educational qualifications while creating the SEP index. I also employed a rigorous statistical procedure pPCA, and checked reliability of the index. These methods created a better proxy of SES as a composite measure and offers greater reliability compared to traditional approaches.

It is hoped that findings from this research will help to facilitate communication with policy makers, will inform advocacy for nutrition, and will help to mobilise policy makers and developing partners to pay attention to reducing social inequalities that can result in stunting. This research therefore has the potential to impact global nutritional policies for successful health interventions at an applied level.

Strengths and limitations of the study

I utilised a large-scale, nationally representative surveillance dataset collected throughout the country, capturing data three times a year over a four-year period to account for seasonality. To create a composite socioeconomic position (SEP) index, I employed an advanced statistical technique that incorporated a range of indicators. The final regression model demonstrated statistical rigor, and all model assumptions were satisfied.

The study relied on cross-sectional data and so the analysis cannot provide evidence of a causal relationship between stunting and other determinants. Secondly, data on personal and household practices were based on mother's recall, which may have been subject to bias. MDD might not be the best option to measure quantitative aspects of a child's diet. Moreover, the existing literature suggests that mechanisms through which social inequalities affect growth operate through endocrine pathways including IGF-1 and growth hormone (Hermanussen & Wit, 2017), for which FSNSP does not have relevant data. These mechanisms deserve to be tested further.

Conclusion

Improving linear growth and reducing stunting is a complex process with various interacting factors. I have shown here that differences in dietary quality have much less effect on the linear growth of children than social hierarchies. Maternal short stature, child wasting, and maternal undernutrition are dominant factors that can further aggravate stunting risk. Focusing solely on the most disadvantaged of households will not reduce stunting inequalities sufficiently. To reduce the steepness of the social gradient in stunting, actions must be universal, but with a scale and intensity that is proportionate to the level of disadvantage. Our recommendation is to tackle stunting at the structural levels, both in research and practical implementation.

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S1. Supplementary file S1: Testing assumptions for the full final linear regression model

The four assumptions on which the multiple linear regression for the final full model was based have been checked and found to be met.

a. Linear relationship: There was a linear relationship between the independent variables and the dependent variable, i.e., HAZ

b. Independence: The residuals were found to be independent.

c. Homoscedasticity: Equal variance of errors is one of the key assumptions for linear regression, i.e., the constant variance of residuals across all of the predictive variables. The heteroscedasticity can be seen by Breusch-Pagan heteroscedasticity. The heteroscedasticity test result came as chi2(1)= 0.11 and p= 0.7450. It implies that there is a homeoscedasticity in the variance and that heteroscedasticity is not an issue and the regression model is acceptable.

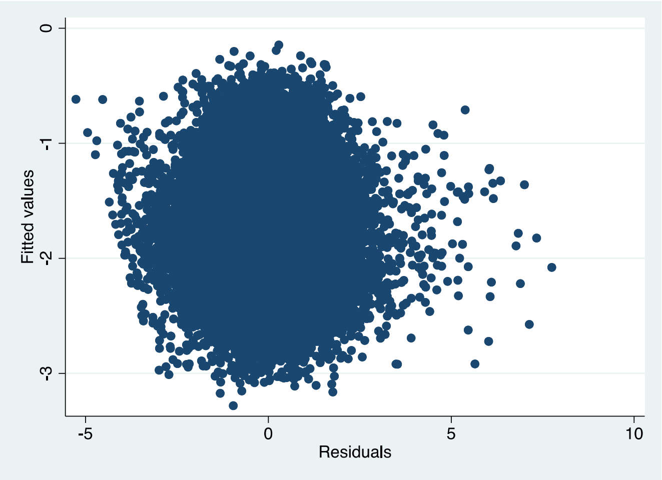

Figure S1. Residuals graph (FSNSP)

d. Normality: The residuals of the model were found normally distributed.

S2. Supplementary file S2: Collinearity Diagnostics test

The following variables were tested for multicollinearity by the Collinearity Diagnostics test expressed by the variance inflation factor (VIF). VIF measures whether a predictor has a strong linear relationship with other predictors. A VIF >10 is an indication of multicollinearity. For our model, each of the VIF for the predicted variables were <2.5 [VIF ≥ 2.5 indicates considerable collinearity (Johnston et al., 2018)], which indicates all of these variables contributed extra information on the model. An average VIF>1 is also an indication of an undesirable influence of multicollinearity on the model. In this case, it was 1.1 which is still within the range of acceptability.

Table S1. The variance inflation factor (VIF) of independent variables and other covariates.

Variables	**VIF**
Independent variables	
Socioeconomic position	1.34
MDD	1.11
Morbidity	1.03
Covariates	
Mother's BMI	1.15
WHZ	1.06
Mother's height	1.01
Region	1.02
Seasonality	1.00
Age group	1.08
Child sex	1.00
Birth order	1.18
Household size	1.25
Time	1.03
Mean VIF	1.10

5. CHAPTER 5

MANUSCRIPT #2 SUCHANA DATA

What better explains variabilities in linear growth among under-two children in an intervention context: the relative contribution of socioeconomic inequalities or nutritional factors?

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Abstract

Background: While "nutrition influences height" has been widely accepted, recent evidence of effectiveness of nutritional interventions on linear growth were inconclusive, whereas an individual's socioeconomic position (SEP) within hierarchical societies is considered an important determinant. In this context, this study aims to understand how nutritional factors and socioeconomic inequality rank in terms of importance in explaining variabilities in linear growth of under-two children participating to a nutrition intervention.

Methods: Cross sectional survey data from 13,062 mother-child (6-23 months) dyads, from an evaluation (baseline 2016; endline 2019) of a multisectoral, nutrition programme, *Suchana*, in Sylhet division (an area of high levels of malnutrition) in Bangladesh targeting the poor and poorest households were analysed. A composite SEP scale was constructed from relevant indicators. Following UNICEF conceptual framework, NF included a child's minimum dietary diversity (MDD) and morbidity status. Hierarchical multiple linear regression was performed for the outcome HAZ with NF and SEP as main variables of interests that explain variabilities in HAZ, controlled for child, maternal and household level covariates with established associations. Difference in coefficients for HAZ between "poor" (SEP values median and above) vs. "poorest" (below median) indicated SEP inequalities. Standardised beta coefficients were used as a measure of relative effects of SEP inequalities and NF.

Results: Statistically significant association existed for HAZ and SEP inequalities (0.12 SD units difference between poorest vs. poor, 95% CI: 0.09, 0.15) , but not for MDD (-0.01 units, 95% CI: -0.03, 0.01) and morbidity (0.01 units, 5% CI: -0.01, 0.03)]. Furthermore, when added to base (demographic) + SEP model, NF did not explain any further variability in HAZ.

Conclusions: Comprehensive strategies for sustainable improvement in child linear growth, encompassing policies that not only reduce poverty but also inequalities; and provides tailored and balanced integration of nutrition specific and nutrition sensitive interventions are required.

Introduction

Globally, around 149 million children aged less than five years are estimated to be stunted in 2020, or have impairment of linear growth [<-2 height-for-age Z-score (HAZ)] (GNR, 2021). While child malnutrition is a significant public health concern in developing countries, most of the stunted children in the world live in sub-Saharan Africa and South Asia. Stunting leads to detrimental outcomes in the next generation, where new-borns from stunted mothers are more likely to be small-for-gestational-age (SGA) with an increased risk of later growth faltering, morbidity and mortality (Argaw et al., 2019; Leroy & Frongillo, 2019). Maternal stunting is also linked to infants born with growth impairment and resulting in an inter-generational cycle of malnutrition, with limiting life's potentials (Katoch, 2022; Khatun et al., 2019; Subramanian et al., 2011).

A large number of observational studies have identified the complex determinants of stunting. Common determinants at the individual level are: child being >12 months old (Torlesse et al., 2016), a boy, born with foetal growth retardation or low birth weight (Aguayo et al., 2016; Danaei et al., 2016), with high morbidity, and not getting adequate dietary diversity and nutrient-rich foods (Dewey, 2016; Rah et al., 2010). Maternal and household related determinants include: maternal low stature and undernutrition (Victora et al., 2021), a poor maternal diet before and during pregnancy, low levels of education (Huda et al., 2017; Semba et al., 2008), detrimental environmental factors including poor sanitation (Danaei et al., 2016), enteropathy (Lin et al., 2013), poverty and inequalities (Black et al., 2013; Huda et al., 2017; Krishna et al., 2018; Kumar et al., 2021; Nguyen et al., 2017; Rabbani et al., 2016; Torlesse et al., 2016).

Given the link between stunting and several connected adverse outcomes, in 2012 the World Health Assembly (WHA) set its first global nutrition target "40% reduction in stunting by 2025" (De Onis et al., 2013). While the existing literature outlined intervention strategies for low and middle income countries (LMIC) using several conceptual frameworks including the Unicef framework (UNICEF, 1991), WHO framework (Stewart et al., 2013), nutrition action framework (Black et al., 2013; Keats et al., 2021), a bioecological frameowork (Veiga et al., 2022), and a nutrition equity framework (Nisbett et al., 2022), all of these emphasised the importance of integrating individual, household, environmental, and cultural aspects in designing programme interventions (Chirande et al., 2015; Danaei et al., 2016; Dewey et al., 2017; Huda et al., 2017; Krishna et al., 2018; Kumar et al., 2021; Torlesse et al., 2016).

A range of interventions, such as micronutrient and food supplements, deworming, maternal knowledge, and water, sanitation and hygiene (WASH) have been provided to prevent stunting (Park et al., 2020). Although food-based interventions have been most often applied in LMIC, the results from such interventions have been mixed. For example, in a study in Ecuador, children were supplemented with one egg daily for six months during the early complementary feeding period, which resulted in a substantial increase in HAZ of 0.63 units (95% CI: 0.38, 0.88), while the prevalence of stunting decreased by 47% (Iannotti et al., 2017). Similarly, in a randomised controlled trial in rural Bangladesh, Ara et al. (2022) provided one egg and milk along with multiple micronutrient powder (MNP) to young children (< 2years) for 12 months, and found that length for age (LAZ) score increased by 0.37 units (95% CI: 0.24, 0.51, $p < 0.001$) (Ara et al., 2022). However, Stewart (2019), in a rural Malawian context, found that the provision of one egg per day for six months to young children had no effect on linear growth (Stewart et al., 2019). The Alive and Thrive (A&T) programme, implemented in Bangladesh, Vietnam, and Ethiopia between 2010 and 2014, aimed to reduce stunting in children under two years of age (Menon et al., 2013). The programme used different strategies, such as improved counselling by health workers during home visits, community mobilization, mass media campaigns involving parents and religious leaders, and policy advocacy. These efforts led to notable improvements in breastfeeding and infant and young child feeding practices. The project did not achieve any positive changes in stunting in Bangladesh (Menon et al., 2016).

Health-related issues are more prevalent in socioeconomically deprived areas, and they tend to be more pronounced in societies with higher levels of inequality (Wilkinson & Pickett, 2010). The steeper the social gradient within society, the more strongly it will exert effects of inequality on health or nutrition. Previous studies, primarily conducted in developed countries, have predominantly examined life expectancy, child wellbeing, and obesity in relation to social gradients (Wilkinson & Pickett, 2010). The impact of socioeconomic inequalities on stunting has been reported by several researchers (Angdembe et al., 2019; da Silva et al., 2018; Huda et al., 2017; Krishna et al., 2018; Rabbani et al., 2016) who argue that inequality is one of the important factor for changes in stunting prevalence in LMIC. Moreover, improvements in relative social status and its effect on linear growth have garnered increasing attention in anthropology and public health.

In order to determine the specific focus for donors and implementing partners to prioritise and target improvement in population health, it is crucial to assess how social inequalities fare over other factors in relation to the linear growth of children. Although the relative importance of risk factors associated with HAZ has been measured in multi-country contexts including Bangladesh (Kim et al., 2017; Svefors et al., 2019), the ranking of these factors may vary substantially in a programme context (i.e., where a nutrition programme is in place). This study, therefore, aims to assess the relative contribution of socioeconomic inequalities and nutritional factors (NF) on child linear growth in rural Bangladesh among children aged <2 years using data from an evaluation programme called "Suchana–ending the cycle of chronic malnutrition". This is an integrated nutrition and food security programme that has aimed to reduce the incidence of stunting among children <2 years by breaking the intergenerational cycle of malnutrition in Sylhet and Moulvibazar Districts (2 out of 64 districts in Bangladesh) from the Sylhet administrative Division of Bangladesh (Choudhury et al., 2020). This study hypothesised that socioeconomic inequalities will rank higher than nutritional factors in terms of explaining variability in HAZ among under-two children in Bangladesh, even in an intervention context.

Methods

This study utilised data from two cross-sectional surveys from Suchana, the first from baseline survey in 2016 and the second from end-line in 2019 after three years of implementation of Suchana. The data were collected from the Sylhet division of Bangladesh. The programme was specifically designed to reduce stunting through a diverse array of implementations, from improving maternal nutritional knowledge to improving nutrition governance that translates political commitments into practice, with support from the Foreign, Commonwealth and Development Office (FCDO) and the European Union (EU) (Choudhury et al., 2020).

The beneficiaries of the Suchana programme were the bottom two (poorest and poor) most vulnerable households which were identified by a combination of a participatory rural approach (e.g., a wealth-ranking method), focus group discussions and individual interviews with local people from different socioeconomic backgrounds. Both the intervention and control households received regular ongoing national level National Nutrition Services (NNS) implemented in the area. Apart from NNS, two types of packages were given to Suchana beneficiaries: 1) ‘a non-asset-based intervention’ for the poor households comprising training for skills development, home gardening, fish cultivation, poultry rearing, health/nutrition/social/gender/legal awareness and links to government/non-government facilities; and 2) ‘an asset-based intervention’ for the very poor households consisting of asset transfers (goats, fish or poultry) along with training and links to government services (asset-based beneficiaries also received a maximum of 8000 Bangladeshi Taka (BDT) (1 US dollar=108.05 BDT; dated 4 July 2023).

For evaluation purposes, Suchana beneficiary households with a child aged <2 years were selected using a systematic sampling method from a ‘Suchana beneficiary list’. Data collection for evaluation purpose followed cross-sectional sample rather than a longitudinal cohort (i.e., under-two children were assessed at both periods). Data were collected from the mother of the child, who was also a beneficiary of Suchana, comprising basic sociodemographic status, household food security status, infant and young child feeding (IYCF) practices, health and health-seeking behaviours, water and sanitation, vulnerability and social protection, empowerment of women with decision- making power, nutritional knowledge and practices, and awareness of quality agricultural products. Anthropometric measurements [height, weight, mid-upper arm circumference (MUAC)] were collected from the children and mothers. SECA 874 weight scales with precision of 0.1kg were used to measure maternal and child weight. Maternal height was measured using locally made wooden height scales. SECA *Infantometer* (Model SECA 416) with a precision of 0.1 cm were used to measure the children’s length. For length/height measurement, third measurement was taken if the first two consecutive measurements differed by > 2 cm. The averages of the anthropometry measurements were used during the analyses.

This study focuses specially on children aged 6-23 months old and data for infants <6 months old were therefore excluded since (following WHO/UNICEF guidelines) these younger children are likely to be exclusively breastfeed by their mothers and were out of scope for dietary intake data collection (WHO/UNICEF, 2021). After excluding children aged <6 months, a total of 13,062 mother-child pairs (baseline 4377, endline 8685), whose records were complete for the required individual and household-level variables, were included in the analyses (Figure 5.1).

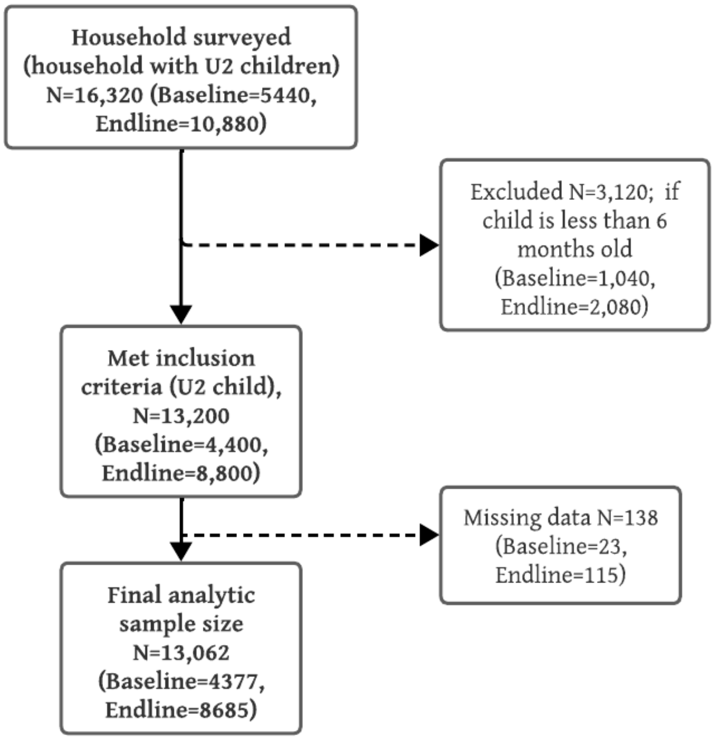

Figure 5.1 Flow chart for final analytic sample size, Suchana data

Variables

The outcome variable in this study was the length-for-age Z scores (LAZ), a measure of linear growth in children. LAZ scores were calculated following WHO criteria (WHO, 2006), and children were categorised as stunted if their LAZ score was <-2 standard deviations (SD) from the median of WHO child growth standards.

Hierarchical multiple linear regression was used for model building, where a base model included demographic variables, and gradually SEP variables, NF variables and combinations were used to assess if NF factors explain any additional variabilities in the outcome LAZ. The final full model included base model (demographic indicators, SEP groups, NF indicators, and other confounders). To explore the relationship between NF and the linear growth of children, two variables were considered: minimum dietary diversity (MDD) and "morbidity" (UNICEF, 1991) (Table 5.1). Following WHO (2010) guidelines, MDD was measured using dietary data collected on consumption from 7 food groups (as listed in Table 5.1) for the last 24 hours among children aged 6-23 months (WHO, 2010).

Table 5.1 List of variables included under nutritional factors

Variables (Nutritional factors)		Description	Type
Minimum Dietary Diversity (MDD)	i. grains, roots, and tubers ii. legumes and nuts iii. dairy products iv. meat/fish v. eggs vi. vitamin A-rich fruits and vegetables vi. other fruits and vegetables	0=Not achieved (<4 food groups) 1=MDD achieved (≥4 food groups)	Binary
Morbidity	i. fever ii. runny nose iii. difficulty breathing iv. diarrhoea	0–4	Continuous

Diarrhoea and other morbidities are known to be detrimental to child growth (Checkley et al., 2008; Fink et al., 2011); therefore morbidity histories were collected during the survey for the two weeks preceding the data collection day comprising: fever, runny nose, diarrhoea, and breathing difficulties. Each instance of morbidity received a score of 1, and the total morbidity score was obtained by summing these individual scores. A score of 0 represented no morbidity, while the highest recorded morbidity score was 4.

To measure socioeconomic inequality, in terms of difference in outcome by socioeconomic position (SEP), available indicators related to social status (prestige) such as educational level, a commonly used indicator, and household material assets were chosen to create a statistically weighted composite index (Table 5.2).

Table 5.2 Variables utilised for constructing socioeconomic index, applying polychoric principal component analysis

Variables	Types	Categories
Household head's education	Ordinal	0=No education
		1=Primary
		2=Secondary and above
Maternal education	Ordinal	0=No education
		1=primary
		2=Secondary and above
Have television	Binary	0=No; 1=Yes
Fan	Binary	0=No; 1=Yes
Showcase	Binary	0=No; 1=Yes
Chair	Binary	0=No; 1=Yes
Table	Binary	0=No; 1=Yes
Sofa	Binary	0=No; 1=Yes
Ceremonial saree	Binary	0=No; 1=Yes
Floor material, *pacca*	Binary	0=No; 1=Yes
Toilet	Ordinal	0=Open defecation
		1=Ring without slab
		2=Ring with slab
		3=Sanitary latrine with septic tank

Applying polychoric principal component analysis (pPCA), the SEP index (Kolenikov & Angeles, 2009) was created combining the indexed variables. The SEP index score was then grouped into two: those with scores below the median were considered 'poorest' and those with above the median were considered as 'poor'. The comparison in outcome between the poorest and poor SEP groups allowed assessment of the relative disparities in socioeconomic status.

Demographic factors known to influence linear growth were included in the base model and was later incorporated into the full final model comparing effects of NF and SEP (Table 5.3). Given the typical variations in nutritional status based on age and sex, these two variables, with age grouped into 6-11 and 12-23 months categories were included (Baig-Ansari et al., 2006; Reinbold, 2011; Shrimpton et al., 2001; Victora et al., 2010).

Table 5.3 Variables with child demographic characteristics, included in the base model

Variables (demographic)	Description	Type
Age	0=6–11 months 1=12–23 months	Ordinal
Gender	0=Girl 1=Boy	Binary

Apart from the main variables of interest (NF, SEP groups), other variables that were seen to have established association with HAZ were included in regression as listed in Table 5.4. For instance, childhood wasting status [low weight-for-height Z-score (WHZ) <-2] was included in the analysis, due to its association with HAZ (Victora et al., 2021). Maternal short stature and maternal low nutritional status (in terms of BMI) are strongly associated with lower HAZ (Black et al., 2013; Goudet et al., 2017; Victora et al., 2021), therefore, maternal short stature and BMI were also included in the analyses. Household size (number of people eating from the same cooking pot) were grouped as a categorical variable: 2-4=0, and ≥5=1, and similarly another categorical variable for child birth order (1st, 2nd, 3rd and 4^{th} +) was also included in regression model.

The Food and Agricultural Organization (FAO) of the United Nations and the Food and Nutrition Technical Assistance III Project have developed a comparatively new indicator of dietary diversity to assess micronutrient adequacy in women of reproductive age, known as the Minimum Dietary Diversity for Women (MDD-W) (FAO, 2021). MDD-W is a dichotomous indicator of whether women aged 15–49 years have consumed at least five out of 10 defined food groups during the previous 24 hours. Data were collected at two-time points, baseline and endline, and therefore 0 was coded for the former and 1 for the latter. Data were also collected from the intervention and control areas, with 1 for an ‘intervention’ area and 0 for a ‘control’ area (Table 5.4).

Table 5.4 List of confounders

Variables (Other confounders)	**Description**	**Type**
Time	0=2016 (Baseline) 1=2019 (Endline)	Binary
Intervention	0=control 1=Intervention	Binary
Wasting [weight-for-height Z-score (WHZ) <-2]	0=not wasted 1=wasted	Binary
Hygiene score based on cleanliness of i. the hands and fingers of the mother ii. the hands and fingers of the child	0–2	Continuous
Minimum dietary diversity for woman (MDD-W) i. All starchy staple foods ii. Beans and peas iii. Nuts and seeds iv. Dairy and milk products v. Animal source foods (meat, chicken) vi. Eggs vii. Other vitamin A-rich vegetables and fruits viii. Vitamin A-rich dark green leafy vegetables ix. Other vegetables x. Other fruits	0=No (<5 food groups) 1=Yes (≥5 food groups)	Binary
Maternal short stature	0= ≥145cm 1= <145 cm	Binary
Maternal BMI	Continuous	Continuous
Nutritional knowledge i. early initiation of breastfeeding ii. exclusive breastfeeding iii. breastfeeding iv. minimum meal frequency v. use of oral rehydration solution vi. use of zinc tablet during diarrhoea vii. use of iron folic acid tablets during pregnancy	0–7	Continuous

Mother received ≥4 ANC services from a skilled provider	0=No (<4 ANC) 1=Yes (≥ 4 ANC)	Binary
Mother received PNC services in her last child birth	0=No 1=Yes	Binary
Mother can take decision by herself or with her husband on: i. food purchases ii. major household purchases, iii. food preparation iv. children's healthcare v. her own healthcare vi. visiting her parental family and relatives.	0–6	Continuous

A mother's nutritional knowledge was assessed by asking her if she knew about seven nutrition relevant knowledge (Table 5.4). All outcomes were treated as binary variables, indicating (yes=1) if the woman had this knowledge and (no=0) if not. Thus, the total knowledge score ranged between 0-7 where 0 meant no knowledge, and 7 was the best knowledge. The spot-check observation method has been used widely for assessing hygiene practices (Nguyen et al., 2017). For this research, hygiene was assessed by using spot-check observations on two items: i.e., cleanliness of the hands and fingers of the mother and her child. Each item was given a score of 1 when it was found clean, or 0 when it was dirty, and the sum was used as the hygiene score which ranged between 0-2.

Apart from maternal nutritional factors, uptake of antenatal care (ANC) and postnatal care (PNC) were also included in the analyse (Table 5.4). A mother's decision-making power was assessed by using questions related to health and household matters, with six variables presented in Table 5.4. Each variable had four categorical options, indicating the extent of decision-making involvement: (a) mainly the mother, (b) the mother and husband jointly, (c) mainly the husband, and (d) others. Based on the Bangladesh Demographic Health Survey guidelines (NIPORT/ICF, 2019), all outcomes were treated as binary variables, indicating (yes=1) if the woman had the ability to take decisions herself (or jointly with her husband) and (no=0) if only the husband or other family members made the decision. Finally, a composite variable that encompassed all six dimensions of decision-making was calculated and thus the total decision-making score ranged between 0-6, where 0 meant no power for decision making, and 6 was the maximum number possible.

Adjustments were made for the complex sampling method when estimating summary statistics and inferential statistics for variables at the population level. All analyses were undertaken where *unions* were considered as 'sampling units'/'clustering' and the Stata "svy" command was used to account for clustering.

An overview of the population was obtained using descriptive statistics. For all comparisons, differences were estimated using chi-square tests for categorical variables and ANOVA and t-tests for quantitative variables. Linear regressions were used to calculate the relationships between SEP, NF and stunting (HAZ) where, the beta coefficient indicated the association between HAZ and explanatory variables, described using their original units. In contrast, the standardised beta coefficient indicated the same associations expressed using standard deviations. All analyses were performed using Stata 16 and the significance level was set at $p<0.05$. The R^2 value was used to determine the proportion of variance in HAZ that could be explained by SEP and NF.

As part of the hierarchical model building approach, five sequential models were constructed for analyses. Model-1 considered base model, included child age and sex as predictors for HAZ, while Model-2 included base model plus NF variables, and Model-3 included SEP groups added to the base model. Thereafter, Model-4 included both NF and SEP as predictors together with the base model. Finally, Model-5 included LAZ (used instead of HAZ as length was measured for under-two children) as the dependent variable with NF and SEP as the main variables of interests along with additional covariates (data collection time, intervention, wasting, birth order, mother's BMI, mother's stature, mother's nutritional knowledge, mother's dietary diversity, mother's decision-making power, mother received at least 4 ANC, mother received PNC). To assess the intervention effects while controlling for the baseline difference between groups, an interaction term (time*intervention) was included in the final model. This interaction term allowed investigating whether the impact of the intervention varied between baseline and endline. Similarly, another interaction term for SEP and the intervention was included to assess if intervention effect varied by SEP group. Additionally, to investigate whether the effect of SEP on the HAZ outcome differed between the baseline and endline periods additional interaction term for time and SEP was included in the same regression model. Results from the final model (Model-5) (beta coefficients, and standardised beta coefficients) were then used to assess the relative contribution of NF and SEP inequalities on HAZ.

Ethics

The Suchana evaluation project was led by the icddr,b, Dhaka, Bangladesh which owns the data sets. Data was given from icddr,b institutional review board. Written informed consent was obtained at all levels of access during the primary questionnaire data collection by research assistants. Ethical clearance for conducting secondary analyses of the dataset was obtained from the Department of Anthropology Ethics Committee at Durham University, UK (Reference number: ANTH-2021-07-30T13:26:50-czfz39).

Results

Baseline household characteristics and maternal and child characteristics of the respondents by control and intervention areas are summarised in Table 5.5 and Table 5.6 respectively. Data were available for a total of 2,190 households in the control and 2,187 households in the intervention areas at baseline. Comparison of sociodemographic characteristics (Table 5.5) found no significant difference across the two groups, except that control group had higher percentage of larger (>5 members) family size suggesting that randomization at the union level was successful in creating comparable groups. Similar to the demographic variables, comparison of child level characteristics found no significant difference across the two groups, except for sex of the children (Table 5.6).

Table 5.5 Baseline sociodemographic characteristics of control and intervention households with children aged under 2 years in Suchana study areas

Characteristics	Control % (n)	Intervention % (n)	Total % (n)	*p* value
Household head's education				
No education	48.2 (1055)	49.3 (1077)	48.7 (2132)	0.828
Primary	38.9 (852)	37.8 (827)	38.4 (1679)	
Secondary and above	12.9 (283)	12.9 (283)	12.9 (566)	
Mother's educational status				
No education	23.8 (522)	23.0 (502)	23.4 (1024)	0.774
Primary	47.1 (1033)	49.3 (1079)	48.2 (2112)	
Secondary and above	29.1 (635)	27.7 (606)	28.4 (1241)	
Household size				
2-4 members	22.1 (485)	25.7 (562)	23.9 (1047)	0.022
≥5 members	77.9 (1705)	74.3 (1625)	76.1 (3330)	
Household floors				
Mud/soil/sand	80.6 (1765)	84.4 (1846)	82.5 (3611)	0.076
Cement	19.4 (425)	15.6 (341)	17.5 (766)	
Toilet facilities				
Bush/open	18.1 (396)	20.7 (452)	19.4 (848)	0.428
Pit/slab	71.6 (1569)	71.4 (1562)	71.5 (3131)	
Safe sanitary	10.3 (225)	7.9 (173)	9.1 (398)	
N	2190	2187	4377	

All values are percent (n)

Table 5.6 Child and maternal characteristics for the control and intervention households in Suchana areas in rural Bangladesh at baseline (year 2016)

Characteristics		Control	Intervention	Total	*p* value
Child characteristics					
Age, % (n)					
	6-11 months	27.3 (598)	27.2 (595)	27.2 (1193)	0.933
	12-23 months	72.7 (1592)	72.8 (1592)	72.8 (3184)	
Sex, % (n)					
	girls	50.7 (1111)	47.2 (1032)	49.0 (2143)	0.016
	boys	49.3 (1079)	52.8 (1155)	51.0 (2234)	
Wasting (WHZs <-2SD) , % (n)					
	No	89.1 (1951)	88.9 (1944)	89.0 (3895)	0.859
	Yes	10.9 (239)	11.1 (243)	11.0 (482)	
Birth order, % (n)					
	1	21.8 (478)	20.2 (441)	21.0 (919)	0.541
	2	23.1 (506)	24.8 (543)	24.0 (1049)	
	3	18.1 (396)	19.0 (415)	18.5 (811)	
	4 or more	37.0 (810)	36.0 (788)	36.5 (1598)	
Minimum dietary diversity achieved (MDD), % (n)					
	No	85.7 (1876)	84.9 (1857)	85.3 (3733)	0.613
	Yes	14.3 (314)	15.1 (330)	14.7 (644)	
Morbidity, mean±SD		0.51±0.6	0.54±0.6	0.52±0.6	0.132
Maternal characteristics					
Short stature, % (n)					
	Normal (≥146cm)	78.5 (1719)	77.3 (1691)	77.9 (3410)	0.384
	Short (<146cm)	21.5 (471)	22.7 (496)	22.1 (967)	
Body mass index (BMI), mean±SD		19.6±3.2	19.5±3.0	19.6±3.1	0.127
Nutritional knowledge score, mean±SD		3.8±1.0	3.9±1.0	3.9±1.0	0.003
Hygiene score, mean±SD		1.2±0.8	1.2±0.8	1.2±0.8	0.130
Maternal dietary diversity, % (n)					
	No	72.3 (1584)	73.9 (1616)	73.1 (3200)	0.540
	Yes	27.7 (606)	26.1 (571)	26.9 (1177)	

Mother received at least 4 antenatal care services, % (n)				
No	87.1 (1908)	83.5 (1827)	85.3 (3735)	0.166
Yes	12.9 (282)	16.5 (360)	14.7 (642)	
Mother received postnatal care services in her last child birth, % (n)				
No	66.7 (1461)	67.4 (1473)	67 (2934)	0.843
Yes	33.3 (729)	32.6 (714)	33 (1443)	
Mother's decision making power, mean±SD	3.0± 2.1	3.1±2.1	3.0±2.1	0.072
Total	**2190**	**2187**	**4377**	

All values are percent (n), unless otherwise indicated

Table 5.7 presents baseline household characteristics by stunting status (intervention and control combined). As expected, statistically significantly higher percentage of children were stunted in households with lower socioeconomic status (Table 5.7).

Table 5.7 Baseline sociodemographic characteristics of households in Suchana areas with children aged under 2 years by stunting status (intervention and control combined)

Characteristics (%)	**Stunted % (n)**	**Not stunted % (n)**	***p* value**
Household head's education			
No education	50.5 (1076)	49.5 (1056)	<0.001
Primary	46.6 (782)	53.4 (897)	
Secondary and above	38.9 (220)	61.1 (346)	
Mother's educational status			
No education	55.2 (565)	44.8 (459)	<0.001
Primary	49 (1035)	51 (1077)	
Secondary and above	38.5 (478)	61.5 (763)	
Household size			
2-4 members	43.6 (456)	56.4 (591)	0.005
≥5 members	48.7 (1622)	51.3 (1708)	
Household floor			
Bamboo/leaves	48.6 (1755)	51.4 (1856)	0.003
Cemented	42.2 (323)	57.8 (443)	
Toilet facilities			
Open	53.5 (454)	46.5 (394)	<0.001
Pit/slab	47.1 (1475)	52.9 (1656)	
Safe sanitary	37.4 (149)	62.6 (249)	
SEP group			
Poorest	68.8 (1429)	56.4 (1297)	<0.001
Poor	31.2 (649)	43.6 (1002)	
N	2078	2299	

Table 5.8 represents maternal and child characteristics of the respondents, both by stunting status (intervention and control combined). All variables were significantly different by stunting status but were not significantly different for dietary diversity, mother's nutritional knowledge, decision-making power and mother's dietary diversity.

Table 5.8 Child and maternal baseline characteristics for the studied population in Suchana area by stunting status

Characteristics		Stunted	Not stunted	p value
Child characteristics				
Age, % (n)				
	6-11 months	34.1 (407)	65.9 (786)	<0.001
	12-23 months	52.5 (1671)	47.5 (1513)	
Gender of the child, % (n)				
	Girls	44.6 (955)	55.4 (1188)	<0.001
	Boys	50.3 (1123)	49.7 (1111)	
Wasting, % (n)				
	Not wasted	45.5 (1773)	54.5 (2122)	<0.001
	Wasted (WHZ <-2SD)	63.3 (305)	36.7 (177)	
Birth order, % (n)				
	1	42.1 (387)	57.9 (532)	<0.001
	2	44.4 (466)	55.6 (583)	
	3	46.0 (373)	54.0 (438)	
	4 or more	53.3 (852)	46.7 (746)	
Child Minimum Dietary Diversity (MDD), % (n)				
	No	47.4 (1768)	52.6 (1965)	0.666
	Yes	48.1 (310)	51.9 (334)	
Morbidity reported, mean±SD		0.51 ± 0.6	0.54 ±0.6	0.156
Maternal characteristics				
Short stature, % (n)				
	Normal (≥146cm)	43.3 (1569)	56.7 (2058)	<0.001
	Short stature (<146cm)	67.9 (509)	32.1 (241)	
Maternal BMI, mean±SD		19.3±3.0	19.8±3.2	<0.001
Maternal nutritional knowledge, mean±SD		3.9±1.0	3.9±1.0	0.703
Hygiene score, mean±SD		1.1±0.9	1.3±0.8	<0.001
Maternal dietary diversity, % (n)				
	No	48.2 (1541)	51.8 (1659)	0.141
	Yes	45.6 (537)	54.4 (640)	

Mother received at least 4 antenatal care services, % (n)				
	No	48.7 (1820)	51.3 (1915)	<0.001
	Yes	40.2 (258)	59.8 (384)	
Mother received postnatal care services in her last child birth, % (n)				
	No	50.0 (1468)	50.0 (1466)	<0.001
	Yes	42.3 (610)	57.7 (833)	
Mother's decision making power, mean±SD		3.0±2.1	3.0±2.1	0.691
N		2078	2299	

All values are percentage (n), unless otherwise indicated

Table 5.9 shows the mean HAZ, the prevalence of MDD and morbidity in the control and intervention areas and at two time points by the two SEP categories. There is no significant change in mean HAZ over the three years of the Suchana Project or between the SEP categories. At baseline, 20% of poor households had children who achieved MDD, whereas it was only 11% in the poorest households. The prevalence of MDD, however, improved from 20 to 34% in the poor households by endline, and 11 to 29% among the poorest households. Children from the poor households reported higher morbidity compared to the poorest households.

Table 5.9 Mean HAZ and prevalence of MDD and morbidity for the studied population in Suchana area at baseline and endline by intervention area and SEP

	Baseline			Endline		
	Poorest	Poor	Total	Poorest	Poor	Total
HAZ, mean (CI: low, high)						
Control	-2.1 (-2.2,-2.0)	-1.7 (-1.8,-1.6)	-1.9 (-2.0,-1.9)	-2.0 (-2.1,-1.9)	-1.8 (-1.9,-1.7)	-1.9 (-2.0,-1.8)
Intervention	-2.0 (-2.1,-2.0)	-1.7 (-1.8,-1.6)	-1.9 (-2.0,-1.8)	-2.0 (-2.1,-2.0)	-1.8 (-1.8,-1.7)	-1.9 (-1.9,-1.8)
Total	-2.1 (-2.1,-2.0)	-1.7 (-1.8,-1.6)	-1.9 (-2.0,-1.9)	-2.0 (-2.1,-2.0)	-1.8 (-1.8,-1.7)	-1.9 (-1.9,-1.8)
MDD achieved, % (CI: low, high)						
Control	11.0 (8.7,13.3)	19.5 (17.0, 22.0)	14.3 (12.3, 16.4)	17.1 (14.2,19.9)	23.1 (20.7, 25.5)	20.4 (18.2, 22.6)
Intervention	11.8 (9.9,13.8)	20.8 (17.5, 24.2)	15.1 (13.0, 17.2)	40.1 (36.3, 43.9)	45.2 (41.9, 48.4)	42.9 (39.8, 45.9)
Total	11.4 (9.9,13.0)	20.1 (18.0, 22.2)	14.7 (13.2, 16.2)	28.6 (24.3, 33.0)	33.9 (30.5, 37.2)	31.5 (28.1, 34.9)
Morbidity reported, % (CI: low, high)						
Control	47.1 (44.1, 50.2)	47.3 (43.9, 50.7)	47.2 (44.7, 49.8)	41.0 (37.9, 44.2)	44.7 (42.0, 47.4)	43.1 (40.6, 45.6)
Intervention	46.4 (42.9, 50.0)	52.3 (48.4, 56.3)	48.6 (45.8, 51.3)	41.1 (39.0, 43.3)	46.7 (43.3, 50.2)	44.2 (41.4, 46.9)
Total	46.8 (44.4, 49.1)	49.7 (47.2, 52.3)	47.9 (46.0, 49.8)	41.1 (39.2, 43.0)	45.7 (43.5, 47.9)	43.6 (41.8, 45.5)

All values are percentage (n), unless otherwise indicated; CI= confidence interval; Table 5.9 includes both baseline and endline data, with a total sample size of N=13062.

Table 5.10 presents the first four regression models. Here, child age and sex were included in all four models regardless of their *p*-value in bi-variate analysis. In Model-1 (base model), the demographic variables accounted for ~4% of the variation in HAZ, while Model-2 including NF to base model, did not change the R^2 value, i.e., NF did not explain any further variabilities in LAZ over that was explained by demographic variables in the base model. In Model-3, the demographic variables and SEP groups together accounted for 6% of the variation, indicating a gain of 2% additional variabilities explained by the SEP groups, over the explainability of base model. Overall, while NF did not make any additional contribution over base model, the addition of NF to SEP in Model-4 also did not improve the explainability (R^2 value) of variabilities in HAZ.

Table 5.10 Models examining the association of HAZ with nutritional factors and SEP among children aged <2 years in Suchana beneficiaries, 2016

variables		**Model-1** Base (CI: low, high)*	**Model-2** Base+Nutrition (CI: low, high)	**Model-3** Base+SEP (CI: low, high)	**Model-4** Base+Nutrition+SEP (CI: low, high)
Child age group					
	6-11mo	Reference	Reference	Reference	Reference
	12-23mo	-0.48 (-0.52, 0.43)	-0.48 (-0.53, 0.43)	-0.47 (-0.52, 0.42)	-0.47 (-0.52, -0.42)
Child sex					
	Girl	Reference	Reference	Reference	Reference
	Boy	-0.12 (-0.16, -0.08)	-0.12 (-0.16, -0.08)	-0.12 (-0.16, -0.08)	-0.12 (-0.16, -0.08)
Time					
	Baseline	Reference	Reference	Reference	Reference
	Endline	0.03 (-0.02, 0.09)	0.03 (-0.02, 0.09)	-0.01 (-0.07, 0.04)	-0.01 (-0.07, 0.04)
MDD⁺					
	<4 food groups	-	Reference	-	Reference
	≥4 food groups	-	0.03 (-0.01, 0.08)	-	0.00 (-0.03, 0.05)
Morbidity		-	0.03 (0.00, 0.07)	-	0.02 (-0.00, 0.06)
Socioeconomic position					
	Poorest	-	-	Reference	Reference
	Poor	-	-	0.28 (0.24, 0.33)	0.28 (0.24, 0.32)
	R^2	0.0397	0.0402	0.0556	0.0558

*CI confidence interval; ⁺MDD=minimum dietary diversity; Table 5.10 includes both baseline and endline data, with a total sample size of N=13062.

Results from Model-5 (Table 5.11) included demographic, NF, SEP, and additional covariates. The difference in mean HAZ was 0.12 units (95% CI: 0.09,0.15) for children in poor households compared to children in the poorest, whereas the difference in HAZ with MDD was only -0.01 units (95% CI: -0.03, 0.01), and morbidity [0.01 units (95% CI: -0.01, 0.03)]. Model-5 also showed that maternal short stature (coefficient: -0.22, CI -0.24, -0.21) and a child's wasting status (coefficient: -0.10, CI -0.12,-0.08) were significantly associated with the HAZ (Figure 5.1). There was no significant interaction between time*intervention (programme exposure) and SEP* intervention, while the interaction of SEP*time yielded a significant negative result.

Table 5.11 Multiple linear regression examining the association of HAZ with nutritional factors and SEP categories among children <2 years from Suchana intervention beneficiaries in rural Bangladesh, 2016-2019

		Model-5		
		5a	5b	
Indicators		+Unstandardised coefficient (confidence intervals: low, high)	+Standardised coefficient (confidence intervals: low, high)	*P* value
Child age group				
	6-11mo	Reference	Reference	
	12-23mo	-0.45 (-0.5,-0.41)	-0.18 (-0.2,-0.16)	<0.001
Child sex				
	Girl	Reference	Reference	
	Boy	-0.11 (-0.15, -0.08)	-0.05 (-0.07, -0.03)	<0.001
Time				
	Baseline (2016)	Reference	Reference	
	Endline (2019)	0.01 (-0.08,0.11)	0.01 (-0.03, 0.04)	0.716
Minimum Dietary Diversity (MDD)				
	<4 food groups	Reference	Reference	
	≥4 food groups	-0.03 (-0.08,0.02)	-0.01 (-0.03,0.01)	0.197
Morbidity		0.02 (-0.01,0.05)	0.01 (-0.01, 0.03)	0.203
Socioeconomic position group				
	Poorest	Reference	Reference	
	Poor	0.26 (0.19, 0.33)	0.12 (0.08, 0.15)	<0.001
Intervention				
	Control	Reference	Reference	
	Intervention	0.05 (-0.05, 0.14)	0.02 (-0.02, 0.06)	0.190
Wasting				
	Not wasted	Reference	Reference	
	Wasted	-0.41 (-0.49,-0.33)	-0.10 (-0.12,-0.08)	<0.001
Birth order				
	1	Reference	Reference	
	2	-0.02 (-0.08,0.05)	-0.01 (-0.03,0.02)	0.564
	3	0.03 (-0.04,0.1)	0.01 (-0.02, 0.04)	0.395
	4 and above	-0.14 (-0.21,-0.07)	-0.06 (-0.09,-0.03)	<0.001

Household size				
	2-4 member	Reference	Reference	
	5+ member	-0.02 (-0.07,0.02)	-0.01 (-0.03,0.01)	0.361
Hygiene score		0.03 (0.01,0.05)	0.02 (0.01, 0.04)	0.015
Mother's BMI		0.03 (0.02, 0.03)	0.08 (0.02, 0.09)	<0.001
Mother is short stature				
	No	Reference		
	Yes	-0.65 (-0.7,-0.61)	-0.21 (-0.23,-0.20)	<0.001
Mother have nutritional knowledge		0.00 (-0.02, 0.02)	0 (-0.02, 0.02)	0.988
Maternal dietary diversity				
	No	Reference	Reference	
	Yes	0.04 (0.01,0.08)	0.02 (0.00,0.04)	0.035
Woman have decision making power		0.00 (-0.01, 0.01)	0.00 (-0.02, 0.02)	0.946
Mother received at least 4 ANC				
	No	Reference	Reference	
	Yes	0.08 (0.04,0.12)	0.03 (0.02,0.04)	0.001
Mother received PNC				
	No	Reference	Reference	
	Yes	0.09 (0.06,0.12)	0.04 (0.02, 0.05)	<0.001
Time*Intervention		-0.03 (-0.15,0.09)	-0.01 (-0.06, 0.04)	0.463
SEP*Intervention		-0.03 (-0.11,0.06)	-0.01 (-0.04, 0.02)	0.510
Time*SEP		-0.13 (-0.2,-0.05)	-0.05 (-0.09, -0.02)	0.001
R^2		0.13	0.13	

+The estimates are the regression coefficient estimates, where 5a column reflects beta coefficients (mean differences in HAZ) and 5b column reflects standardised beta coefficients, expressed in SD units; Table 5.11 includes both baseline and endline data, with a total sample size of N=13062.

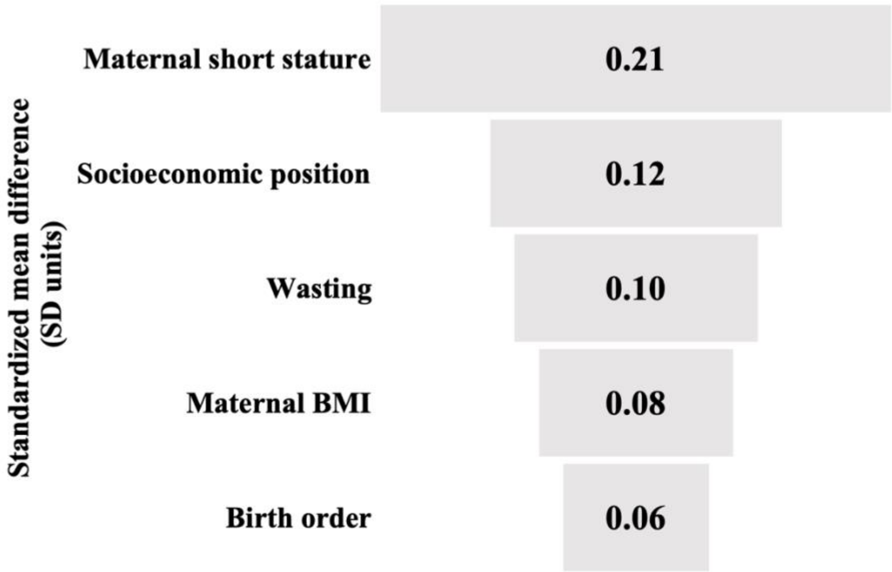

Figure 5.2 Top five ranked associated factors with HAZ among children 6-23 months in the Suchana programme area.

Figure data did not consider directionality, but extent of standardised mean difference is presented as a coefficient

Discussion

This study presented an analysis of factors associated with LAZ among children aged <2 years from households belonging to the lowest two socioeconomic position groups in Sylhet division in north-east Bangladesh to assess whether socioeconomic inequalities can better explain the prevalence of child stunting compared to NF. The findings supported the initial hypothesis and reflected that socioeconomic inequalities were statistically significantly associated with LAZ and ranked as the second most important variable in terms of explaining variabilities in linear growth of under-two children, whereas neither of the variables (MDD, morbidity scores) included under NF were significantly associated with LAZ, in an adjusted model. In terms of the strength of this association, the top five ranked associated factors were mother's short stature, SEP inequalities, child wasting status, mother's BMI (low BMI) and child's birth order.

The methodology employed in this study sets it apart from previous research in several key ways. For instance, Angdembe et al. (2019), Huda et al. (2017), and Rabbani et al. (2016) utilised Demographic Health Survey (DHS) data, while Nguyen et al. (2017) focused on intervention data and acknowledged the role of inequalities in changes of stunting prevalence over time (Angdembe et al., 2019; Huda et al., 2017; Nguyen et al., 2017; Rabbani et al., 2016). Some other articles, such as Argaw et al. (2019), Danaei et al. (2016), and Kim et al. (2017) ranked factors associated with stunting based on the strength of associations using multiple statistical models (Argaw et al., 2019; Danaei et al., 2016; Kim et al., 2017). The approach utilised in this study, on the other hand, aimed for a comprehensive analysis by including a holistic set of indicators within an intervention context, all in a single model. Since in real life settings multiple factors coexist and interact, the final full model including important relevant factors altogether in a model for the outcome LAZ (used instead of HAZ, as length was measured in under-two children) offers findings with realistic implications. This analysis identifies the relative contribution of SEP and NF while controlling for possible relevant factors as covariates, regardless of whether they were proximate, intermediate, or distal in nature. In conducting this analysis, variables were selected carefully through an extensive literature review and also checked that no variables with multicollinearity were included in our analysis (Supplementary file S3).

Before investigating the comparison of SEP and NF, it is essential to highlight the significance of maternal short stature as a key determinant of lower HAZ. This study findings align with previous research that also emphasises the importance of maternal height in influencing child HAZ (Huda et al., 2017; Rabbani et al., 2016; Svefors et al., 2019; Victora et al., 2021). Maternal short stature can impact a child's HAZ by affecting foetal growth, which is strongly associated with the mother's nutritional status during her own development (Martorell & Zongrone, 2012). While some articles mention the role of genetic factors in determining final height (Svefors et al., 2019; Ulijaszek, 2020), Bogin (2021) proposes that socioeconomic, political, and emotional (SEPE) factors might hold greater importance than genetic in explaining HAZ (Bogin, 2021).

This study findings provide strong evidence that SEP has a significant impact on linear growth in infants aged 6-23 months, surpassing the influence of child's MDD or morbidity status. The influence of social inequalities is particularly evident in developed countries, where various social issues e.g., school dropouts, prevalence of social problems like drug use, and crime are more prevalent in societies with higher levels of inequality. In developed nations, societal well-being is affected by the relative differences between individuals and their social position within society (Wilkinson & Pickett, 2010). Inequality originates from how individuals and groups may be treated based on structural determinants, e.g., social norms and cultural values, for instance, prioritising food distribution among male household members or imposing restrictions on food intake for women during pregnancy (Nisbett et al., 2022). Social position and human social capital (e.g., education/literacy) also interact, for example, where an illiterate woman may not seek or receive adequate ANC during her pregnancy. When social and policy systems fail to acknowledge these disparities and also fail to address various forms of discrimination, it contributes to the continuation and establishment of social inequalities (Nisbett et al., 2022). As per the WHO social determinants of health recommendation, attention needs to be given to in daily living conditions and tackling the inequitable distribution of power and resources (WHO, 2008).

The unequal distribution of power and resources affects not only individuals but also extends to programme implementers and donors. Since NGOs are reliant on donors for funding, especially in the context of Bangladesh, they are obligated to fulfil donor expectations. These donors have increasingly prioritised quick and tangible results (Qayum et al., 2023) at the expense of addressing more time-consuming goals such as reducing social inequalities. Understanding such power dynamics in global health research is an emerging issue to improve the depth and breadth of knowledge regarding the root causes of inequities in health (Nisbett et al., 2022). Hence, it is imperative for nutrition researchers and practitioners to recognise and acknowledge explicitly the existence of inequality as a foundational factor. Furthermore, a reassessment of resource allocations and shifting priorities may be necessary rather than traditionally focusing more ‘downstream’ in the malnutrition framework (Nisbett et al., 2022; UNICEF, 1991; Veiga et al., 2022).

In Model-5, child wasting and maternal nutritional status were also found to be important predictors of HAZ. Possible reasons for this might be the mother's nutritional status before and during pregnancy, as well as during breastfeeding, which could have an impact on the availability and quality of nutrients the child receives (Victora et al., 2021). However, inadequate dietary diversity and morbidity were not found to be significant factors for changes in HAZ when all other variables were included in the final model. This finding contradicts prior randomised controlled trials (Ara et al., 2022; Christian et al., 2015), a systematic review with 14 papers (Lassi et al., 2020), and a meta-analysis with 15 papers (Mamun et al., 2023). The observed difference may be due to the variations in the study populations, since these were derived from poor and extremely poor households in rural Bangladesh. Otherwise, the difference might be related to issues of measurement and/or self-reported data.

However, the lack of an association between diet and HAZ supports the contention that HAZ is less related to nutritional factors than has been previously thought (Hermanussen et al., 2018; Leroy & Frongillo, 2019; Scheffler et al., 2020). Other studies have also supported the finding that dietary quality does not contribute significantly to stunting prevalence (Menon et al., 2016; Mumm & Scheffler, 2019; Nguyen et al., 2017). The evaluation data utilised indicated that only one-tenth of children from the poorest households at baseline had diets that met minimal requirements in terms of dietary diversity, which is far below national estimates (38%) for rural Bangladesh (NIPORT/ICF, 2019). Three years later at endline, a significant positive change was found in dietary diversity in both the poor and poorest households (higher in intervention areas compared to control) but the improvement of feeding practices from the Suchana interventions did not demonstrate any positive impact on linear growth. A possible explanation is that MDD is a only proxy variable for dietary quality. Once a relatively better

MDD is achieved, any further improvements in MDD would only contribute negligibly to HAZ if other underlying factors such as maternal education, SEP remained stagnant. In many instances, interventions address a specific risk factor or a set of factors in isolation. For instance, a nutrition specific intervention ‘feeding practice’ is likely to be implemented without addressing social and structural factors such as women's education, household poverty, social exclusion and inequality (Black et al., 2013; Kim et al., 2017; Kundu et al., 2022). As a result, no significant result can be seen within the programme life time.

However, contrary to expectations, children from poor households, as opposed to the poorest households, exhibited a higher prevalence of morbidity. This difference could potentially be attributed either to poultry rearing practices or the reporting of morbidity may have been more accurate/reliable among poor compared to poorest households. Given that poor households, under the context of the Suchana programme, were relatively better off compared to the poorest households, it was anticipated that these households might engage in poultry farming. Our data also reveal that poultry (chicken) ownership in poor households was 63%, compared to 56% for the poorest households (data not presented in the results section). Raising poultry domestically is a common practice in various rural areas of Bangladesh. However, the presence of domestic poultry or livestock can elevate the risk of children's infection with diarrheal pathogens such as *Campylobacter jejuni* (Harvey et al., 2003).

Strengths and limitations

Strengths: This study analysed a comprehensive dataset obtained from a large-scale programme evaluation. To construct the SEP index, this research utilised an advanced statistical technique that considered a wide range of indicators. The resulting regression model exhibited robust statistical rigor, and all the underlying assumptions were met.

Limitations: There are some limitations in this study. This research focuses specifically on the poorest and poor populations, making the analysis less diverse, consequently, the generalizability of the findings may be limited. Moreover, Suchana had already defined its beneficiaries into two groups called "poor" and "very poor" based on relative wealth ranking. However, SEP index was constructed specific to the population group, which I believe is a more reliable variable for assessing inequalities.

Conclusions

This study reveals that the factors contributing to linear growth among young children, even in an intervention setting, are present at structural levels. To address such inequalities effectively, government and policymakers must implement direct and targeted measures that enables sustained improved among the most deprived groups, offer pro-poor polices and supports aimed at reducing existing socioeconomic inequalities so children can grow to fulfil their potentials and enjoy life with more choices it can offer.

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S3. Supplementary file S3

The four assumptions (namely linear relationship with independent and dependent variable, independence or residuals, homoscedasticity and normality) on which the multiple linear regression for the final full model was based have been checked and found to be met. The heteroscedasticity test result came as chi2(1)= 0.05 and p= 0.8302. As a result, I cannot reject the null hypothesis (i.e,. null of constant variance) because here the p-value was high. It implies that there is a homeoscedasticity in the variance and the regression model is acceptable.

Table S3. The variance inflation factor (VIF) of independent variables and other covariates.

Variables	**VIF**
Child age group	1.02
Child sex	1.00
Time	1.17
Minimum Dietary Diversity (MDD)	1.25
Morbidity	1.01
Socioeconomic position Index	1.22
Intervention	1.10
Wasting	1.02
Birth order	1.41
Household size	1.28
Hygiene score	1.07
Mother’s BMI	1.05
Mother is short stature	1.01
Mother have nutritional knowledge	1.10
Women dietary diversity	1.23
Woman have decision making power	1.21
Mother received at least 4 ANC	1.17
Mother received PNC	1.12
Mean VIF	**1.14**

6. CHAPTER 6

CONCLUSIONS

To comprehend how to address stunting effectively, it becomes imperative to investigate the implications of social inequality as a key determinant to help in assessing the priorities for policy design to enhance childhood growth. Despite numerous frameworks recognising the significance of factors like socioeconomic conditions, maternal influences, and child feeding practices on early childhood growth, there remains a gap in research that compares and prioritises the relative importance of two factors: NF and socioeconomic inequality, at low-and middle-income countries (LMIC), particularly for Bangladesh.

This research has compared the relative contribution of nutritional factors (NF) and socio-economic inequalities in explaining variations in linear growth of children in Bangladesh, both in the context of rural national sample (children ages <5) and from the poor and poorest households (with children <2) in an intervention context (Suchana programme) within a region with a high prevalence of malnutrition in Bangladesh. I found that socioeconomic inequalities explained much larger variabilities in linear growth (HAZ) than what was explained by NF. These findings draw attention to the landscape of several existing policies and programmes that have primarily focused on improving nutrition through knowledge exchange or dietary modifications and that have met with little success. These programmes have, however, not been able to address the social determinants and the staggering growing inequalities that can challenge progress in health and nutrition and towards achieving World Health Assembly targets and thereby meeting the UN SDGs.

The reduction of stunting is considered a key indicator of the SDG 2.2.1, within the goal of SDG 2 (Zero hunger). Stunting in children poses significant risks, as it hampers individual's full potential, increases susceptibility to chronic diseases, and raises the likelihood of giving birth to LBW infants. Consequently, considerable efforts have been invested in the past decade to mitigate stunting. However, the task of improving linear growth is complex and interconnected with various factors, particularly the issue of inequalities. Inequalities exists not only at the regional level, within wealth groups, and also within households based that are affected by deprivation and social inequalities. This underscores the importance of investigating deeper into an understanding of inequalities and dedicating significant attention to addressing its complexities.

Although there has been a significant reduction in national poverty levels for Bangladesh, but it is equally important to address and reduce inequalities to promote sustained economic growth. According to data from the Bangladesh Household Income and Expenditure Survey (HIES) 2022 data, income inequality seems to have increased over time (compared with 2016 HIES data). However, the Bangladesh Demographic and Health Survey (BDHS) data indicates a remarkable reduction in stunting rates from 51% in 2004 to 24% in 2022 (Figure 1. 11). Despite this improvement, the most vulnerable groups still experienced a high stunting prevalence of 35% (in 2022), with only a 5% reduction compared to 2019. It is essential to consider that BDHS 2022 data was collected just after the onset of the COVID-19 pandemic (Jun-Dec 2022), and the situation for the most deprived may have further changed since then. Hence, monitoring and addressing the inequality in stunting reduction remain critical in ensuring sustainable progress in child health and nutrition.

To comprehend the impact of inequality, the initial step lies in determining an appropriate measure of inequality. Various researchers have employed different methods, such as use of simple asset or wealth indices, parental education and occupation as a proxy measure of social status to assess inequalities at household level or using the Gini coefficient at national level to assess inequality. It is important to note that wealth, parental occupational status, and educational level are all dimensions within the domain of SEP, and they often exhibit correlations with each other. In my research, I specifically adopted a method using polychoric PCA (pPCA), a robust and advanced statistically technique, as it handles correlated variables in making a composite score. Through this approach, I discovered that the most influential factors measuring SEP may vary between rural settings and context-specific intervention areas, highlighting the contextual nuances that need to be considered in studying inequality.

Limitation of knowledge deficit approach

To understand the limited effectiveness of information, education, and counselling (IEC) in improving linear growth sustainably or reducing stunting, it is crucial to examine the role of inequality within the framework of intervention programmes. Inequality can have both direct and indirect impacts on the outcomes of such interventions. For instance, inequality may influence psychosocial factors, leading to feelings of insufficiency and hindered potential among those facing economic hardships. This, in turn, may affect their ability to utilise their resources and to provide adequate care or attention to themselves and also to their children, contributing to the persistence of stunting. Therefore, it is essential to address the underlying issue of inequality to improve the efficacy of IEC in tackling stunting effectively.

Moreover, maternal height, education, and BMI have been identified as highly significant factors influencing linear growth outcomes (Black et al., 2013; Goudet et al., 2017; Semba et al., 2008; Victora et al., 2021). In my research, I observed similar trends, as SEP, maternal height, and BMI factors emerged as the top five factors associated with linear growth in both data sets. It is important to recognise that these maternal characteristics, along with child linear growth, are all influenced by the broader context of inequality. The socioeconomic and environmental factors associated with maternal height, education, and nutrition are shaped by the prevailing levels of inequality within society.

Several conceptual frameworks have highlighted the significance of nutritional factors in addressing stunting in nutrition programmes. In evaluating nutrition programmes, there has been a promotion of multi-sectoral approaches, with a focus on both nutrition-specific and nutrition-sensitive interventions. Consistent with these trends, my research findings also emphasise the importance of a multi-sectoral approach. For example, through regression analysis, I calculated the R-Squared (R^2) value, (the coefficient of determination) which is a statistical measure in a regression model that determines the proportion of variance in the dependent variable that can be explained by the independent variable. However, R^2 values indicated that the inclusion of SEP in the various models resulted in higher explanatory power in the models. Subsequently, the addition of NF variables did not significantly contribute to further improvements. This suggests that SEP plays a more dominant role in influencing outcomes related to stunting in comparison to NF. The final model about FSNSP data was able to explain 16% of the total variability in linear growth, whereas the Suchana data explained 13% variability. Although it may seem the models have large amount of variability, this is in line with what others have reported when using stunting or linear growth (Nguyen et al., 2017).

Despite being designed with a multi-sectoral approach, the Suchana programme did not generate significant changes in stunting reduction. This suggests that the implementation process might be a critical factor influencing its impact. Currently, implementation research has garnered increasing attention globally, emphasising the importance of strategies to effectively implement interventions to achieve the desired impact, which can be an essential ingredient for successful outcome for a well-designed intervention.

My research not only highlights the importance of social determinants but also rising inequalities that appear to have a larger negative influence on child growth potential. I would therefore strongly recommend that LMIC countries present data comprehensively categorized by all possible 'equity strata' (e.g., place of residence, race/ ethnicity /culture /language, occupation, gender/sex, religion, education, socioeconomic status, and social capital). This approach would help to distinguish interventions that have proven effective in alleviating inequalities in health and nutrition. This should be promoted through advocacy by development initiatives and funders, as well as by local governments, and facilitated through active engagement with policy makers. It is also crucial to emphasize implementation research to augment the effectiveness of programmes, thereby achieving the desired outcomes in reducing stunting prevalence, and to ensure effective use of limited resources. A specific focus on the assessment of inequalities, plus targeted initiatives, together with carefully designed studies assessing the effectiveness of interventions can all reduce inequalities and their harmful effects on future generations.

Furthermore, an important policy implication of my research is to emphasise that interventions focused solely on specific single risk factor for stunting is inadequate. The results presented here can assist international development agencies and programmes in refining their potential strategies and outcomes. Moreover, nutrition researchers and practitioners must acknowledge the existence of inequality, which fundamentally shapes who is affected by malnutrition. Socio-political factors, which are related to the societal structure and distribution of resources, are challenging to align without political recognition and investment. Despite the substantial research and advocacy efforts by scholars and advocates from high-income countries (HICs), relative social inequalities have been on the rise in various countries over the last few decades. In countries with more autocratic governments, the issue of social inequality may be even more severe or challenging. Autocratic regimes may have limited mechanisms for addressing inequality, making the situation worse for vulnerable populations. While the research in question might not directly address socio-political factors, a significant change in political will is necessary to address the root causes of social inequality and, consequently, improve childhood growth outcomes in the long term.

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7. APPENDICES

A1. Significant milestones

Table 7.1 Significant milestone in the field of nutrition in Bangladesh following the liberation war (Chowdhury et al., 2023)

Year	Programme/ Research/Survey	Programme component	Outcome
1973	Programme for the prevention of blindness by the government of Bangladesh	High potency Vitamin A capsule to children from 6 months to 6 years of age. Training primary health workers on Vitamin A Hospitals are encouraged to pay special attention	The blindless programme scaled up all over the country and successfully saved 30000 children from the curse of blindness caused by Vitamin A deficiency
1974-75	Rural Bangladesh nutrition survey by Institute of Nutrition and Food Science (INFS), Dhaka university	-	Findings: • Night blindness • Iron deficiency anaemia • Goiter • Lathyrism were alarmingly high among rural population A person received protein 58.5g/day
1974	Establishment of Institute of Public Health and Nutrition	-	-
1975	Establishment of Bangladesh national nutrition council	-	-
1977-78	Household income and expenditure survey (HIES)	-	Findings: Only 25% of people could met their daily food requirements
1978-79	Development of methodology	With a proposal for implementation of nutrition surveillance	Limitations: But no clear information on whether this would be implemented or not
1981-82	The second national nutrition survey by INFS, Dhaka university		Findings: most of the people in the country did not even meet their minimum calorie requirements A person received protein 48g/day; Stunting prevalence 59%; Delayed complementary feeding; Children were fed packaged formula milk Challenges: Lack of proper policy or strategies

1983	INFS got fund from Ministry of health and population control for the treatment of goitre	On the treatment of goitre by means of the Lipodol injection which proven to be effective	Ministry took this project up and began to administer this injection to children, teenagers and woman of reproductive age. This was costly, therefore government lost its interest.
1984	Policy document		The breast milk substitutes (regulation of marketing) ordinance was drawn up
1989	Iodine deficiency disease prevention act	Begin adding iodine in salt	Bangladesh became one of the first countries to begin adding iodine to salt Ministries of industries took up the initiative to add iodine
1985-90	Third five year plan	Good attention was given to nutrition for the first time	Food security and nutrition were raised at the government policy making level
1989-90	Child nutrition status survey by Bangladesh Bureau of Statistics (BBS)		94% of the children were suffering from some form of malnutrition Addressing only micronutrient deficiencies (Vit A and Iodine) was not enough to eradicate malnutrition. Attention would have to be paid to food security and macro nutrients (protein, carbohydrates and fat) Families with lowest income had the highest rate of malnutrition where children were fed primarily on rice and wheat It was also noted that undernourished children was the lowest in January, the time when major crops are harvested
1990	Policy document		Amendment of the breast milk substitutes (regulation of marketing) ordinance
1990-95	Fourth five year plan	Nutrition was included in the Fourth five year Plan, and Nutrition was one of the important objectives of the health sector Targets were: • Calorie intake 2100 Kcal	Very little is available on the impact of the fourth five year plan

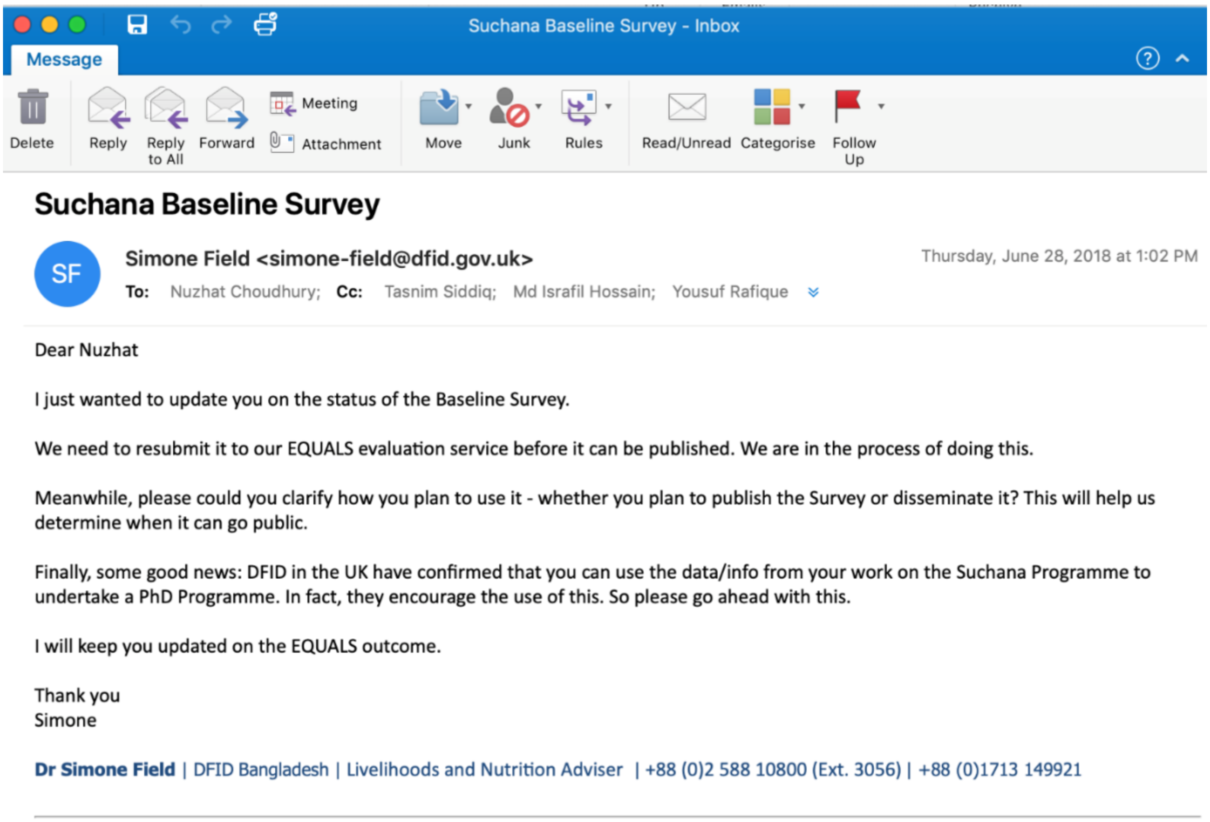
		• Starting of nutrition surveillance • Establishment of child nutrition unit in the thana health complex • Plans for - prevention of blindness, elimination of iodine deficiency, and ensuring deworming	
1993-94	Bangladesh Demographic Health survey (BDHS), by BBS		breast milk consumption at 6 months 46%; 70% did not start complementary feeding at the age of 6 months
1993	BRAC started a community based nutrition project	Nutritious *naru* (ball shaped snacks) made of flattened rice, rice flour, nuts, and molases, were given to children and woman	
1995	Bangladesh Demographic Health survey (BDHS), by BBS		56% of the children were underweight. 52% of the woman were malnourished.
1996	Nutrition began to gain more importance at the policy making level. BINP started	A six year community based programme with financial support from World Bank. BINP started with government-NGO partnership Project included: Revised version of nutritious *naru* i.e., *Pushti* packet, and homestead vegetable farming and poultry rearing Also: growth monitoring, and nutrition awareness, teaching mothers the recipe for complementary food	A baseline was conducted but no endline was conducted.
1997	NNC was involved in preparing the First national food and nutrition policy	The national food and nutrition policy was approved to improve people's nutritional status, elderly, and persons at nutrition risk	Policy mentioned that: Nutrition is a multidimensional matter Agriculture, Food and Health were involved with nutrition The policy called to strengthen communication among these three sectors
1999-00	BDHS		48% children were underweight 45% were stunted

			50% of women still suffered from some form of malnutrition Challenges: Nutritionists were sceptical if the positive change was due to BINP or not
2000	Bangladesh entered into new era with the MDG	The first goal was to alleviate extreme poverty and hunger MDG goals was to reduce underweight (the goal was 33%) There were VGD VGF but no poverty elimination strategy’	~49% of the population was living in poverty
2002	BINP was then changed to National nutrition project (NNP)	Health and population sector programme began, where nutrition was separately implemented in the form of NNP, as part of governments’ operational plan Malnutrition remained included as part of IPHN’s operational plan, and nutrition remained outside of the mainstream health system	No evaluation was made on NNP Save the Children published a review report on BINP and NNP, where they did not find any evidence of these two projects bringing about change to the state of nutrition. They blamed the design and implementation strategy of the projects
2004	BDHS		49% children were underweight
2005	A poverty alleviation strategy paper was drawn up	Here, nutrition was included as one of the main issues to tackle	
2006	Policy document	National food policy was published	Policy mentioned: The supply and adequacy of nutritious safe food would be ensured Adequate nutrition for all Challenges: No plan of action was taken up until 2008
2008	BDHS		No improvement in nutritional status
2011	SUN movement	Bangladesh government joined the international SUN (scaling up nutrition) Movement.	Political commitment was ensured and a large change was brought about in the government’s plans regarding the improvement of nutrition

2011-	A new operation plan NNS was drawn Country investment plan		
2015-16	National nutrition policy	Policy Approved	
2016	National Nutrition Plan of Action (NPAN)	Published in 2017	17 ministries were required to be involved in implementing thus plan of action and 10 year plan would entail 125 billion taka. With support of the ministry of health and family welfare and development partners, NGOS, implementation of this plan of action is still on going
2020	National nutrition council revived and restructured	NNC was dormant due to lack of guidelines NNC is now responsible for coordination with other ministries	
2022	BDHS		Maternal nutritional status has improved Stunting status has improved (now 31%)

A2. FCDO and icddr,b's consent to use Suchana data

A2.1. Consent from the donor, UKAid, was obtained in 2019 to use the Suchana data (email communication).



Suchana Baseline Survey - Inbox

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Suchana Baseline Survey

SF **Simone Field <simone-field@dfid.gov.uk>** — Thursday, June 28, 2018 at 1:02 PM

To: Nuzhat Choudhury; **Cc:** Tasnim Siddiq; Md Israfil Hossain; Yousuf Rafique

Dear Nuzhat

I just wanted to update you on the status of the Baseline Survey.

We need to resubmit it to our EQUALS evaluation service before it can be published. We are in the process of doing this.

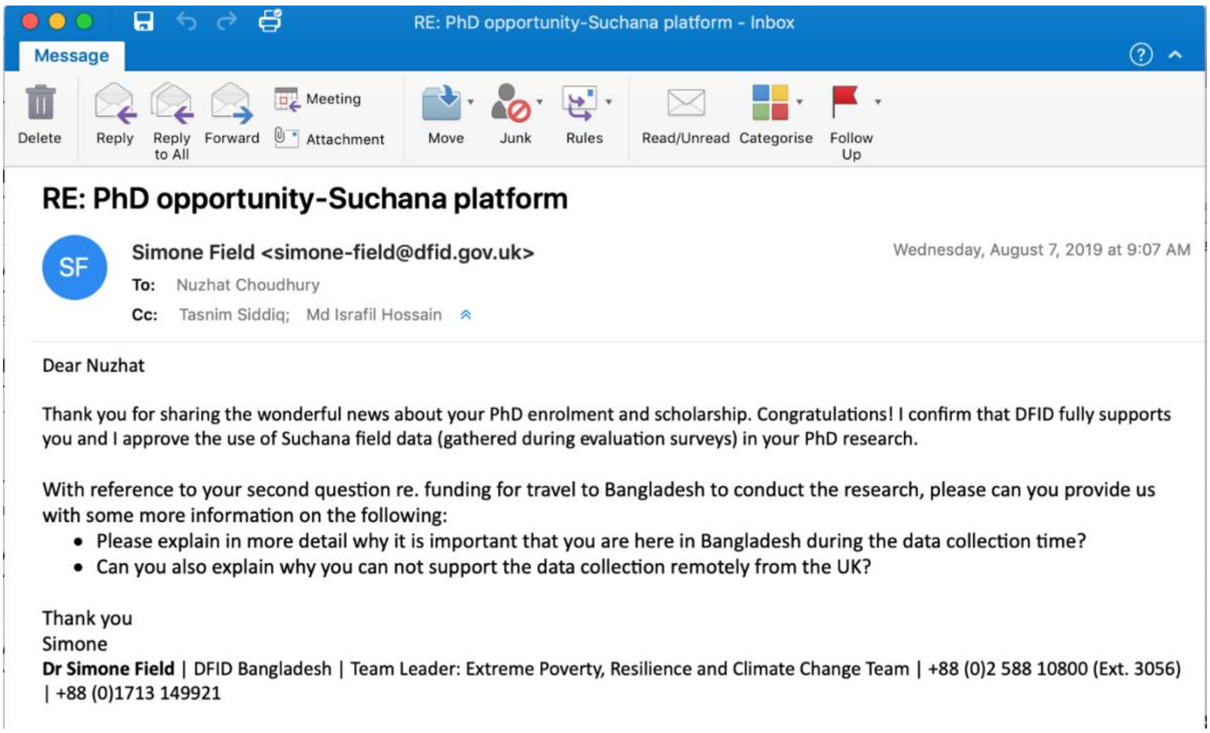
Meanwhile, please could you clarify how you plan to use it - whether you plan to publish the Survey or disseminate it? This will help us determine when it can go public.

Finally, some good news: DFID in the UK have confirmed that you can use the data/info from your work on the Suchana Programme to undertake a PhD Programme. In fact, they encourage the use of this. So please go ahead with this.

I will keep you updated on the EQUALS outcome.

Thank you
Simone

Dr Simone Field | DFID Bangladesh | Livelihoods and Nutrition Adviser | +88 (0)2 588 10800 (Ext. 3056) | +88 (0)1713 149921



RE: PhD opportunity-Suchana platform - Inbox

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RE: PhD opportunity-Suchana platform

SF **Simone Field <simone-field@dfid.gov.uk>** — Wednesday, August 7, 2019 at 9:07 AM

To: Nuzhat Choudhury

Cc: Tasnim Siddiq; Md Israfil Hossain

Dear Nuzhat

Thank you for sharing the wonderful news about your PhD enrolment and scholarship. Congratulations! I confirm that DFID fully supports you and I approve the use of Suchana field data (gathered during evaluation surveys) in your PhD research.

With reference to your second question re. funding for travel to Bangladesh to conduct the research, please can you provide us with some more information on the following:

- Please explain in more detail why it is important that you are here in Bangladesh during the data collection time?
- Can you also explain why you can not support the data collection remotely from the UK?

Thank you
Simone
Dr Simone Field | DFID Bangladesh | Team Leader: Extreme Poverty, Resilience and Climate Change Team | +88 (0)2 588 10800 (Ext. 3056) | +88 (0)1713 149921

A2.2 icddr,b, agreed to let me use the Suchana data

Moreover, icddr,b, that collected the data as part of evaluation of Suchana, agreed to let me use the Suchana data set for my PhD (Human Resource Leave Application form is given).

Employee: Click here to enter text.	Employee ID: Click here to enter text.	
i) Any other information: Click here to enter text.	[signature] Signature of the Direct Supervisor	Date: 3.2.2020

I. Reviewed by Human Resources

IV. Comments from the Division Director

Nuzhat Choudhury has been awarded a scholarship to pursue doctoral studies in UK. Her area would be qualitative research and she is likely to use data from the ongoing SUCHANA project. She will contribute to the evaluation of the SUCHANA project, which is now being overseen by Dr. ASG Faruque. This is as per discussion with Nuzhat Choudhury and Dr. Faruque. The funders of the project are also apprised of the situation arising out of the transition.

Signature: [signature]
Date: 3.2.2020

A2.3 icddr,b Institutional Review Board permission

icddr,b

IRB Secretariat, RA, CS icddr,b, Mohakhali, Dhaka

To Whom It May Concern

IRB No.: **IRB00001822** FWA No. **00001468**

Project title: **"Evaluation of the impact of *Suchana* on preventing chronic malnutrition: a cluster randomized trial", IRB # PR-16020.**

Date of IRB approval: **March 13, 2021**

This is to certify that Ms Nuzhat Choudhury, Associate Scientist, Nutrition and Clinical Services Division (NCSD) of icddr,b was the initial Principal Investigator (PI) of the above-mentioned study. At the time of her departure to pursue doctoral study, she had delegated the PI-ship to Dr A S G Faruque, a Senior Scientist of the same Division and Ms Choudhury remains as an investigator of the study.

According to the existing policy of icddr,b; any study investigator has exclusive right to use her/his study data until three years of completion of that study. After three years of completion, icddr,b will become the owner of the data. So, Ms Choudhury has exclusive right to use the above study data for her Doctoral programme until August 2024. The current PI and Division Director of the study also do not have any objection for using this data for her PhD programme. I am pleased to accord ethical **approval** for using the above-mentioned data for Ms Choudhury's Doctoral study purpose. Ms Choudhury is advised to submit a copy of the findings of her doctoral study to the Ethics Review Committee of icddr,b when it is completed.

I wish her every success in pursuing the doctoral programme.

Thank you.

_______________ *13 March 2021*

Professor Ahmed Abu Saleh
Chairperson
Ethical Review Committee of icddr,b
Cell #: +880 1718378953
Email: aasaleh@gmail.com

Copy: - Senior Director, NCSD
- Dr ASG Faruque, PI of the above study

Ethical Review Committee, IRB Secretariat, Research Administration, CMS
International Centre for Diarrhoeal Disease Research, Bangladesh
68, Shaheed Tajuddin Ahmed Sarani, Mohakhali, Dhaka 1212, Bangladesh
Mail: icddr,b, GPO Box 128, Dhaka 1000, Bangladesh
Phone: 880-2-9827084, Web: http://www.icddrb.org

A3.1 Percentage of variance explained by the first component in other studies

Table 7.2 Percentage of variance explained by the first component in other studies

Reference	Country	Variability explained from 1st component, %
(Vyas & Kumaranayake, 2006)	rural Brazil	16.0
	urban Brazil	13.4
	rural Ethiopia	11.1
	urban Ethiopia	14.9
(El Arifeen et al., 2008)	Bangladesh	15.0
(Houweling et al., 2003)	Bolivia	17.0
	Brazil	13.0
	Cameroon	20.0
	Chad	19.0
	Indonesia	14.0
	Kenya	17.0
	Malawi	18.0
	Pakistan	20.0
	Tanzania	16.0
	Uganda	12.0
(Hargreaves et al., 2007)	Rural South Africa	22.7