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A statistical model to predict the performance of factors involved in reducing childhood stunting

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1 A statistical model to predict the performance of factors involved in reducing childhood 2 stunting

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19 Abstract

20 **Objective** The goal of this study was to construct a predictive modelling approach using logistic
21 regression analysis. We propose that such a model may help to develop an intervention study to
22 significantly reduce the prevalence of stunting among children aged 12-23 months.

23
24 **Design** A cluster randomized pre-post design was followed to measure the impacts on several
25 indicators of livelihood, health, and nutrition. The study comprised a large dataset that was
26 collected from two cross-sectional studies (baseline and endline).

27
28 **Setting** This study was conducted in Sylhet, a population in the northeast of Bangladesh that is
29 vulnerable to both natural catastrophes and the consequences of poverty. It specifically targeted
30 children between the ages of 12 and 23 months.

31
32 **Main outcome measures** The outcome variable in this study was childhood stunting, which was
33 defined as a length-for-age z-score (LAZ) <-2. A multiple logistic regression model was
34 established to predict the factors associated with childhood stunting. The predictive performance

of the model was assessed by computing classification status based on model sensitivity and specificity, and area under the receiver operating characteristic (ROC) curve analysis.

Results The prevalence of stunting at baseline survey was 52.7%, whereas 50.0% were stunted at endline survey. We found that several factors were associated with childhood stunting. The sensitivity and specificity of the model were 61% and 56%, respectively. The correctly classified rate was 59%, and the area under ROC curve was 0.615.

Conclusion We predict that childhood stunting can only be reduced once the associated factors are improved by programmes or interventions. Importantly, based on the post-estimation findings and area under the ROC curve analysis, the predictive performance of the model was low. As a result, the other factors that significantly influence childhood stunting that are not included in our model urgently need to be identified.

Study registration: RIDIE-STUDY-ID-5d5678361809b

Keywords: Nutrition, Statistics, epidemiology, public health

Strengths and limitations of this study

- More precise anthropometry tools were used to measure the child's length
- The predictive performance of the logistic regression model was calculated
- To avoid seasonality, we conducted the baseline and endline surveys at the same time of year
- We did not collect food intake data, but only gathered recall data from the previous 24 hours
- Biological data were not collected

Introduction

Childhood stunting, which is defined as a height/length-for-age z-score (HAZ/LAZ) < -2 , is a major concern for public health and has been widely used as an indicator of chronic malnutrition in children¹. Although childhood stunting scenarios have much improved globally, the prevalence

of child malnutrition is still very high in low-resource settings, including countries such as Bangladesh. According to the 2018 Global Nutrition Report, 150.8 million children (22.2%) under five years-of-age are stunted globally, compared to 198.4 million (32.6%) and 165 million children in 2000 and 2011, respectively ²³. Asian countries have observed a decline in the rate of stunting among children under five from 38.1% to 23.2% between 2000 and 2018; however, the prevalence of stunting in South Asia is 38.9%, which is reported to be the highest level across this region ². In Bangladesh, about 5.5 million (36%) children under five were stunted in 2014 ⁴, and in 2018, childhood stunting reduced to about 31% of this population ⁵. As the World Health Organization (WHO) considers a childhood stunting rate of 15% to be an emergency situation, the current prevalence of childhood stunting in Bangladesh reflects an alarming situation of chronic undernutrition [28].

Undernutrition during childhood has several causes, including poor maternal health and nutrition, low maternal education, and inadequate infant and young child feeding (IYCF) practices [28]. Moreover, evidence suggests that a number of characteristics at the household level, which relate to both children and mothers, can influence childhood stunting. The characteristics of the household head, household food insecurity, the presence of unhygienic latrines, hand-washing status, household income and savings, household involvement in several earning activities, maternal healthcare service-seeking during pregnancy, household dietary diversity, number of children, maternal nutritional profile, as well as the age and sex of the child are most often reported to be associated with stunting in the literature ⁶⁻¹¹. However, these findings are mostly based on nationally representative cross-sectional and cohort studies, or studies conducted in urban settings ^{12 13}. Therefore, a knowledge gap exists on whether similar results would be obtained when nationwide data are compared with data for study populations from poor or very poor rural households in specific vulnerable regions.

Sylhet is one such vulnerable region of north-east Bangladesh, and is comprised of diverse terrain such as plain land, hilly land, *Haor* (wetland), and flash flood-prone areas. This region is reported to perform poorly for all important maternal healthcare indicators ¹⁴, despite the fact that Bangladesh has made substantial progress in improving the overall health of the population ¹⁵. Moreover, the socio-economic profile of the inhabitants in Sylhet region includes both very rich

1
2
3 98 and extremely poor people. This scenario may worsen without implementation of appropriate
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5 99 strategies in the near future. Sylhet region is also performing poorly compared to the national
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7 100 averages for a number of health and nutritional indicators. Critical indicators such as the infant
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9 101 mortality rate and unemployment status of women are high ¹². In comparison to the overall
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11 102 situation of Bangladesh, where stunting among children under five has decreased, the Bangladesh
12
13 103 Demographic and Health Survey (BDHS) 2014 indicates the prevalence of childhood stunting in
14
15 104 Sylhet is astonishingly high, at 50% ¹². This alarming figure provided the rationale for
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17 105 implementation of a comprehensive intervention programme in this region. A large-scale nutrition
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19 106 programme, *Suchana: Ending the Cycle of Undernutrition in Bangladesh; a multi-sectoral*
20
21 107 *nutrition programme*, was undertaken with the aim to prevent chronic malnutrition in Sylhet. The
22
23 108 primary objective of the *Suchana* programme was to reduce the prevalence of childhood stunting
24
25 109 in the intervention areas. The secondary objectives were to assess the changes in *Suchana*
26
27 110 beneficiaries' households, in terms of an increase and diversification of household income, food
28
29 111 security status, optimal infant and young child feeding (IYCF) practices, haemoglobin status of
30
31 112 children, the empowerment of women, and adolescents' nutritional knowledge and practices.

32
33 114 The *Suchana* programme substantially improved nutritional behaviour, maternal healthcare
34
35 115 practices, women's empowerment, household income, and household food security in the
36
37 116 intervention area compared to the control area ¹⁶. Contrary to predictions, however, *Suchana* did
38
39 117 not result in any significant reduction in the prevalence of childhood stunting. Therefore, although
40
41 118 most other factors related to childhood stunting improved, this raises the question of why the
42
43 119 prevalence of stunting did not reduce after the intervention. An important observation from the
44
45 120 *Suchana* survey was that the proportion of households in this study population using hygienic
46
47 121 latrines was quite low. This factor was associated with stunting in children, and did not
48
49 122 significantly improve by endline in the intervention areas compared to the control areas.

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51 123
52
53 124 In this study, we aimed to construct a predictive model to attempt to explain whether any
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55 125 improvements in associated factors may promote a significant reduction in stunting among
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57 126 children aged 12-23 months from poor and extremely poor households in Sylhet region. Thus, we
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59 127 constructed a predictive model using logistic regression analysis. This model could help to inform
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128 the development and design of future intervention studies that aim to significantly reduce the

129 prevalence of stunting in children aged 12-23 months from poor and extremely poor households
130 in vulnerable regions.

131

132

133 **Methods**

134 **Study design and population**

135 **Source of data:** The data for this study was extracted from the evaluation data of *Suchana*, a large-
136 scale nutrition programme. This study was performed in the population resident in Sylhet
137 (targeting children aged 12–23 months); this region in the north-east of Bangladesh is vulnerable
138 to natural disasters as well as the consequences of poverty^{17 18}. A pre-post design was followed to
139 measure the impacts on several indicators of livelihood, health, and nutrition. The study comprised
140 a large dataset that was collected from two cross-sectional studies (baseline and endline). The
141 baseline survey was conducted between November 2016 and February 2017, while the endline
142 survey was undertaken three years later, during the same months. The sample size for this analysis
143 was 9600 mother-child pairs (baseline: 3200, and endline: 6400). This sample size was estimated
144 to be required to effectively test the hypothesis that the *Suchana* intervention would lead to a
145 significant reduction in stunting among children aged 12–23 months¹⁷.

146

147 **Variables under study:** The outcome variable in this study was childhood stunting, which was
148 defined as a length-for-age z-score (LAZ) <-2. Initially, a list of several independent variables was
149 finalized through results obtained from descriptive and bi-variate analyses, as well as a
150 comprehensive literature review. These included characteristics pertaining to children (age, sex,
151 whether they received colostrum), maternal characteristics (nutritional status, whether they
152 received at least four ANC visits by a skilled service provider, if delivery was assisted by a skilled
153 birth attendant in a facility, their involvement in earning activities, consumption of fleshy foods,
154 number of children in the family) and household characteristics (household food insecurity access
155 scale [HFIAS], household size, hygienic latrine availability, water and soap available at
156 handwashing place, household income, savings at the household level, sex of the head of the
157 household, and active participation in aquaculture). HFIAS was measured using the Food and
158 Nutrition Technical Assistance's Guideline, which categorizes household food insecurity into four
159 levels: a) food secure, b) mildly food insecure, c) moderately food insecure, and d) severely food

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3 160 insecure¹⁹. In the analysis herein, this indicator was redefined as a binary indicator: severely food
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5 161 insecure or not severely food insecure.
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8 163 **Statistical analysis**

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10 164 **Descriptive statistics:** Stata-14 software (StataCorp LP, College Station, TX, USA) was used to
11
12 165 analyse the data. Several statistical plots were used for data visualization. Descriptive statistics,
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14 166 such as frequency and proportions for categorical variables and mean and standard deviations for
15
16 167 quantitative variables, were used to summarize the data at baseline and endline.
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18 168

19 169 **Regression model:** Due to the dichotomous outcome variable, a binary logit model was used in
20
21 170 regression analysis to investigate which factors were significantly associated with childhood
22
23 171 stunting, and estimate their effect size, in order to predict whether changes in behavioural practices
24
25 172 might potentially help to achieve targeted reductions in stunting. Then, *union* was adjusted for as
26
27 173 a cluster variable to control intra-cluster correlation. First, simple logistic regression models were
28
29 174 used to examine the bivariate associations between stunting and all possible explanatory variables.
30
31 175 In the second step, variables with *p*-values <0.25 in the simple model were included in the multiple
32
33 176 regression models²⁰. In the final step, any independent variables thought to be likely predictors
34
35 177 were added to the multiple regression model using the stepwise forward selection method. Some
36
37 178 indicators, e.g., age, sex, and maternal nutritional status, were added regardless of their *p*-value
38
39 179 due to their scientific plausibility. Furthermore, for the explanation of the regression model, a *p*-
40
41 180 value <0.05 was considered as significant, and the confidence interval (CI) of 95% was also
42
43 181 reviewed. From the fitted model, the adjusted effect size or adjusted prevalence adjusted risk
44
45 182 difference (aRD) against all predictors was estimated using the Stata “*adjrr*” package.
46
47 183

48 184 **Model evaluation:** The Hosmer-Lemeshow Chi-Square test was used to test the goodness-of-fit of
49
50 185 the model. The predictive performance was assessed by computing the classification status using
51
52 186 model sensitivity and specificity, area under the receiver operating curve (ROC) analysis. Data
53
54 187 were randomly split into a training set (75% of the data) and a test set (25%) to calculate the
55
56 188 accuracy of the algorithm. The same training and test datasets were used for all algorithms and
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58 189 performance predictions.
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60 190

191 Patient and public involvement

192 Patients and public were not actively involved in formulating the research question and or protocol
 193 development, including the outcome measures. To expedite the field implementation, however,
 194 local elites e.g. teachers, religious person, and local government council members were informed
 195 about the study.

199 Results

200 **General characteristics:** With respect to the outcome indicator, stunting in children aged 12-23
 201 months, 52.7% of children were stunted at the baseline survey (intervention group: 52.6%; control
 202 group: 52.8%), whereas the proportion of children exhibiting stunting at endline was 50.0%
 203 (intervention: 49.9%; control: 50.1%; Figure 1). Figure 2 describes some other output indicators
 204 related to maternal and child health. Status of consuming minimum acceptable diet (intervention:
 205 35.2%; control: 14.9%), minimum dietary diversity (intervention: 42.8%; control: 20.4%),
 206 maternal decision making (intervention: 45.0%; control: 31.0%), at least four maternal ANC visits
 207 by a skilled service provider (intervention: 36.1%; control: 17.7%), minimum dietary diversity for
 208 women (intervention: 52.6%; control: 33.5%), a household dietary diversity score of at least seven
 209 (intervention: 88.9%; control: 78.3%), and household food security status (intervention: 26.6%;
 210 control: 20.2%) were significantly improved in the intervention group compared to the control
 211 group at endline survey. The availability of hygienic latrines (intervention: 44.0%; control: 44.0%)
 212 did not increase after the intervention. The households' socio-demographic characteristics,
 213 women's general characteristics, and children's characteristics at baseline and endline are shown
 214 in Table 1.

216 **Table 1. General characteristics of the *Suchana* beneficiaries**

Indicators, <i>n</i> (%)	Baseline <i>N</i> =3200	Endline <i>N</i> =6300	Total <i>N</i> =9500
At least four ANC visits by a skilled service provider			
Yes	408 (12.8)	1530 (24.3)	1938 (20.4)
No	2792 (87.3)	4771 (75.7)	7563 (79.6)
Delivery at skilled birth attendant/facility			
Yes	1000 (31.3)	2769 (44)	3769 (39.7)

Indicators, n (%)	Baseline N=3200	Endline N=6300	Total N=9500
No	2200 (68.8)	3532 (56.1)	5732 (60.3)
Had tetanus toxoid injection			
No	834 (26.1)	1131 (18)	1965 (20.7)
Yes	2366 (73.9)	5170 (82.1)	7536 (79.3)
Mother involved in income-generating activities			
No	3102 (96.9)	5665 (89.9)	8767 (92.3)
Yes	98 (3.1)	639 (10.1)	737 (7.8)
Maternal BMI			
BMI \geq 18.5	1859 (58.1)	4073 (64.6)	5932 (62.4)
BMI <18.5	1341 (41.9)	2231 (35.4)	3572 (37.6)
Mother completed primary education			
Yes	1721 (53.8)	3808 (60.4)	5529 (58.2)
No	1479 (46.2)	2496 (39.6)	3975 (41.8)
Maternal age			
Age <30 years	2145 (67)	3559 (56.5)	5704 (60)
Age \geq 30 years	1055 (33)	2745 (43.5)	3800 (40)
Type of delivery			
Normal	2879 (90)	5529 (87.8)	8408 (88.5)
Caesarean	321 (10)	772 (12.3)	1093 (11.5)
PNC			
No	2152 (67.3)	4128 (65.5)	6280 (66.1)
Yes	1048 (32.8)	2173 (34.5)	3221 (33.9)
Household severely food insecure			
Yes	912 (28.5)	1016 (16.12)	1928 (20.3)
No	2288 (71.5)	5285 (83.9)	7573 (79.7)
Household monthly income \geq 15000 BDT			
Yes	424 (13.3)	1015 (16.1)	1439 (15.1)
No	2776 (86.8)	5289 (83.9)	8065 (84.9)
Household involved with aquaculture			
Yes	161 (5)	561 (8.9)	722 (7.6)
No	3039 (95)	5740 (91.1)	8779 (92.4)
Hygienic latrine			
Yes	1121 (35)	2782 (44.2)	3903 (41.1)
No	2079 (65)	3519 (55.9)	5598 (58.9)
Water and soap available in handwashing place			
Yes	862 (26.9)	3170 (50.3)	4032 (42.4)
No	2338 (73.1)	3131 (49.7)	5469 (57.6)
Household savings			
No	1080 (33.8)	2876 (45.6)	3956 (41.6)
Yes	2120 (66.3)	3425 (54.4)	5545 (58.4)
Sex of household head			
Female	110 (3.4)	501 (8)	611 (6.4)
Male	3090 (96.6)	5799 (92.1)	8889 (93.6)
Source of drinking water			
Tube well	2748 (85.9)	5713 (90.7)	8461 (89.1)
Others	452 (14.1)	588 (9.3)	1040 (11)
Household dietary diversity score			
HDDS \geq 7	2182 (68.2)	5322 (84.5)	7504 (79)
HDDS <7	1018 (31.8)	979 (15.5)	1997 (21)

Indicators, <i>n</i> (%)	Baseline <i>N</i> =3200	Endline <i>N</i> =6300	Total <i>N</i> =9500
Household monthly income (Thousand BDT) ¹	6.7 (5, 10)	7.5 (5.1, 10.8)	7.1 (5, 10.4)
Per capita income (Thousand) ¹	2.6 (1.8, 3.7)	2.9 (2, 4.1)	2.8 (2, 4)
Household size ¹	6.2±2.4	5.9±2.1	6±2.2
Child's age in months ²	17.9±3.5	17.3±3.6	17.5±3.6
Length-for-age z-score ²	-2.1±1.2	-2±1.1	-2±1.1
Weight-for-age z-score ²	-1.7±1.1	-1.5±1.0	-1.5±1.0
Weight-for-length z-score ²	-0.9±1.0	-0.7±0.9	-0.7±1.0
Child's age			
Age <18 months	1745 (54.5)	3710 (58.9)	5455 (57.4)
Age ≥18 months	1455 (45.5)	2594 (41.2)	4049 (42.6)
Child's sex			
Female	1567 (49)	3044 (48.3)	4611 (48.5)
Male	1633 (51)	3257 (51.7)	4890 (51.5)
Child experienced respiratory illness in last 15 days			
Yes	2867 (89.6)	5763 (91.5)	8630 (90.8)
No	333 (10.4)	538 (8.5)	871 (9.2)

¹Median (IQR); ²Mean ± SD.

Associated factors: The factors associated with childhood stunting as determined by model fitting are shown in Table 2. Less than four ANC visits [aOR: 1.16 (95% CI: 1.05, 1.30); *P*=0.005], unskilled birth attendant/facility [aOR: 1.11 (95% CI: 1.02, 1.20); *P*=0.012], mother involved in income-generating activities [aOR: 1.18 (95% CI: 1.02, 1.37); *P*=0.030], maternal BMI <18.5 [aOR: 1.23 (95% CI: 1.12, 1.36); *P*<0.001], maternal education: no schooling [aOR: 1.31 (95% CI: 1.20, 1.42); *P*<0.001], household severely food insecure [aOR: 1.12 (95% CI: 1.00, 1.24); *P*=0.041], household monthly income <15000 BDT [aOR: 1.12 (95% CI: 1.01, 1.25); *P*=0.037], household not involved with aquaculture [aOR: 1.19 (95% CI: 1.03, 1.38); *P*=0.018], having an unhygienic latrine [aOR: 1.20 (95% CI: 1.10, 1.30); *P*<0.001], no soap available in handwashing place [aOR: 1.19 (95% CI: 1.08, 1.30); *P*<0.001], household size >7 [aOR: 1.20 (95% CI: 1.11, 1.31); *P*<0.001], household dietary diversity score <7 [aOR: 1.17 (95% CI: 1.07, 1.29); *P*=0.001], child's age >18 months [aOR: 1.52 (95% CI: 1.39, 1.67); *P*<0.001], child's sex: male [aOR: 1.22 (95% CI: 1.11, 1.34); *P*<0.001], childhood illness in the last 15 days [aOR: 1.20 (95% CI: 1.06, 1.36); *P*=0.003], and no access to mass media [aOR: 1.15 (95% CI: 1.02, 1.30); *P*=0.025] were associated with childhood stunting. Predictive ability of various indicators for the adjusted prevalence of stunting and adjusted prevalence difference (effect size) are given in Supplementary Table 1.

238 Table 2. Logistic regression of factors influencing stunting in children aged 12-23 months.

Indicators	Unadjusted OR (95% CI)	p-value	Adjusted OR (95% CI)	p-value
At least four ANC visits by a skilled service provider				
Yes	Reference		Reference	
No	1.40 (1.26, 1.56)	<0.001	1.16 (1.05, 1.30)	0.005
Birth attendant/facility				
Skilled	Reference		Reference	
Unskilled	1.29 (1.20, 1.39)	<0.001	1.11 (1.02, 1.20)	0.012
Mother involved in income-generating activities				
No	Reference		Reference	
Yes	1.12 (0.97, 1.29)	0.116	1.18 (1.02, 1.37)	0.030
Maternal BMI				
BMI \geq 18.5	Reference		Reference	
BMI <18.5	1.31 (1.19, 1.45)	<0.001	1.23 (1.12, 1.36)	<0.001
Maternal education was primary completed				
Yes	Reference		Reference	
No	1.51 (1.39, 1.64)	<0.001	1.31 (1.20, 1.42)	<0.001
HH food insecurity				
Below severe	Reference		Reference	
Severe	1.34 (1.21, 1.48)	<0.001	1.12 (1.00, 1.24)	0.041
HH monthly income \geq15000 BDT				
Yes	Reference		Reference	
No	1.25 (1.13, 1.37)	<0.001	1.12 (1.01, 1.25)	0.037
Involved with aquaculture				
Yes	Reference		Reference	
No	1.34 (1.16, 1.54)	<0.001	1.19 (1.03, 1.38)	0.018
Hygienic latrine				
Yes	Reference		Reference	
No	1.38 (1.28, 1.50)	<0.001	1.20 (1.10, 1.30)	<0.001
Water and soap available in handwashing place				
Yes	Reference		Reference	
No	1.38 (1.26, 1.52)	<0.001	1.19 (1.08, 1.30)	<0.001
HH size				
Below seven	Reference		Reference	
Seven or above	1.19 (1.10, 1.29)	<0.001	1.20 (1.11, 1.31)	<0.001
HH dietary diversity				
HDDS \geq 7	Reference		Reference	
HDDS <7	1.32 (1.20, 1.44)	<0.001	1.17 (1.07, 1.29)	<0.001
Child's age				
Age \leq 18 months	Reference		Reference	
Age >18 months	1.49 (1.36, 1.63)	<0.001	1.52 (1.39, 1.67)	<0.001
Child's sex				
Female	Reference		Reference	
Male	1.23 (1.12, 1.34)	<0.001	1.22 (1.11, 1.34)	<0.001
Childhood illness in the last 15 days				
No	Reference		Reference	
Yes	1.16 (1.03, 1.31)	0.016	1.20 (1.06, 1.36)	0.003
Access of mass media				
Yes	Reference		Reference	
No	1.39 (1.22, 1.58)	<0.001	1.15 (1.02, 1.30)	0.025

239 Unions were adjusted as clusters. Baseline and endline were adjusted as time variables.

240

241

242 **Model diagnostics:** The Chi-square value for the Hosmer-Lemeshow goodness-of-fit test was
243 9482 ($P=0.430$), which indicated that the model was a good fit. Figure 3A describes the model
244 validation based on sensitivity, specificity, and whether the model was correctly classified for the
245 overall dataset, as well as the training and test datasets. The sensitivity and specificity of the model
246 were 61% and 56%, respectively. The correctly classified rate was 59%, and the area under ROC
247 curve was 0.615 (Figure 3B). We found that these values were approximately equal among the
248 three datasets (main, training, and test datasets); however, the predictive performance of the model
249 was low.

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252 Discussion

253 This study examined data collected during the baseline and endline surveys of the *Suchana*
254 programme to identify factors significantly associated with childhood stunting, with the goal of
255 understanding why this programme did not significantly reduce the prevalence of childhood
256 stunting. After controlling for *union* as a cluster variable, we found numerous factors were
257 significantly associated with stunting, including less than four maternal ANC visits by a skilled
258 service provider, unskilled birth attendant in facility, mothers being involved in earning activities,
259 maternal BMI <18.5, maternal education: no schooling, households being severely food insecure,
260 household monthly income <15000 BDT, no household involvement with aquaculture, having an
261 unhygienic latrine, unavailability of soap in handwashing place, male head of the household,
262 household size >7, household dietary diversity score <7, child's age in months, if the child was
263 male, or if the child experienced respiratory illness in the last 15 days.

264

265 Of these indicators, the status of ANC visits by a skilled service provider, household dietary
266 diversity, household food security, and household monthly income improved after the intervention.
267 Notably, household food security status did not reach its target value of 50%, and this is an
268 important factor associated with childhood stunting^{6 21 22}. Other *Suchana* outcome indicators, such
269 as the dietary diversity of children, maternal dietary diversity, and maternal empowerment, were

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3 270 not associated with stunting in this study. We found a negative association between stunting and
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5 271 maternal involvement in income-generating activities, which means the risk of stunting was higher
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7 272 among children whose mothers were involved in various types of earning activities. The proportion
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9 273 of mothers involved in income-generating activities increased after the study, although the increase
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11 274 was very small.

12 275
13 276 The current study indicates that although some programme indicators improved significantly after
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15 277 the intervention, the *Suchana* programme did not lead to a significant reduction in the prevalence
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17 278 of childhood stunting. The most important factors associated with childhood stunting, such as
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19 279 maternal nutrition and education, having a hygienic latrine, soap being available in handwashing
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21 280 places, and improved sources of drinking water, were not improved after the intervention. More
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23 281 so, both maternal education and nutrition are factors that can only be improved on the large-scale
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25 282 when appropriate measures are taken at the policy-level.

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27 284 This study will help programme managers to prioritize attention when designing appropriate
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29 285 interventions to reduce childhood stunting. In our evaluation study, some important indicators such
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31 286 as maternal undernutrition, low levels of maternal education, household food insecurity,
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33 287 households not being involved with aquaculture, unsanitary latrines, lack of soap in the
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35 288 handwashing place, and child morbidity did not improve—as expected. Therefore, one would only
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37 289 expect childhood stunting to reduce to the target level once these factors are improved or addressed
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39 290 by future programmes/interventions. Implementing short-term initiatives could help to improve
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41 291 some of these factors. *Per se*, attending courtyard workshops and campaigns organized by
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43 292 healthcare practitioners can boost ANC visits, skilled birth attendance and handwashing practices.
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45 293 Greater access to the media can help people in these vulnerable communities to receive the full
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47 294 benefits of government welfare programs. Simply purchasing media and information gadgets can
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49 295 boost households' access to mass media. Food security, income, sanitation, aquaculture, and illness
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51 296 are all time-dependent factors. For instance, to reduce household food insecurity, the yields of
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53 297 produce need to be increased through self-production or purchases to fulfil the dietary demands of
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55 298 all household members. However, a family's ability to acquire appropriate food is also impacted
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57 299 by the family's wealth index, not to mention the number of accessible marketplaces nearby;
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59 300 however, amelioration of all these elements takes a considerable amount of time. Increasing

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3 301 production yields through self-production is also time-consuming. Promotion of aquaculture
4 302 during the *Suchana* programme increased the availability of fish and provided a viable source of
5 303 protein, which resulted in better nutrition and food security; however, establishing such facilities
6 304 also takes a significant amount of time. Furthermore, improved sanitation can only be facilitated
7 305 by improving socioeconomic status, which is also a time-intensive process. National surveys,
8 306 including the BDHS and The Food Security and National Surveillance Project (FSNSP) have
9 307 indicated a substantial amount of time is required to improve stunting. To improve maternal
10 308 nutrition, women should be provided with adequate food to improve their nutritional status during
11 309 adolescence, as children born to malnourished mothers are at a higher risk of malnutrition.
12 310 Moreover, according to a previous literature review, a mother's education is a strong predictor of
13 311 her child's nutritional status. Childhood stunting is significantly associated with the level of
14 312 maternal education, with the children of mothers with either no or less than secondary education
15 313 at higher risk of stunting compared to the children of mothers that have completed secondary
16 314 education or more. Moreover, emphasis on the education of female children may contribute to
17 315 breaking the vicious cycle of poverty and childhood stunting in developing countries like
18 316 Bangladesh. However, both maternal education and nutrition can only be improved on the large-
19 317 scale only when appropriate measures are taken at the policy level. In addition, comprehensive
20 318 initiatives to encourage income-generating activities among women and address domestic violence
21 319 against women should be implemented to help reduce childhood stunting in developing countries.
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38 321 Another important finding based on the post-estimation findings as well as the value of the area
39 322 under the ROC curve was that the predictive performance of the model was low. Thus, we need to
40 323 identify other the indicators that influence childhood stunting that were not included in our model.
41 324 From the literature, environmental enteropathy has been implicated in poor growth among children
42 325 in rural Bangladesh²³. Environmental enteropathy may also represent an important hidden factor
43 326 with respect to the *Suchana* study population. While it was not assessed in this study, some
44 327 indicators of the enteropathogen burden—such as unsanitary latrines, low education, unimproved
45 328 floors, and a lack of handwashing practice—were available in this study^{13 24}. Poultry was one of
46 329 the intervention components. Our qualitative findings revealed that the people in the majority of
47 330 households were living in the same place as their poultry, ducks, or other animals, which may
48 331 increase the risk of infections with *Campylobacter* species, a leading food-borne pathogen^{13 25}.
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3 332 Studies have provided evidence of a strong association between stunting and enteropathy among
4 333 children who fail to respond to nutritional interventions ²⁶. Findings from rural Bangladesh have
5 334 also shown significant associations between environmental conditions and stunting in children ²⁷
6 335 ²⁸. However, assessment of environmental enteropathy was beyond the scope of the *Suchana*
7 336 evaluation. For evaluation purposes, evaluation teams could collect data on indicators of
8 337 enteropathy in the intervention and control areas, and then use the model to assess the impact of
9 338 appropriate interventions.

10 339
11 340 The large sample size, randomization, and appropriate sampling techniques were among the major
12 341 strengths of this study. There was a dedicated quality control team who were involved in checking
13 342 data by re-visiting randomly selected households which had been used to previously collect data.
14 343 We used highly precise anthropometry instruments, and the anthropometry measurement team
15 344 received separate training from a qualified trainer. To avoid seasonality, we conducted the baseline
16 345 and endline surveys at the same time of year. Among the limitations of this study is the fact that
17 346 we did not collect food intake data, but only gathered recall data from the previous 24 hours. These
18 347 data may be subject to recall bias, thus caution is necessary when drawing conclusions, especially
19 348 for indicators such as dietary diversity, household food insecurity, domestic violence, and maternal
20 349 healthcare.

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23 352 **Conclusion**

24 353 By acknowledging that undernutrition is a complex problem caused by a variety of factors, the
25 354 *Suchana* model offers a holistic and integrated approach to tackling food and nutrition security.
26 355 The endline survey showed many of the programme indicators improved considerably as a result
27 356 of the intervention. Our model revealed that ANC visits, being attended by an unskilled birth
28 357 attendant, maternal income-generating activities, maternal undernutrition, maternal education,
29 358 food security, household income, participation in aquaculture, an unhygienic latrine, a lack of soap
30 359 availability, male household head, household size, dietary diversity score, child's age, a male child,
31 360 and childhood respiratory illness were all associated with stunting. However, the performance of
32 361 our predictive model was low. Ultimately, the design of *Suchana* offers a meaningful solution to
33 362 tackle undernutrition through a multi-sector approach. However, some additional

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3 363 recommendations related to both nutrition-sensitive and specific activities can be made, which
4 364 could be taken on board and put into action by policy makers. Food security status should be
5 365 improved through sustainable mechanisms. Climate-resilient agricultural technologies should be
6 366 constantly promoted and effectively monitored as a component of recommended improved
7 367 agricultural strategies. Improved capacity for preparedness and response plans against flooding are
8 368 also required, so that poor people are not continuously set back by shocks. Coverage for water,
9 369 sanitation, and hygiene must be increased at the community level. However, the *Suchana*
10 370 programme, one of the largest nutrition interventions ever implemented globally, successfully led
11 371 to positive changes in most critical study indicators. Long-term positive changes in the health and
12 372 livelihoods of the beneficiaries are expected in the years to follow.

13 373
14 374
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3 394 **Conflicts of Interest:** The authors declare no conflict of interest.
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7 396 **Author Contributions:** TA and NC originated the idea for the study and led the protocol design.
8
9 397 MAH conceptualized the manuscript. SMTA, SSR, MJR, MAH, NC, FDF, and TA contributed to
10
11 398 the survey design. MAH performed statistical analysis and drafted the manuscript. NC and ASGF
12
13 399 supervised the work, and critically reviewed and provided feedback for revising the manuscript.
14
15 400 MAH, NC, MA, FDF, FN, AK, RA, BZW, TJS, ASGF, TA, and SSR contributed to the revision
16
17 401 of the final draft for submission. All authors are responsible for the final content of the manuscript.
18

19 403 **Ethics approval:** This study was approved by the Research Review Committee and Ethical
20
21 404 Review Committee, the two obligatory components of the Institutional Review Board (IRB) of
22
23 405 icddr,b (PR-16020). Informed written consent was obtained from study participants.
24

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26 407 **Data availability statement:** The data that support the findings of this study are available on
27
28 408 request from the corresponding author. The data are not publicly available due to privacy and
29
30 409 ethical restrictions.
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3 496 Figure 1. Prevalence of childhood stunting in the intervention and control areas at baseline
4 compared to endline.
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8 499 Figure 2. Results framework and *Suchana* log frame indicators. ANC: antenatal care, HDDS:
9 household dietary diversity score, MDD-w: minimum dietary diversity for women.
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13 502 Figure 3. (A) Predictive performance of the model for stunting based on classification,
14 sensitivity, and specificity in the full, training and test datasets. (B) Area under the receiver
15 operating characteristic (ROC) curve analysis of the predictive performance of the logistic
16 regression model for stunting.
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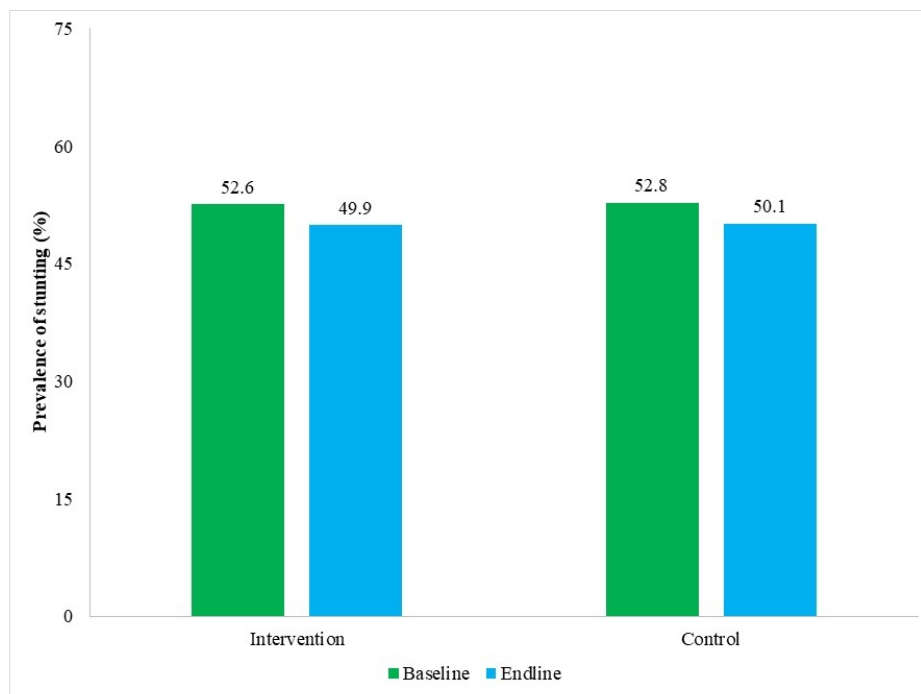


Figure 1. Prevalence of childhood stunting in the intervention and control areas at baseline compared to endline.

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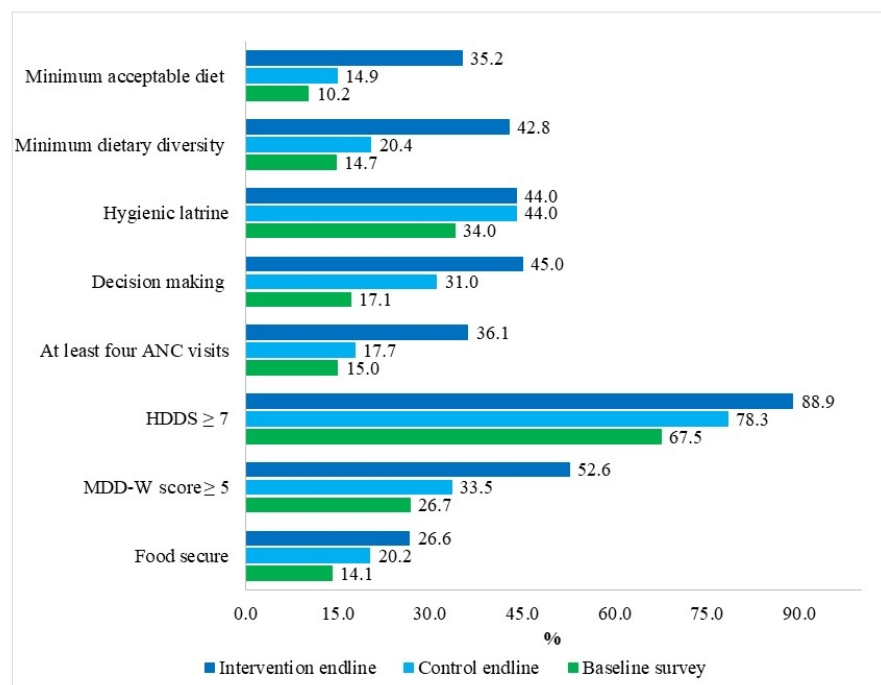


Figure 2. Results framework and Suchana log frame indicators. ANC: antenatal care, HDDS: household dietary diversity score, MDD-w: minimum dietary diversity for women.

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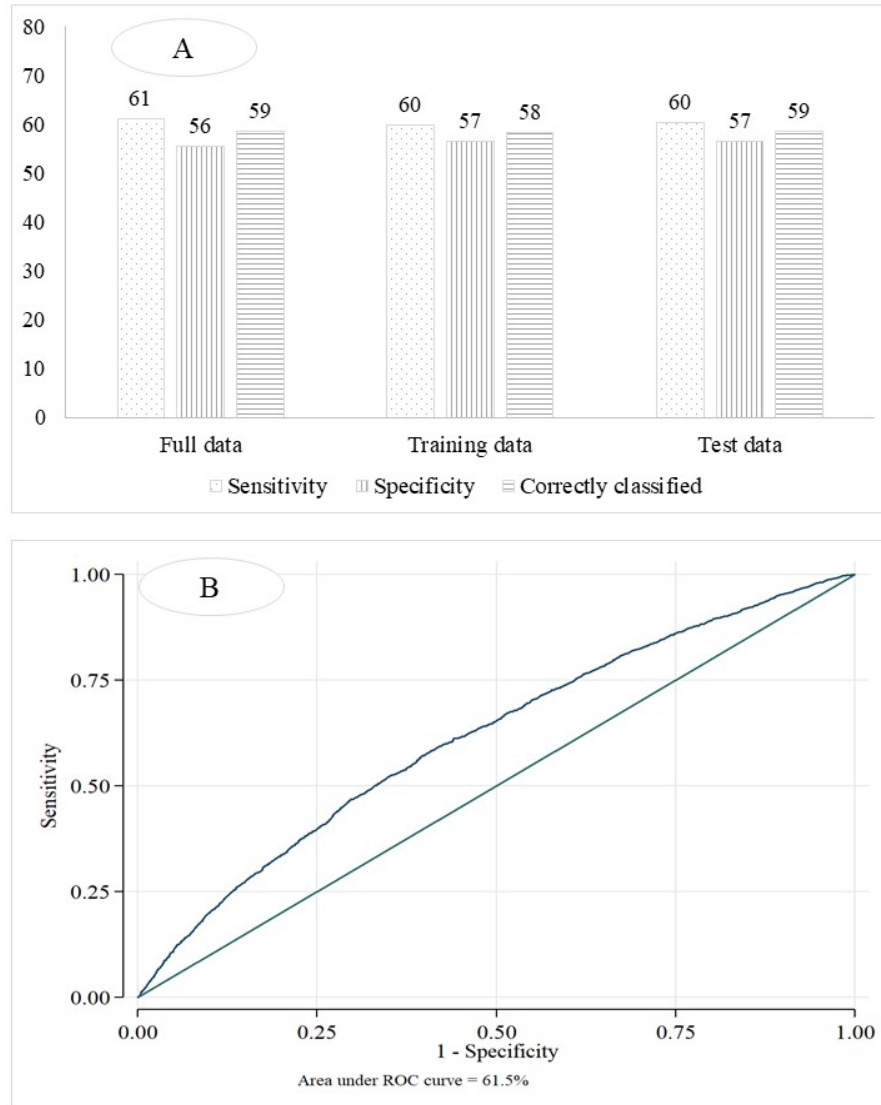


Figure 3. (A) Predictive performance of the model for stunting based on classification, sensitivity, and specificity in the full, training and test datasets. (B) Area under the receiver operating characteristic (ROC) curve analysis of the predictive performance of the logistic regression model for stunting.

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Supplementary Table 1 Predictive ability of various indicators for the adjusted prevalence of stunting and adjusted prevalence difference (effect size) in the fitted multiple logistic regression model.

	Prediction of adjusted stunting [% (95% CI)]	Prediction of adjusted prevalence difference as effect size*	p-value
At least four ANC visits by a skilled service provider			
Yes	51.64 (50.05, 53.23)	Reference	
No	47.99 (45.46, 50.53)	3.65 (1.07, 6.22)	0.006
Birth attendant/facility			
Skilled	51.87 (50.23, 53.51)	Reference	0.000
Unskilled	49.42 (47.48, 51.36)	2.45 (0.55, 4.35)	0.012
Mother involved in income-generating activities			
No	54.55 (50.90, 58.19)	Reference	0.000
Yes	50.59 (49.08, 52.11)	3.95 (0.40, 7.51)	0.029
Maternal BMI			
BMI \geq 18.5	54.04 (52.01, 56.07)	Reference	0.000
BMI <18.5	49.01 (47.21, 50.81)	5.03 (2.66, 7.41)	0.000
Maternal education was primary completed			
Yes	54.66 (52.58, 56.74)	Reference	0.000
No	48.21 (46.67, 49.75)	6.45 (4.49, 8.40)	0.000
HH food insecurity			
Below severe	53.03 (50.91, 55.15)	Reference	0.000
Severe	50.36 (48.63, 52.09)	2.66 (0.11, 5.22)	0.041
HH monthly income \geq15000 BDT			
Yes	51.31 (49.79, 52.84)	Reference	0.000
No	48.58 (45.86, 51.30)	2.73 (0.17, 5.30)	0.037
Involved with aquaculture			
Yes	51.22 (49.72, 52.72)	Reference	0.000
No	46.99 (43.30, 50.69)	4.23 (0.73, 7.73)	0.018
Hygienic latrine			
Yes	52.67 (50.94, 54.4)	Reference	0.000
No	48.36 (46.5, 50.23)	4.31 (2.34, 6.28)	0.000
Water and soap available in handwashing place			
Yes	52.64 (50.71, 54.58)	Reference	0.000
No	48.54 (46.74, 50.33)	4.10 (1.83, 6.38)	0.000
HH size			
Below seven	53.86 (51.98, 55.74)	Reference	0.000
Seven or above	49.41 (47.70, 51.13)	4.44 (2.43, 6.46)	0.000
HH dietary diversity			
HDDS \geq 7	53.92 (51.25, 56.60)	Reference	0.000
HDDS <7	50.10 (48.70, 51.50)	3.83 (1.63, 6.02)	0.000
Child's age			
Age \leq 18 months	56.72 (54.77, 58.67)	Reference	0.000
Age >18 months	46.59 (44.82, 48.35)	10.1 (7.94, 12.32)	0.000
Child's sex			
Female	53.25 (51.17, 55.34)	Reference	0.000
Male	48.40 (46.78, 50.03)	4.85 (2.59, 7.10)	0.000
Childhood illness in the last 15 days			
No	54.90 (52.04, 57.77)	Reference	0.000
Yes	50.49 (48.94, 52.05)	4.41 (1.48, 7.34)	0.003
Access of mass media			
Yes	51.51 (49.88, 53.15)	Reference	0.000
No	48.13 (45.39, 50.88)	3.38 (0.42, 6.34)	0.028

*Differences in the predicted values of stunting between the two groups were calculated using the Stata “*adjrr*” package.

STROBE Statement—Checklist of items that should be included in reports of *cross-sectional studies*

	Item No	Recommendation	Page No
Title and abstract	1	(a) Indicate the study's design with a commonly used term in the title or the abstract	1
		(b) Provide in the abstract an informative and balanced summary of what was done and what was found	1-2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	3-5
Objectives	3	State specific objectives, including any prespecified hypotheses	5
Methods			
Study design	4	Present key elements of study design early in the paper	5
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	5-6
Participants	6	(a) Give the eligibility criteria, and the sources and methods of selection of participants	5-6
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	5-6
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	5-6
Bias	9	Describe any efforts to address potential sources of bias	10
Study size	10	Explain how the study size was arrived at	5
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	5-6
Statistical methods	12	(a) Describe all statistical methods, including those used to control for confounding	6-7
		(b) Describe any methods used to examine subgroups and interactions	
		(c) Explain how missing data were addressed	
		(d) If applicable, describe analytical methods taking account of sampling strategy	6-7
		(e) Describe any sensitivity analyses	
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	7
		(b) Give reasons for non-participation at each stage	
		(c) Consider use of a flow diagram	
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	7
		(b) Indicate number of participants with missing data for each variable of interest	
Outcome data	15*	Report numbers of outcome events or summary measures	7
Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	7-8

		(b) Report category boundaries when continuous variables were categorized	
		(c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	7-8
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	
Discussion			
Key results	18	Summarise key results with reference to study objectives	8-9
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	10
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	9-10
Generalisability	21	Discuss the generalisability (external validity) of the study results	9-10
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	13

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at <http://www.plosmedicine.org/>, Annals of Internal Medicine at <http://www.annals.org/>, and Epidemiology at <http://www.epidem.com/>). Information on the STROBE Initiative is available at www.strobe-statement.org.

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1 A predictive modelling approach to illustrate factors correlating with stunting

2
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15
16 Word count: 4165

17 **Abstract**

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19 **Objective** The goal of this study was to construct a predictive modelling approach using logistic
20 regression analysis. We propose that such a model may help to develop an intervention study to
21 significantly reduce the prevalence of stunting among children aged 12-23 months.

22
23 **Design** A cluster randomized pre-post design was followed to measure the impacts on several
24 indicators of livelihood, health, and nutrition. The study comprised a large dataset that was
25 collected from two cross-sectional studies (baseline and endline).

26
27 **Setting** This study was conducted in the northeastern Bangladeshi city of Sylhet, which is
28 vulnerable to both natural catastrophes and the consequences of poverty. It specifically targeted
29 children between the ages of 12 and 23 months.

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3 31 **Main outcome measures** The outcome variable in this study was childhood stunting, which was
4 32 defined as a length-for-age z-score (LAZ) <-2. A multiple logistic regression model was
5 33 established to predict the factors associated with childhood stunting. The predictive performance
6 34 of the model was assessed by computing classification status based on model sensitivity and
7 35 specificity, and area under the receiver operating characteristic (ROC) curve analysis.
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13 37 **Results** The prevalence of stunting at baseline survey was 52.7%, whereas 50.0% were stunted at
14 38 endline survey. We found that several factors were associated with childhood stunting. The
15 39 sensitivity and specificity of the model were 61% and 56%, respectively. The correctly classified
16 40 rate was 59%, and the area under the ROC curve was 0.615.
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22 42 **Conclusion** Based on the post-estimation findings and area under the ROC curve analysis, the
23 43 predictive performance of the model was low. As a result, it is urgently necessary to identify the
24 44 other factors that significantly influence on childhood stunting but are not included in our model
25 45 and were unavailable in the database.
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31 47 **Study registration:** RIDIE-STUDY-ID-5d5678361809b
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34 49 **Keywords:** Nutrition, Statistics, Epidemiology, Public health
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38 51 **Strengths and limitations of this study**

- 39 52
- 40 53 • More precise anthropometry tools were used to measure the child's length
 - 41 54 • Both parametric and non-parametric models were used and the predictive performance of
42 55 the analytical models was calculated
 - 43 56 • To avoid seasonality, we conducted the baseline and endline surveys at the same time of
44 57 year
 - 45 58 • We did not collect food intake data, but only gathered recall data from the previous 24
46 59 hours
 - 47 60 • Biological data were not collected
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62 Introduction

63 Childhood stunting, which is defined as length-for-age z-score (LAZ) < -2, is a major concern for
64 public health and has been widely used as an indicator of chronic malnutrition in children ¹.
65 Although childhood stunting scenarios have much improved globally, the prevalence of child
66 malnutrition is still very high in low-resource settings, including countries such as Bangladesh.
67 According to the 2018 Global Nutrition Report, 150.8 million children (22.2%) under five years-
68 of-age are stunted globally, compared to 198.4 million (32.6%) and 165 million children in 2000
69 and 2011, respectively ^{2,3}. Asian countries have observed a decrease in the rate of stunting among
70 children under five from 38.1% to 23.2% between 2000 and 2018; nevertheless, South Asia still
71 has the highest prevalence of stunting across the region, at 38.9%. ². In Bangladesh, about 5.5
72 million (36%) children under five were stunted in 2014 ⁴, however by 2018, childhood stunting
73 has reduced to about 31% ⁵. As the World Health Organization (WHO) considers a childhood
74 stunting rate of 15% to be an emergency situation, the current prevalence of childhood stunting in
75 Bangladesh reflects an alarming situation of chronic undernutrition [28].

77 Undernutrition during childhood has several causes, including poor maternal health and nutrition,
78 low maternal education, and inadequate infant and young child feeding (IYCF) practices [28].
79 Moreover, evidence suggests that a number of characteristics at the household level, which relate
80 to both children and mothers, can influence childhood stunting. The characteristics of the
81 household head, household food insecurity, the presence of unhygienic latrines, hand-washing
82 status, household income and savings, household involvement in several earning activities,
83 maternal healthcare service-seeking during pregnancy, household dietary diversity, number of
84 children, maternal nutritional profile, as well as the age and sex of the child are most often reported
85 to be associated with stunting in the literature ⁶⁻¹¹. However, these findings are mostly based on
86 nationally representative cross-sectional and cohort studies, or studies conducted in urban settings
87 ^{12 13}. Therefore, a knowledge gap exists on whether similar results would be obtained when
88 nationwide data are compared with data for study populations from poor or very poor rural
89 households in specific vulnerable regions.

91 Sylhet is one such vulnerable region of north-east Bangladesh, comprising diverse terrains such as
92 plain land, hilly land, *Haor* (wetland), and flash flood-prone areas. This region is reported to

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3 93 perform poorly for all important maternal healthcare indicators ¹⁴, despite the fact that Bangladesh
4 94 has made substantial progress in improving the overall health of the population ¹⁵. Moreover, the
5 95 socio-economic profile of the inhabitants in Sylhet region includes both very rich and extremely
6 96 poor people. This scenario may worsen without the implementation of appropriate strategies in the
7 97 near future. Sylhet region is also performing poorly compared to the national averages for a number
8 98 of health and nutritional indicators. Critical indicators such as the infant mortality rate and
9 99 unemployment status of women are high ¹². In comparison to the overall situation of Bangladesh,
10 100 where stunting among children under five has decreased, the Bangladesh Demographic and Health
11 101 Survey (BDHS) 2014 indicates the prevalence of childhood stunting in Sylhet is astonishingly
12 102 high, at 50% ¹². This alarming figure provided the rationale for implementation of a comprehensive
13 103 intervention programme in this region. A large-scale nutrition programme, *Suchana: Ending the*
14 104 *Cycle of Undernutrition in Bangladesh; a multi-sectoral nutrition programme*, was undertaken
15 105 with the aim to prevent chronic malnutrition in Sylhet.
16 106

17 107 In general, *Suchana* nutrition interventions can be divided into two types: nutrition-sensitive and
18 108 nutrition-specific. The concept of nutrition-sensitive intervention refers to an intervention that
19 109 benefits the beneficiaries in terms of food and nutrition security, and also influences the underlying
20 110 determinants of nutrition. This type of intervention is largely delivered through the agricultural
21 111 sector (homestead vegetable and fruit production, pro-poor nutrition-sensitive aquaculture),
22 112 improved technology (mono-sex tilapia and carp-tilapia polyculture, subsistence fishing, fish
23 113 drying), demonstrations (village model farms and demo ponds, livestock, food security, promotion
24 114 of climate-smart technologies), and supported income-generating activities (skill development in
25 115 business management, engagement with the private sector and other sectors). As nutrition-specific
26 116 interventions were delivered through nutrition-sensitive interventions, their coverage,
27 117 effectiveness, and scale can be increased. It can meet the targets by lowering them and
28 118 implementing nutrition-specific interventions. A nutrition-specific intervention addresses the
29 119 immediate cause of malnutrition. Direct determinants of nutrition are the focus of this intervention.
30 120 There is a strong focus on nutrition-specific interventions in the health sector. Whether
31 121 implemented alone or jointly, nutrition-specific interventions improve health outcomes. Some
32 122 examples of nutrition-specific interventions are: counselling for mothers at the household level,
33 123 community-based nutrition education for spouses and in-laws, growth monitoring and promotion

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3 124 (GMP) sessions integrated with EPI in communities, GoB health facilities equipped with severe
4 125 acute malnutrition (SAM) service delivery, and support for NNS service delivery through
5 126 community clinics, FWCs, and UHCs.
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10 128 The primary objective of the *Suchana* programme was to reduce the prevalence of childhood
11 129 stunting in the intervention areas. The secondary objectives were to assess the changes in *Suchana*
12 130 beneficiaries' households, in terms of an increase and diversification of household income, food
13 131 security status, optimal infant and young child feeding (IYCF) practices, haemoglobin status of
14 132 children, the empowerment of women, and adolescents' nutritional knowledge and practices.
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20 134 The *Suchana* programme substantially improved nutritional behaviour, maternal healthcare
21 135 practices, women's empowerment, household income, and household food security in the
22 136 intervention area compared to the control area¹⁶. Contrary to predictions, however, *Suchana* did
23 137 not result in any significant reduction in the prevalence of childhood stunting. Therefore, although
24 138 most other factors related to childhood stunting improved, this raises the question of why the
25 139 prevalence of stunting did not reduce after the intervention. An important observation from the
26 140 *Suchana* survey was that the proportion of households in this study population using hygienic
27 141 latrines was quite low. This factor was associated with stunting in children⁶, and did not
28 142 significantly improve by endline in the intervention areas compared to the control areas.
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37 144 In this study, we aimed to construct a predictive model to attempt to explain whether any
38 145 improvements in associated factors may promote a significant reduction in stunting among
39 146 children aged 12-23 months from poor and extremely poor households in the Sylhet region.
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44 148 **Methods**

45 149 **Implementation design**

46 150 *Suchana* was implemented in 157 unions over 20 sub-districts in the Sylhet region in the north-
47 151 east of Bangladesh. The *Suchana* program's protocol has been previously thoroughly explained¹⁷.
48 152 Union, the smallest local government and administrative entity in rural Bangladesh, was classified
49 153 as a cluster. Unions were sorted into one of four phases at random. For this study, Phase-1 was the
50 154 study's intervention group, while Phase-4 was the control group¹⁷ and other Phases were treated
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3 155 as learning Phases. For implementation purposes, vulnerable villages were selected within. The
4 156 staff of the programme chose vulnerable villages in each union based on their vulnerability (e.g.,
5 157 frequent floods or submerging, little or no intervention from other development programmes,
6 158 poverty or household living circumstances, remoteness and accessibility issues, a high prevalence
7 159 of superstitions and social taboos). After consultation with local government representatives,
8 160 elected officials, and local elites as well as field visits, this selection method was decided upon.
9 161

15 162 **Evaluation design**

16 163 **Setting:** The impacts of the intervention on livelihood, health, and nutrition were measured using
17 164 a pre-post design. A large dataset was collected from two cross-sectional studies (baseline and
18 165 endline) for the study. The baseline survey was conducted in November 2016 and February 2017,
19 166 followed by the endline survey in the same months three years later.
20 167

21 168 **Sample size:** The sample size was calculated with STATA “*clustersampsi*” command module and
22 169 considered the number of clusters in the surveys (Supplementary file). It was assumed that the
23 170 expected prevalence of childhood stunting in the control group was 47%. Hypothesis was that the
24 171 prevalence would be reduced to 41% after three years of intervention. The estimated sample size
25 172 per arm was 1520 when considering 5% level of significance, 80% power, 40 clusters per arm, and
26 173 an intra cluster correlation coefficient (ICC) of 0.01. After considering the rounding figure, the
27 174 estimated sample size per arm was 1620. The 2nd arm has an equal sample size since it was
28 175 assumed that the sampling ratio between control and intervention groups is 1:1. Then total sample
29 176 size is 3200 at the baseline survey. However, for evaluation purposes, the sample size at endline
30 177 was doubled due to stratification of the intervention component. Finally, 9600 mother-child pairs
31 178 were included in this analysis (baseline: 3200, and endline: 6400) ¹⁷.
32 179

33 180 **Sampling:** Eight villages at baseline survey and twelve villages at endline survey were randomly
34 181 selected from each union using a list of vulnerable villages provided by Save the Children. Once
35 182 the villages were identified, the most vulnerable households were identified, listed and verified
36 183 following the *Suchana* programme inclusion criteria (Supplementary Table 1) and, if eligible for
37 184 the study, given an identification number to prepare the sampling frame. Then, required
38 185 households were systematically selected for the surveys from the frame.
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5 187 **Data collection:** The Suchana data collection software contained built-in validation rules. As the
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7 188 data were entered at the interviewer level and the records were uploaded to a server at the icddr,b
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9 189 using the built-in internet connectivity of the devices, maximum validation rules were set in the
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11 190 data system to prevent errors during data entry, which reduced the data entry burden. This allowed
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13 191 the data analysis team to review the consistency of the data every day. Data were synchronized to
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15 192 the central server “Web Service” developed in Asp.Net based on the C# (C Sharp) code. Activities
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17 193 such as editing (after receiving any feedback from field staff members), updating, range checks,
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19 194 duplication checks, consistency checks, frequency checks and cross tabulation were regularly
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21 195 performed during the data entry period. In case of any unusual observations, the issues were
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23 196 discussed and resolved.

24
25 198 **Variables under study:** The outcome variable in this study was childhood stunting, which was
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27 199 defined as a length-for-age z-score (LAZ) <-2. Initially, a list of several independent variables was
28
29 200 finalized through results obtained from descriptive and bi-variate analyses, as well as a
30
31 201 comprehensive literature review (Table 1). These included at least four ANC visits by a skilled
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33 202 service provider, additional resting during pregnancy, additional food consumption during
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35 203 pregnancy, consumption of at least 100 IFA tablets during pregnancy, receiving vitamin A capsule
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37 204 after last delivery, birth attendant/facility, mother involved in income-generating activities,
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39 205 maternal BMI, maternal education, HH food insecurity, HH monthly income >15000 BDT,
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41 206 involved with aquaculture, hygienic latrine, water and soap available in handwashing place, HH
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43 207 size, HH dietary diversity, sex of household head, religion, received any grant/allowance/stipend
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45 208 from the government, access of mass media, child's age, child's sex, childhood illness in the last
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47 209 15 days, minimum dietary diversity, early initiation of breastfeeding, and received colostrum.
48
49 210 HFIAS was measured using the Food and Nutrition Technical Assistance's Guideline, which
50
51 211 categorizes household food insecurity into four levels: a) food secure, b) mildly food insecure, c)
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53 212 moderately food insecure, and d) severely food insecure¹⁸. In the analysis herein, this indicator
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55 213 was redefined as a binary indicator: severely food insecure or not severely food insecure.

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59 215 **Statistical analysis**

216 **Descriptive statistics:** Stata-14 software (StataCorp LP, College Station, TX, USA) and R 4.2.2
 217 (*rpart*) were used to analyse the data. Several statistical plots were used for data visualization.
 218 Descriptive statistics, such as frequency and proportions for categorical variables and mean and
 219 standard deviations for quantitative variables, were used to summarize the data at baseline and
 220 endline.

222 **Predictive model:** Three statistical models were used as predictive models. Two parametric
 223 models, such as Logistic and Probit regression models, and Decision Tree as a non-parametric
 224 model. Logistic and Probit regression models were used as predictive models as well as classifier
 225 models. The models were also used to investigate which factors were significantly associated with
 226 childhood stunting, and estimate their effect size, in order to predict whether changes in
 227 behavioural practices might potentially help to achieve targeted reductions in stunting. Using those
 228 variables, a decision tree was applied, and the predictive performance was compared to other
 229 models.

231 For the parametric models, first, Chi-Square test was used to examine the bivariate associations
 232 between stunting and all possible explanatory variables. In the second step, variables with *p*-values
 233 <0.25 in the simple model were included in the multiple regression models¹⁹. In the final step, any
 234 independent variables thought to be likely predictors were added to the multiple regression model
 235 using the stepwise forward selection method. Some indicators, e.g., age, sex, and maternal
 236 nutritional status, were added regardless of their *p*-value due to their scientific plausibility. The
 237 mathematical equation of logistic and probit regression models were given in the supplementary
 238 file. As a cluster variable, union was used to adjust the standard errors. Furthermore, for the
 239 explanation of the regression model, a *p*-value <0.05 was considered as significant, and the
 240 confidence interval (CI) of 95% was also reviewed. From the fitted model, the adjusted effect size
 241 (adjusted prevalence difference) against all predictors was estimated using the Stata “*adjrr*”
 242 package. The list of independent variables with the values used in the model is given in Table 1.

243
 244 **Table 1. List of all independent variables**

Indicators	Label	Value/Code	Selection in the model
At least four ANC visits by a skilled service provider			Selected
	At least four ANC visits by a skilled service provider	0	

	Less than four ANC visits by a skilled service provider	1	
	Additional resting during pregnancy		Not selected
	Took more rest	0	
	Did not take more rest	1	
	Additional food consumption during pregnancy		Not selected
	Consumed more food	0	
	Did not consumed more food	1	
	Consumption of at least 100 IFA tablets during pregnancy		Not selected
	Consumed at least 100 IFA tablets	0	
	Did not consumed at least 100 IFA tablets	1	
	Received vitamin A capsule after last delivery		Not selected
	Received	0	
	Did not receive	1	
	Birth attendant/facility		Selected
	Skilled	0	
	Unskilled	1	
	Mother involved in income-generating activities		Selected
	No	0	
	Yes	1	
	Maternal BMI		Selected
	BMI ≥ 18.5	0	
	BMI < 18.5	1	
	Maternal education		Selected
	At least one-year formal education	0	
	No schooling	1	
	HH food insecurity		Selected
	Below severe	0	
	Severe	1	
	HH monthly income ≥ 15000 BDT		Selected
	≥ 15000 BDT	0	
	< 15000 BDT	1	
	Involved with aquaculture		Selected
	Involved	0	
	Did not involved	1	
	Hygienic latrine		Selected
	Hygienic latrine	0	
	Unhygienic latrine	1	
	Water and soap available in handwashing place		Selected
	Available	0	
	Unavailable	1	
	HH size		Selected
	Below seven	0	
	Seven or above	1	
	HH dietary diversity		Selected
	HDHS ≥ 7	0	
	HDHS < 7	1	
	Sex of household head		Not selected
	Female	0	
	Male	1	
	Maternal education		Not selected
	At least one-year formal education	0	
	No schooling	1	
	Religion		Not selected

	Muslim	0	
	Non-Muslim	1	
Received any grant/allowance/stipend from the government			
	Received	0	
	Did not receive	1	
Access of mass media			
	Access	0	Selected
	No access	1	
Child's age			
	Age ≤18 months	0	Selected
	Age >18 months	1	
Child's sex			
	Female	0	Selected
	Male	1	
Childhood illness in the last 15 days			
	No	0	Selected
	Yes	1	
Minimum dietary diversity			
	Received	0	Not selected
	Did not receive	1	
Early initiation of breastfeeding			
	Received	0	Not selected
	Did not receive	1	
Received colostrum			
	Received	0	Not selected
	Did not receive	1	

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247 **Model evaluation:** The predictive performance was assessed by computing the classification status
 248 using model sensitivity and specificity, area under the receiver operating curve (ROC) analysis.
 249 Data were randomly split into a training set (75% of the data) and a test set (25%) with random-
 250 number seed 113843 to calculate the accuracy of the algorithm. The same training and test datasets
 251 were used for all algorithms and performance predictions.

252

253 Patient and public involvement

254 Patients and public were not actively involved in formulating the research question and or protocol
 255 development, including the outcome measures. To expedite the field implementation, however,
 256 local elites e.g. teachers, religious persons, and local government council members were informed
 257 about the study.

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260 Results

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General characteristics: With respect to the outcome indicator, stunting in children aged 12-23 months, 52.7% of children were stunted at the baseline survey (intervention group: 52.6%; control group: 52.8%), whereas the proportion of children exhibiting stunting at endline was 50.0% (intervention: 49.9%; control: 50.1%; Figure 1). Figure 2 describes some other output indicators related to maternal and child health. Status of consuming minimum acceptable diet (intervention: 35.2%; control: 14.9%), minimum dietary diversity (intervention: 42.8%; control: 20.4%), maternal decision making (intervention: 45.0%; control: 31.0%), at least four maternal ANC visits by a skilled service provider (intervention: 36.1%; control: 17.7%), minimum dietary diversity for women (intervention: 52.6%; control: 33.5%), a household dietary diversity score of at least seven (intervention: 88.9%; control: 78.3%), and household food security status (intervention: 26.6%; control: 20.2%) were significantly improved in the intervention group compared to the control group at endline survey. The availability of hygienic latrines (intervention: 44.0%; control: 44.0%) did not increase after the intervention. The households' socio-demographic characteristics, women's general characteristics, and children's characteristics at baseline and endline are shown in Table 2.

Table 2. General characteristics of the *Suchana* beneficiaries

Indicators, <i>n</i> (%)	Baseline <i>N</i> =3200	Endline <i>N</i> =6300	Total <i>N</i> =9500
At least four ANC visits by a skilled service provider			
Yes	408 (12.8)	1530 (24.3)	1938 (20.4)
No	2792 (87.3)	4771 (75.7)	7563 (79.6)
Delivery at skilled birth attendant/facility			
Yes	1000 (31.3)	2769 (44)	3769 (39.7)
No	2200 (68.8)	3532 (56.1)	5732 (60.3)
Had tetanus toxoid injection			
No	834 (26.1)	1131 (18)	1965 (20.7)
Yes	2366 (73.9)	5170 (82.1)	7536 (79.3)
Mother involved in income-generating activities			
No	3102 (96.9)	5665 (89.9)	8767 (92.3)
Yes	98 (3.1)	639 (10.1)	737 (7.8)
Maternal BMI			
BMI \geq 18.5	1859 (58.1)	4073 (64.6)	5932 (62.4)
BMI <18.5	1341 (41.9)	2231 (35.4)	3572 (37.6)
Mother completed primary education			
Yes	1721 (53.8)	3808 (60.4)	5529 (58.2)
No	1479 (46.2)	2496 (39.6)	3975 (41.8)
Maternal age			
Age <30 years	2145 (67)	3559 (56.5)	5704 (60)

Indicators, n (%)	Baseline N=3200	Endline N=6300	Total N=9500
Age ≥30 years	1055 (33)	2745 (43.5)	3800 (40)
Type of delivery			
Normal	2879 (90)	5529 (87.8)	8408 (88.5)
Caesarean	321 (10)	772 (12.3)	1093 (11.5)
PNC			
No	2152 (67.3)	4128 (65.5)	6280 (66.1)
Yes	1048 (32.8)	2173 (34.5)	3221 (33.9)
Household severely food insecure			
Yes	912 (28.5)	1016 (16.12)	1928 (20.3)
No	2288 (71.5)	5285 (83.9)	7573 (79.7)
Household monthly income ≥15000 BDT			
Yes	424 (13.3)	1015 (16.1)	1439 (15.1)
No	2776 (86.8)	5289 (83.9)	8065 (84.9)
Household involved with aquaculture			
Yes	161 (5)	561 (8.9)	722 (7.6)
No	3039 (95)	5740 (91.1)	8779 (92.4)
Hygienic latrine			
Yes	1121 (35)	2782 (44.2)	3903 (41.1)
No	2079 (65)	3519 (55.9)	5598 (58.9)
Water and soap available in handwashing place			
Yes	862 (26.9)	3170 (50.3)	4032 (42.4)
No	2338 (73.1)	3131 (49.7)	5469 (57.6)
Household savings			
No	1080 (33.8)	2876 (45.6)	3956 (41.6)
Yes	2120 (66.3)	3425 (54.4)	5545 (58.4)
Sex of household head			
Female	110 (3.4)	501 (8)	611 (6.4)
Male	3090 (96.6)	5799 (92.1)	8889 (93.6)
Source of drinking water			
Tube well	2748 (85.9)	5713 (90.7)	8461 (89.1)
Others	452 (14.1)	588 (9.3)	1040 (11)
Household dietary diversity score			
HDDS ≥7	2182 (68.2)	5322 (84.5)	7504 (79)
HDDS <7	1018 (31.8)	979 (15.5)	1997 (21)
Household monthly income (Thousand BDT) ¹	6.7 (5, 10)	7.5 (5.1, 10.8)	7.1 (5, 10.4)
Per capita income (Thousand) ¹	2.6 (1.8, 3.7)	2.9 (2, 4.1)	2.8 (2, 4)
Household size ¹	6.2±2.4	5.9±2.1	6±2.2
Child's age in months ²	17.9±3.5	17.3±3.6	17.5±3.6
Length-for-age z-score ²	-2.1±1.2	-2±1.1	-2±1.1
Weight-for-age z-score ²	-1.7±1.1	-1.5±1.0	-1.5±1.0
Weight-for-length z-score ²	-0.9±1.0	-0.7±0.9	-0.7±1.0
Child's age			
Age <18 months	1745 (54.5)	3710 (58.9)	5455 (57.4)
Age ≥18 months	1455 (45.5)	2594 (41.2)	4049 (42.6)
Child's sex			
Female	1567 (49)	3044 (48.3)	4611 (48.5)
Male	1633 (51)	3257 (51.7)	4890 (51.5)
Child experienced respiratory illness in last 15 days			
Yes	2867 (89.6)	5763 (91.5)	8630 (90.8)

Indicators, <i>n</i> (%)	Baseline <i>N</i> =3200	Endline <i>N</i> =6300	Total <i>N</i> =9500
No	333 (10.4)	538 (8.5)	871 (9.2)

¹Median (IQR); ²Mean \pm SD.

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279

280 **Associated factors:** The correlates of childhood stunting as determined using two parametric
281 predictive models are shown in Table 3 and Figure 3. Less than four ANC visits by a skilled service
282 provider, unskilled birth attendant/facility, mother involved in income-generating activities,
283 maternal BMI <18.5, maternal education: no schooling, household severely food insecure,
284 household monthly income <15000 BDT, household not involved with aquaculture, having an
285 unhygienic latrine, no soap available in handwashing place, household size >7, household dietary
286 diversity score <7, child's age >18 months, child's sex: male, childhood illness in the last 15 days,
287 and no access to mass media were significantly correlated with childhood stunting. Predictive
288 ability of various indicators for the adjusted prevalence of stunting and adjusted prevalence
289 difference (effect size) are given in Supplementary Table 2a and 2b.

290

291 Table 3. Factors influencing stunting in children aged 12-23 months, computed using logistic and
292 probit regression analyses

Indicators	Logistic		Probit	
	Adjusted OR (95% CI)	p-value	Adjusted Coef. (95% CI)	p-value
At least four ANC visits by a skilled service provider				
Yes	Reference		Reference	
No	1.16 (1.05, 1.30)	0.005	0.09 (0.03, 0.16)	0.005
Birth attendant/facility				
Skilled	Reference		Reference	
Unskilled	1.11 (1.02, 1.20)	0.012	0.06 (0.01, 0.11)	0.012
Mother involved in income-generating activities				
No	Reference		Reference	
Yes	1.18 (1.02, 1.37)	0.030	0.10 (0.01, 0.19)	0.030
Maternal BMI				
BMI \geq 18.5				
BMI <18.5	1.23 (1.12, 1.36)	0.000	0.13 (0.07, 0.19)	0.000
Maternal education was primary completed				
Yes	Reference		Reference	
No	1.31 (1.20, 1.42)	0.000	0.17 (0.12, 0.22)	0.000
HH food insecurity				
Below severe				
Severe	1.12 (1.00, 1.24)	0.041	0.07 (0.00, 0.13)	0.042
HH monthly income \geq15000 BDT				
Yes	Reference		Reference	
No	1.12 (1.01, 1.25)	0.037	0.07 (0.00, 0.14)	0.035

Involved with aquaculture					
	Yes	Reference		Reference	
	No	1.19 (1.03, 1.38)	0.018	0.11 (0.02, 0.20)	0.018
Hygienic latrine					
	Yes	Reference		Reference	
	No	1.20 (1.10, 1.30)	0.000	0.11 (0.06, 0.16)	0.000
Water and soap available in handwashing place					
	Yes	Reference		Reference	
	No	1.19 (1.08, 1.30)	0.000	0.11 (0.05, 0.16)	0.000
HH size					
	Below seven	Reference		Reference	
	Seven or above	1.20 (1.11, 1.31)	0.000	0.12 (0.06, 0.17)	0.000
HH dietary diversity					
	HDSD ≥ 7	Reference		Reference	
	HDSD < 7	1.17 (1.07, 1.29)	0.001	0.10 (0.04, 0.16)	0.001
Child's age					
	Age ≤ 18 months	Reference		Reference	
	Age > 18 months	1.52 (1.39, 1.67)	0.000	0.26 (0.2, 0.32)	0.000
Child's sex					
	Female	Reference		Reference	
	Male	1.22 (1.11, 1.34)	0.000	0.13 (0.07, 0.18)	0.000
Childhood illness in the last 15 days					
	No	Reference		Reference	
	Yes	1.20 (1.06, 1.36)	0.003	0.11 (0.04, 0.19)	0.003
Access of mass media					
	Yes	Reference		Reference	
	No	1.15 (1.02, 1.30)	0.025	0.09 (0.01, 0.16)	0.025

293 Unions were adjusted as clusters. Baseline and endline were adjusted as time variables.

294

295 **Predictive performance:** Table 4 describes the model validation based on sensitivity, specificity,
 296 and whether the model was correctly classified for the overall dataset, as well as the training and
 297 test datasets. The sensitivity and specificity of the model were around 60% and 55%, respectively
 298 for all models. The correctly classified rate was 59%, and the area under the ROC curve was around
 299 61%. We found that these values were approximately equal among the three datasets (main,
 300 training, and test datasets); however, the predictive performance of the model was low.

301

302 Table 4. Predictive performance of the model for stunting based on classification, sensitivity, and
 303 specificity in the full, training and test datasets with area under the receiver operating characteristic
 304 curve analysis

	Full dataset			Training Dataset			Test Dataset		
	LR	PR	DT	LR	PR	DT	LR	PR	DT
Overall accuracy	58.46	58.38	56.51	58.83	58.62	57.66	58.11	58.19	56.67

Sensitivity	61.21	61.25	61.15	61.59	61.70	63.93	60.23	60.23	61.58
Specificity	55.61	55.41	51.70	55.36	55.42	51.61	55.90	56.07	51.94
Area under the curve	61.54	61.54	56.72	61.37	61.37	58.44	61.76	61.77	58.01

LR: Logistic regression, PR: Probit regression, DT: Decision tree

Discussion

In order to demonstrate why the *Suchana* programme did not significantly lower the prevalence of childhood stunting after intervention, this study examined data from the baseline and endline surveys of the programme to identify factors that significantly correlate with childhood stunting and compute the predictive performance. After controlling for *union* as a cluster variable, we found numerous factors that were significantly correlated with stunting. Of these indicators, the status of ANC visits by a skilled service provider, household dietary diversity, household food security, and household monthly income improved as outcome indicators after the intervention. Notably, household food security status did not reach its target value of 50%, though this is an important factor associated with childhood stunting^{6 20 21}. Other *Suchana* outcome indicators, such as dietary diversity of children, maternal dietary diversity, and maternal empowerment were not associated with stunting in this study.

The current study indicates that although some programme indicators improved significantly after the intervention, the *Suchana* programme did not lead to a significant reduction in the prevalence of childhood stunting. The most important factors associated with childhood stunting, such as maternal nutrition and education, household food security, involvement with aquaculture, having a hygienic latrine, soap being available in handwashing places, and improved sources of drinking water did not improve after the intervention. We found a negative association between stunting and maternal involvement in income-generating activities, which means the risk of stunting was higher among children whose mothers were involved in various types of earning activities. The proportion of mothers involved in income-generating activities increased after the study, although the increase was very small. The essential necessities of the child should not be impeded by the mother's working status.

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3 333 This study will help programme managers in prioritizing attention while designing appropriate
4 334 interventions to reduce childhood stunting. Sustainable interventions should be implemented as
5 335 per the beneficiary's need. Implementing short-term initiatives could help to improve some of
6 336 these factors. *Per se*, attending courtyard workshops and campaigns organized by healthcare
7 337 practitioners can boost ANC visits, skilled birth attendance, and handwashing practices. The
8 338 establishment of women's health care services with a focus on women's health before and during
9 339 pregnancy as well as child nutrition and health would also aid in lowering the extent of growth
10 340 retardation in both the mother and children. Greater access to the media can help people in these
11 341 vulnerable communities receive the full benefits of government welfare programs. Food security,
12 342 income, sanitation, aquaculture, and illness are all time-dependent factors. To satisfy the
13 343 nutritional needs of every household member, for instance, it is necessary to increase production
14 344 yields through self-production or purchasing in order to lower household food insecurity.
15 345 However, a family's wealth index and the quantity of easily accessible marketplaces nearby have
16 346 an impact on their ability to buy nutritious food as well. In agriculture, climate change adaptation
17 347 is essential to minimise current risks, and prepare for future climatic uncertainties. In addition, in
18 348 today's climate, using organic fertilizer inputs in agricultural areas has significant environmental
19 349 benefits over using chemical fertilizers. It can reduce the demand for pesticides, minimize threats
20 350 to human health and biodiversity, and reduce the risk of water contamination. Because of the
21 351 reductions, this may lead to cost savings or cost neutrality. Promotion of aquaculture during the
22 352 *Suchana* programme increased the availability of fish, and provided a viable source of protein,
23 353 which resulted in better nutrition and food security; however, establishing such facilities requires
24 354 a significant amount of time. Furthermore, improved sanitation can only be facilitated by
25 355 improving socioeconomic status, which is also a time-intensive process. National surveys,
26 356 including the BDHS and the Food Security and National Surveillance Project (FSNSP) have
27 357 indicated that a substantial amount of time is required to improve stunting. To improve maternal
28 358 nutrition, women should be provided with adequate food to improve their nutritional status during
29 359 adolescence, as children born to malnourished mothers are at a higher risk of malnutrition.
30 360 Moreover, according to a previous literature review, a mother's education is a strong predictor of
31 361 her child's nutritional status. The level of maternal education has a significant impact on the risk
32 362 of childhood stunting, with children of mothers with no or only a secondary education being more
33 363 at risk than those whose mothers have completed secondary education or more. Moreover, placing

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2
3 364 emphasis on the education of female children may contribute to breaking the vicious cycle of
4 365 poverty and childhood stunting in developing countries like Bangladesh. Therefore, an intricate
5 366 intervention along with nutritional support and food security as well as maternal education might
6
7 367 be worthwhile for short and long-term prevention of childhood stunting. In addition,
8
9 368 comprehensive initiatives to encourage income-generating activities among women and address
10
11 369 domestic violence against women should be implemented to help reduce childhood stunting in
12
13 370 developing countries.

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16 372 Another important finding based on the post-estimation findings as well as the value of the area
17
18 373 under the ROC curve was that the predictive performance of the model was low. Thus, we need to
19
20 374 identify other indicators influencing childhood stunting that were not included in our model. From
21
22 375 the literature, environmental enteropathy has been implicated in poor growth among children in
23
24 376 rural Bangladesh²². Environmental enteropathy may also represent an important hidden factor
25
26 377 with respect to the *Suchana* study population. While it was not assessed in this study, some
27
28 378 indicators of the enteropathogen burden—such as unsanitary latrines, unimproved floors, lack of
29
30 379 handwashing practice, and low education were available in this study^{13 23}. It is possible to reduce
31
32 380 the burden of stunting in young children if improvements are made in WASH variables,
33
34 381 particularly the latrine facilities and handwashing practices. Poultry was one of the intervention
35
36 382 components. Our qualitative findings revealed that people in majority of the households were
37
38 383 sharing their living place with poultry, ducks, or other animals, which may increase the risk of
39
40 384 infections with *Campylobacter* species, a leading food-borne pathogen^{13 24}. Studies have provided
41
42 385 evidence of a strong association between stunting and enteropathy among children who fail to
43
44 386 respond to nutritional interventions²⁵. Findings from rural Bangladesh have also shown significant
45
46 387 association between environmental conditions and stunting in children^{26 27}. However, assessment
47
48 388 of environmental enteropathy was beyond the scope of the *Suchana* evaluation. For evaluation
49
50 389 purposes, evaluation team could collect data on indicators of enteropathy in the intervention and
51
52 390 control areas, and then use the model to assess the impact of appropriate interventions.

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55 392 **Recommendation:** The *Suchana* model offers a holistic and integrated approach in tackling food
56
57 393 and nutrition security by acknowledging undernutrition as a complex problem caused by a variety
58
59 394 of factors. The endline survey of *Suchana* showed that many of the programme indicators have

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3 395 considerably improved as a result of the intervention. Ultimately, the design of Suchana offers a
4
5 396 meaningful solution to confront undernutrition through multi-sector approach. However, some
6
7 397 additional recommendations related to both nutrition-sensitive and specific activities can be made
8
9 398 which could be undertaken by the policy makers. Climate-resilient agricultural technologies
10
11 399 should be promoted and effectively monitored as a component of improved agricultural strategies.
12
13 400 Improved capacity on preparedness and response plan against flooding is compulsory, so that poor
14
15 401 people are not continuously set back by the shocks. Food security situation should be improved
16
17 402 through a sustainable mechanism. Coverage for water, sanitation and hygiene must be increased
18
19 403 at the community level. Innovative approaches need to be tailored to maintain a safe distance and
20
21 404 proper management of livestock and human habitations to prevent pathogens exposed through
22
23 405 poultry droppings from entering the human body. Also, the awareness of seasonal
24
25 406 diseases/infections associated with livestock and poultry should be emphasized through veterinary
26
27 407 treatment and should complete the worming dose or follow-up. Additionally, some indicators such
28
29 408 as child sex, maternal education and nutrition could be adjusted during randomization at the design
30
31 409 level. The *Suchana* programme, one of the largest nutrition interventions ever implemented
32
33 410 globally, successfully led to positive changes in most critical study indicators. Long-term positive
34
35 411 changes in the health and livelihood of the beneficiaries are expected in the years to follow, even
36
37 412 after the programme ends.

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41 414 **Strength and limitation:** The large sample size, randomization, and appropriate sampling
42
43 415 techniques were among the major strengths of this study. A dedicated quality control team was
44
45 416 involved in checking the data by re-visiting randomly selected households. We used highly precise
46
47 417 anthropometry instruments, and the anthropometry measurement team received separate training
48
49 418 from a qualified trainer. To avoid seasonality, we conducted the baseline and endline surveys at
50
51 419 the same time of the year. Among the limitations of this study is the fact that, we did not collect
52
53 420 food intake data, but only gathered recall data of previous 24 hours. These data may be subject to
54
55 421 recall bias; thus, caution is necessary while concluding, especially for indicators such as dietary
56
57 422 diversity, household food insecurity, domestic violence, and maternal healthcare.

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60 424

61 425 **Conclusion**

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3 426 Childhood stunting is heavily influenced by a number of factors that were not included in this
4
5 427 model due to being unavailable in the questionnaire and urgently need to be identified. Policy
6
7 428 makers and programme planners should consider, and enhance the collaboration and coordination
8
9 429 between nutrition-sensitive and specific activities designed to alleviate nutritional deficiencies and
10
11 430 family health programmes.
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2
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458

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460

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4
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8
9 467

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11
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13
14 470 icddr,b (PR-16020). Informed written consent was obtained from study participants.
15
16 471

17 472 **Data availability statement:** The data that support the findings of this study are available on
18
19 473 request from the corresponding author. The data are not publicly available due to privacy and
20
21 474 ethical restrictions.
22
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24 476

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3 559 Figure 1. Prevalence of childhood stunting in the intervention and control areas at baseline
4 560 compared to endline.

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8 562 Figure 2. Results framework and *Suchana* log frame indicators. ANC: antenatal care, HDDS:
9 563 household dietary diversity score, MDD-w: minimum dietary diversity for women.

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11
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13 565 Figure 3. Factors influencing stunting in children aged 12-23 months, computed using decision
14 566 tree analysis
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For peer review only

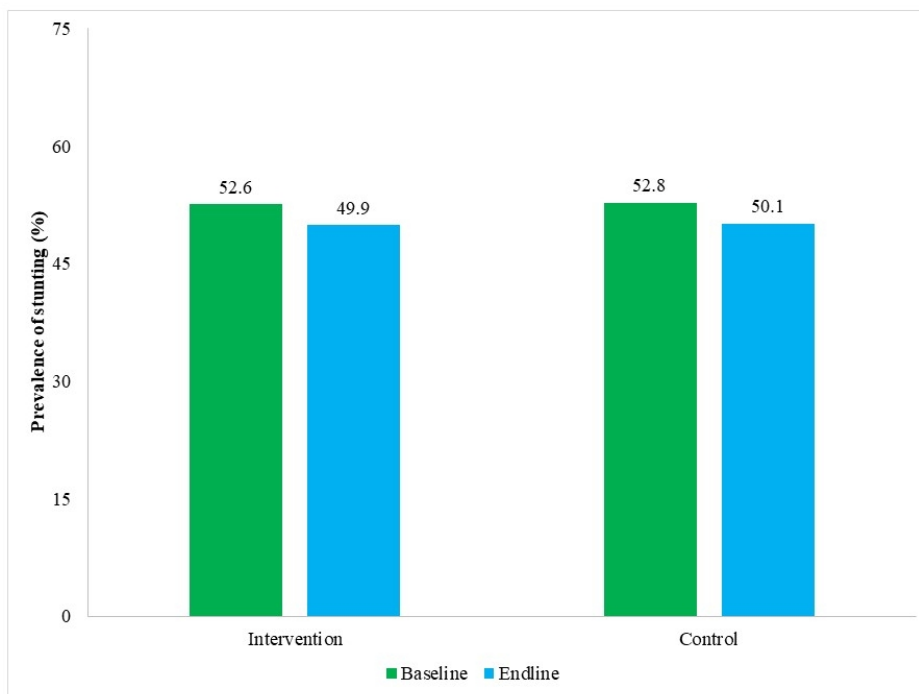


Figure 1. Prevalence of childhood stunting in the intervention and control areas at baseline compared to endline

254x190mm (96 x 96 DPI)

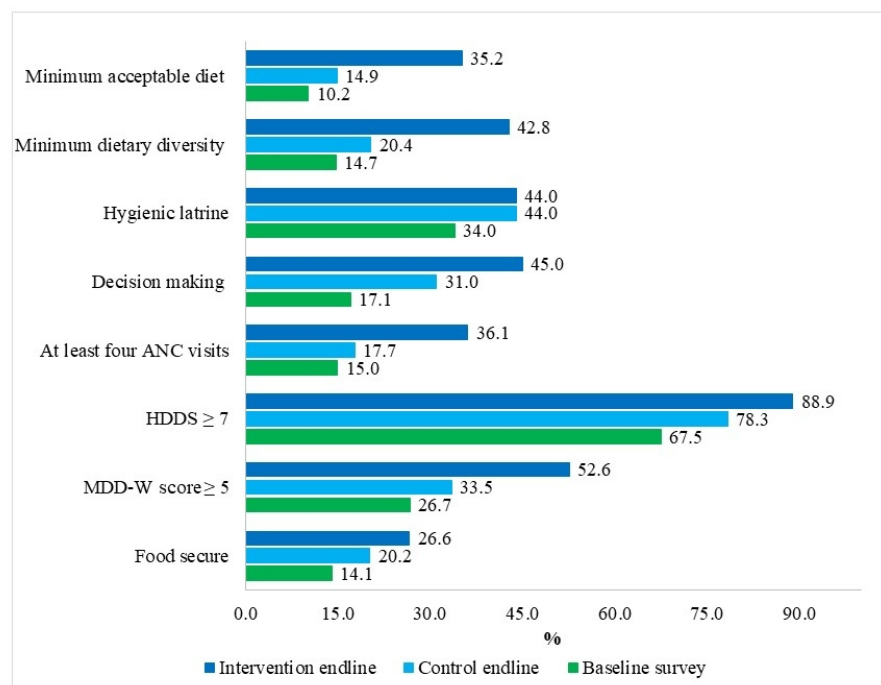


Figure 2. Results framework and Suchana log frame indicators. ANC: antenatal care, HDDS: household dietary diversity score, MDD-w: minimum dietary diversity for women

254x190mm (96 x 96 DPI)

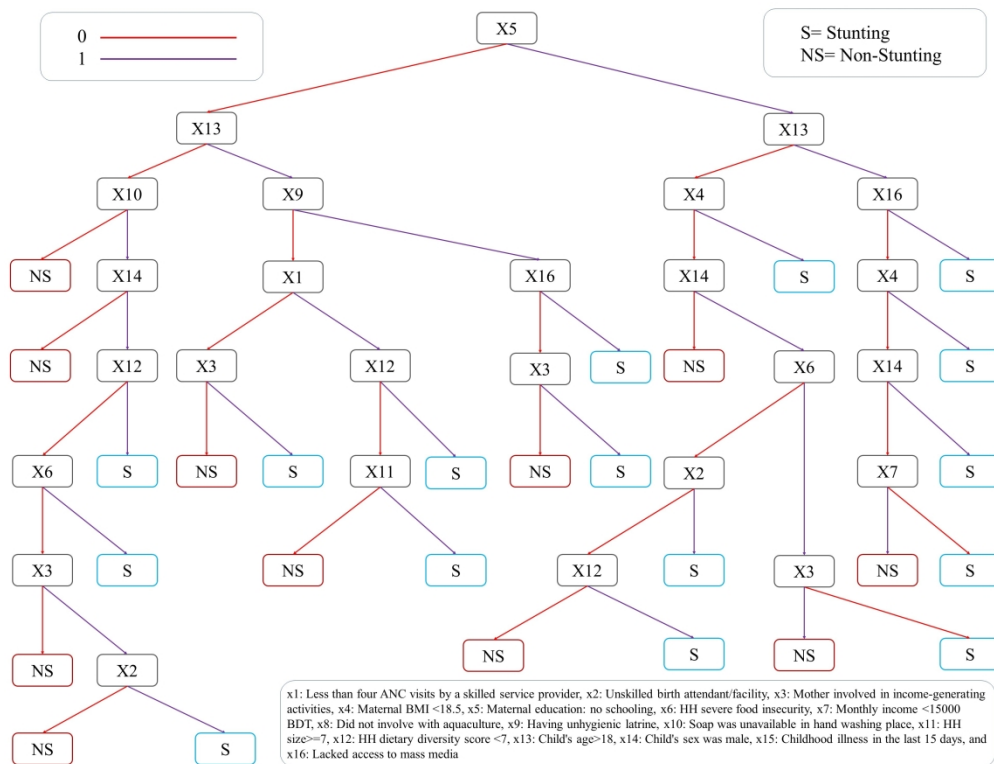


Figure 3. Factors influencing stunting in children aged 12-23 months, computed using decision tree analysis

325x254mm (300 x 300 DPI)

Sample size calculation

```
clustersampsi, binomial samplesize p1(0.47) p2(0.41) k40) rho0.01)alpha(0.05) beta(0.8)
```

Output of the STATA command for sample size calculation

Sample size calculation to determine number of observations required per cluster, for a two-sample comparison of proportions (using normal approximations) without continuity correction.

For the user specified parameters:

```
p1: 0.4700
p2: 0.4100
significance level: 0.05
power: 0.80
number of clusters available: 40
intra cluster correlation (ICC): 0.0100
```

clustersampsi estimated parameters:

```
Firstly, assuming individual randomisation: sample size per arm: 1071
Then, allowing for cluster randomisation: average cluster size required: 38
sample size per arm: 1520
```

Supplementary Table 1. Suchana inclusion criteria for registration of enrolling as vulnerable households

Vulnerable household verification questions	Inclusion criteria
Step 1	
<ul style="list-style-type: none"> Households currently participating/member of any livelihood, food security or asset transfer program 	If “NO” go ahead for next questions
Step 2	
<ul style="list-style-type: none"> Ability to afford three (3) full meals per day for all family members round the year Households monthly income BDT 7,500 or more Household productive asset value worth BDT 15,000 or more (excluding land, pond and homestead) Ownership of homestead land 10 decimals or more Ownership of cultivable land 50 decimals or more (excluding homestead or pond) 	If anyone is “NO” go ahead for next questions
Step 3	
<ul style="list-style-type: none"> Households have married women with in child bearing age (15 to 45 years) Households have pregnant women (including abandoned or widowed woman) Households have 0-23 months old children Households have adolescent girls (15-19 years) 	If anyone is ‘Yes’ go ahead for registration of enrolling as vulnerable Household
Sampling frame was prepared for collecting data from mother-child pair if the households had 0-23 months old children	

Supplementary Equation of logistic and probit regression

$$\text{logit}(y) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 X_6 + \beta_7 X_7 + \beta_8 X_8 + \beta_9 X_9 + \beta_{10} X_{10} + \beta_{12} X_{12} + \beta_{13} X_{13} + \beta_{14} X_{14} + \beta_{15} X_{15} + \beta_{16} X_{16}$$

$$\text{probit}(y) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 X_6 + \beta_7 X_7 + \beta_8 X_8 + \beta_9 X_9 + \beta_{10} X_{10} + \beta_{12} X_{12} + \beta_{13} X_{13} + \beta_{14} X_{14} + \beta_{15} X_{15} + \beta_{16} X_{16}$$

Where,

x1: Less than four ANC visits by a skilled service provider

x2: Unskilled birth attendant/facility

x3: Mother involved in income-generating activities

x4: Maternal BMI <18.5

x5: Maternal education: no schooling

x6: HH severe food insecurity

x7: Monthly income <15000 BDT

x8: Did not involve with aquaculture

x9: Having unhygienic latrine

x10: Soap was unavailable in hand washing place

x11: HH size ≥ 7

x12: HH dietary diversity score <7

x13: Child's age >18

x14: Child's sex was male

x15: Childhood illness in the last 15 days

x16: Lacked access to mass media

and

$$\text{logit}(y) = \log[y/(1-y)]$$

Supplementary Table 2a. Predictive ability of various indicators for the adjusted prevalence of stunting and adjusted prevalence difference (effect size) in the fitted multiple logistic regression model.

	Prediction of adjusted stunting [% (95% CI)]	Prediction of adjusted prevalence difference as effect size*	p-value
At least four ANC visits by a skilled service provider			
Yes	51.64 (50.05, 53.23)	Reference	
No	47.99 (45.46, 50.53)	3.65 (1.07, 6.22)	0.006
Birth attendant/facility			
Skilled	51.87 (50.23, 53.51)	Reference	
Unskilled	49.42 (47.48, 51.36)	2.45 (0.55, 4.35)	0.012
Mother involved in income-generating activities			
No	54.55 (50.90, 58.19)	Reference	
Yes	50.59 (49.08, 52.11)	3.95 (0.40, 7.51)	0.029
Maternal BMI			
BMI ≥ 18.5	54.04 (52.01, 56.07)	Reference	
BMI < 18.5	49.01 (47.21, 50.81)	5.03 (2.66, 7.41)	<0.001
Maternal education was primary completed			
Yes	54.66 (52.58, 56.74)	Reference	
No	48.21 (46.67, 49.75)	6.45 (4.49, 8.40)	<0.001
HH food insecurity			
Below severe	53.03 (50.91, 55.15)	Reference	
Severe	50.36 (48.63, 52.09)	2.66 (0.11, 5.22)	0.041
HH monthly income ≥ 15000 BDT			
Yes	51.31 (49.79, 52.84)	Reference	
No	48.58 (45.86, 51.30)	2.73 (0.17, 5.30)	0.037
Involved with aquaculture			
Yes	51.22 (49.72, 52.72)	Reference	
No	46.99 (43.30, 50.69)	4.23 (0.73, 7.73)	0.018
Hygienic latrine			
Yes	52.67 (50.94, 54.4)	Reference	
No	48.36 (46.5, 50.23)	4.31 (2.34, 6.28)	<0.001
Water and soap available in handwashing place			
Yes	52.64 (50.71, 54.58)	Reference	
No	48.54 (46.74, 50.33)	4.10 (1.83, 6.38)	<0.001
HH size			
Below seven	53.86 (51.98, 55.74)	Reference	
Seven or above	49.41 (47.70, 51.13)	4.44 (2.43, 6.46)	<0.001
HH dietary diversity			
HDDS ≥ 7	53.92 (51.25, 56.60)	Reference	
HDDS < 7	50.10 (48.70, 51.50)	3.83 (1.63, 6.02)	<0.001
Child's age			
Age ≤ 18 months	56.72 (54.77, 58.67)	Reference	
Age > 18 months	46.59 (44.82, 48.35)	10.1 (7.94, 12.32)	<0.001
Child's sex			
Female	53.25 (51.17, 55.34)	Reference	
Male	48.40 (46.78, 50.03)	4.85 (2.59, 7.10)	<0.001
Childhood illness in the last 15 days			
No	54.90 (52.04, 57.77)	Reference	
Yes	50.49 (48.94, 52.05)	4.41 (1.48, 7.34)	0.003
Access of mass media			
Yes	51.51 (49.88, 53.15)	Reference	
No	48.13 (45.39, 50.88)	3.38 (0.42, 6.34)	0.028

*Differences in the predicted values of stunting between the two groups were calculated using the Stata "adjrr" package

Supplementary Table 2b. Predictive ability of various indicators for the adjusted prevalence of stunting and adjusted prevalence difference (effect size) in the fitted multiple probit regression model.

	Prediction of adjusted stunting [% (95% CI)]	Prediction of adjusted prevalence difference as effect size*	p-value
At least four ANC visits by a skilled service provider			
Yes	51.64 (50.05, 53.23)	Reference	
No	47.99 (45.46, 50.53)	3.65 (1.08, 6.22)	0.007
Birth attendant/facility			
Skilled	51.87 (50.23, 53.51)	Reference	
Unskilled	49.42 (47.48, 51.36)	2.45 (0.54, 4.35)	0.011
Mother involved in income-generating activities			
No	54.55 (50.90, 58.16)	Reference	
Yes	50.59 (49.08, 52.11)	3.93 (0.39, 7.48)	0.024
Maternal BMI			
BMI ≥ 18.5	54.04 (52.01, 56.07)	Reference	
BMI < 18.5	49.01 (47.21, 50.81)	5.03 (2.66, 7.40)	<0.001
Maternal education was primary completed			
Yes	54.66 (52.58, 56.74)	Reference	
No	48.21 (46.67, 49.75)	6.45 (4.49, 8.41)	<0.001
HH food insecurity			
Below severe	53.01 (50.89, 55.12)	Reference	
Severe	50.37 (48.64, 52.10)	2.64 (0.09, 5.19)	0.042
HH monthly income ≥ 15000 BDT			
Yes	51.32 (49.79, 52.84)	Reference	
No	48.56 (45.84, 51.28)	2.75 (0.19, 5.32)	0.035
Involved with aquaculture			
Yes	51.22 (49.73, 52.71)	Reference	
No	46.99 (43.28, 50.69)	4.24 (0.73, 7.74)	0.018
Hygienic latrine			
Yes	52.67 (50.94, 54.4)	Reference	
No	48.36 (46.5, 50.23)	4.31 (2.34, 6.28)	<0.001
Water and soap available in handwashing place			
Yes	52.64 (50.71, 54.58)	Reference	
No	48.53 (46.74, 50.33)	4.11 (1.83, 6.39)	<0.001
HH size			
Below seven	53.86 (51.98, 55.73)	Reference	
Seven or above	49.41 (47.70, 51.13)	4.44 (2.43, 6.46)	<0.001
HH dietary diversity			
HDDS ≥ 7	53.90 (51.23, 56.57)	Reference	
HDDS < 7	50.10 (48.71, 51.50)	3.79 (1.60, 5.98)	<0.001
Child's age			
Age ≤ 18 months	56.72 (54.76, 58.67)	Reference	
Age > 18 months	46.59 (44.83, 48.35)	10.1 (7.93, 12.3)	<0.001
Child's sex			
Female	53.25 (51.17, 55.33)	Reference	
Male	48.41 (46.78, 50.03)	4.85 (2.60, 7.10)	<0.001
Childhood illness in the last 15 days			
No	54.90 (52.04, 57.75)	Reference	
Yes	50.50 (48.94, 52.05)	4.40 (1.47, 7.33)	0.003
Access of mass media			
Yes	51.51 (49.88, 53.15)	Reference	
No	48.13 (45.40, 50.86)	3.38 (0.42, 6.34)	0.028

*Differences in the predicted values of stunting between the two groups were calculated using the Stata "adjrr" package

STROBE Statement—Checklist of items that should be included in reports of *cross-sectional studies*

	Item No	Recommendation	Page No
Title and abstract	1	(a) Indicate the study's design with a commonly used term in the title or the abstract	1
		(b) Provide in the abstract an informative and balanced summary of what was done and what was found	1-2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	3-5
Objectives	3	State specific objectives, including any prespecified hypotheses	5
Methods			
Study design	4	Present key elements of study design early in the paper	5-6
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	6
Participants	6	(a) Give the eligibility criteria, and the sources and methods of selection of participants	5-6
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	7
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	5-6
Bias	9	Describe any efforts to address potential sources of bias	10
Study size	10	Explain how the study size was arrived at	5
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	7
Statistical methods	12	(a) Describe all statistical methods, including those used to control for confounding	7-8
		(b) Describe any methods used to examine subgroups and interactions	
		(c) Explain how missing data were addressed	
		(d) If applicable, describe analytical methods taking account of sampling strategy	
		(e) Describe any sensitivity analyses	8
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	11
		(b) Give reasons for non-participation at each stage	
		(c) Consider use of a flow diagram	
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	11
		(b) Indicate number of participants with missing data for each variable of interest	
Outcome data	15*	Report numbers of outcome events or summary measures	11
Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	11-14

		(b) Report category boundaries when continuous variables were categorized	
		(c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	11-14
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	
Discussion			
Key results	18	Summarise key results with reference to study objectives	15
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	15
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	15
Generalisability	21	Discuss the generalisability (external validity) of the study results	15-18
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	20

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at <http://www.plosmedicine.org/>, Annals of Internal Medicine at <http://www.annals.org/>, and Epidemiology at <http://www.epidem.com/>). Information on the STROBE Initiative is available at www.strobe-statement.org.

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A predictive modelling approach to illustrate factors correlating with stunting

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1 A predictive modelling approach to illustrate factors correlating with stunting

2
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13
14 Word count: 4539

15 16 **Abstract**

17 **Objective** The aim of this study was to construct a predictive model in order to develop an
18 intervention study to reduce the prevalence of stunting among children aged 12-23 months.

19
20 **Design** The study followed a cluster randomized pre-post design and measured the impacts on
21 various indicators of livelihood, health, and nutrition. The study was based on a large dataset
22 collected from two cross-sectional studies (baseline and endline).

23
24 **Setting** The study was conducted in the north-eastern region of Bangladesh under the Sylhet
25 division, which is vulnerable to both natural disasters and poverty. The study specifically targeted
26 children between the ages of 12 and 23 months.

27
28 **Main outcome measures** Childhood stunting, defined as a length-for-age z-score (LAZ) <-2 , was
29 the outcome variable in this study. Logistic and probit regression models and a decision tree were
30 constructed to predict the factors associated with childhood stunting. The predictive performance

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3 31 of the models was evaluated by computing the area under the receiver operating characteristic
4 32 (ROC) curve analysis.
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8 34 **Results** The baseline survey showed a prevalence of 52.7% stunting, while 50.0% were stunted at
9 35 endline. Several factors were found to be associated with childhood stunting. The model's
10 36 sensitivity was 61% and specificity was 56%, with a correctly classified rate of 59% and an area
11 37 under the ROC curve of 0.615.
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17 39 **Conclusion** The study showed that childhood stunting in the study area was largely influenced by
18 40 factors such as maternal nutrition and education, food insecurity, and hygiene practices. Despite
19 41 efforts to address these factors, they remain largely unchanged. The study suggests that a more
20 42 effective approach may be developed in future to target adolescent mothers, as maternal nutrition
21 43 and education are age-dependent variables. Policymakers and programme planners need to
22 44 consider incorporating both nutrition-sensitive and specific activities and enhancing collaboration
23 45 in their efforts to improve the health of vulnerable rural populations.
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34 48 **Study registration:** RIDIE-STUDY-ID-5d5678361809b
35 49

36 50 **Keywords:** Predictive model, Nutrition, Statistics, Logistic regression, Probit regression,
37 51 Decision tree
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43 53 **Strengths and limitations of this study**

- 44 54 • Both parametric and non-parametric models were used and the predictive performance of
45 55 the analytical models was calculated
- 46 56 • The study was designed to mitigate potential impact of seasonal factors by conducting the
47 57 baseline and endline surveys at the same time of the year
- 48 58 • Use of recall data from the previous 24 hours for dietary diversity, household food
49 59 insecurity, domestic violence, and maternal healthcare may be subject to recall bias
- 50 60 • Biological data has not been collected such as enteropathogen and environmental enteric
51 61 dysfunction, which could have been related to childhood stunting

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63 Introduction

64 Childhood stunting, which is defined as length-for-age z-score (LAZ)<-2, is a major concern for
65 public health and has been widely used as an indicator of chronic malnutrition in children.¹

66 Although childhood stunting scenarios have much improved globally, the prevalence of childhood
67 stunting is still very high in low-resource settings, including countries such as Bangladesh.

68 According to the 2018 Global Nutrition Report, 150.8 million children (22.2%) under five years-
69 of-age are stunted globally, compared to 198.4 million (32.6%) and 165 million children in 2000
70 and 2011, respectively.^{2,3} Asian countries have observed a decrease in the rate of stunting among
71 children under five from 38.1% to 23.2% between 2000 and 2018; nevertheless, South Asia still
72 has the highest prevalence of stunting across the region, at 38.9%.² In Bangladesh, about 5.5
73 million (36%) children under five were stunted in 2014,⁴ however by 2018, childhood stunting has
74 reduced to about 31%.⁵ As the World Health Organization (WHO) considers a childhood stunting
75 rate of 15% to be an emergency situation, the current prevalence of childhood stunting in
76 Bangladesh reflects an alarming situation of chronic undernutrition.⁶

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78 Literature suggests that the prevalence of stunting is higher in children whose mothers receive
79 appropriate antenatal care, take more rest, consume additional food, and take iron-folic acid (IFA)
80 tablets during pregnancy.⁷⁻⁹ Mass media exposure, receive a vitamin A capsule; have a skilled birth
81 attendant; and have maternal nutritional status and maternal education, both of which are linked to
82 childhood stunting.^{6,8,10-12} On the other hand, in poor households in Bangladesh, children's stunting
83 status is higher among the employed mothers.¹³ Moreover, evidence suggests that a number of
84 characteristics at the household level, which relate to both children and mothers, can influence
85 childhood stunting. The characteristics of the household head, household food insecurity and lower
86 dietary diversity, household lower-income, household involvement in several earning activities,
87 availability of sanitation facility at home, hand-washing status, family size, religion, and receive
88 several types of allowance from government are most often reported to be associated with stunting
89 in the literature.^{6,8,11,14-16}

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91 Based on child characteristics, several indicators are associated with stunting. This status is
92 associated with two basic characteristics: a child's gender and age.⁸ Children are commonly

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3 93 affected by the co-occurrence of illness in low- and middle-income countries, which is one of the
4 94 most common causes of stunting.¹⁷ Inadequate infant and young child feeding (IYCF) practices
5 95 also reduce child growth.^{8 15} However, these findings are mostly based on nationally representative
6 96 cross-sectional and cohort studies, or studies conducted in urban settings.^{18 19} Therefore, a
7 97 knowledge gap exists on whether similar results would be obtained when nationwide data are
8 98 compared with data for study populations from poor or very poor rural households in specific
9 99 vulnerable regions.

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17 101 Sylhet is one such vulnerable region of north-east Bangladesh, comprising diverse terrains such as
18 102 plain land, hilly land, *Haor* (wetland), and flash flood-prone areas. This region is reported to
19 103 perform poorly for all important maternal healthcare indicators,²⁰ despite the fact that Bangladesh
20 104 has made substantial progress in improving the overall health of the population.²¹ Moreover, the
21 105 socio-economic profile of the inhabitants in Sylhet region includes both very rich and extremely
22 106 poor people. This scenario may worsen without the implementation of appropriate strategies in the
23 107 near future. Sylhet region is also performing poorly compared to the national averages for a number
24 108 of health and nutritional indicators. Critical indicators such as the infant mortality rate and
25 109 unemployment status of women are high.¹⁹ In comparison to the overall situation of Bangladesh,
26 110 where stunting among children under five has decreased, the Bangladesh Demographic and Health
27 111 Survey (BDHS) 2014 indicates the prevalence of childhood stunting in Sylhet is astonishingly
28 112 high, at 50%.¹⁹ This alarming figure provided the rationale for implementation of a comprehensive
29 113 intervention programme in this region. A large-scale nutrition programme, *Suchana: Ending the*
30 114 *Cycle of Undernutrition in Bangladesh; a multi-sectoral nutrition programme*, was undertaken
31 115 with the aim to prevent chronic malnutrition in Sylhet.

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45 117 In general, *Suchana* nutrition interventions can be divided into two types: nutrition-sensitive and
46 118 nutrition-specific.²² The concept of nutrition-sensitive intervention refers to an intervention that
47 119 benefits the beneficiaries in terms of food and nutrition security, and also influences the underlying
48 120 determinants of nutrition. This type of intervention is largely delivered through the agricultural
49 121 sector (homestead vegetable and fruit production, pro-poor nutrition-sensitive aquaculture),
50 122 improved technology (mono-sex tilapia and carp-tilapia polyculture, subsistence fishing, fish
51 123 drying), demonstrations (village model farms and demo ponds, livestock, food security, promotion

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3 124 of climate-smart technologies), and supported income-generating activities (skill development in
4 125 business management, engagement with the private sector and other sectors). As nutrition-specific
5 126 interventions were delivered through nutrition-sensitive interventions, their coverage,
6 127 effectiveness, and scale can be increased. It can meet the targets by lowering them and
7 128 implementing nutrition-specific interventions. A nutrition-specific intervention addresses the
8 129 immediate cause of malnutrition. Direct determinants of nutrition are the focus of this intervention.
9 130 There is a strong focus on nutrition-specific interventions in the health sector. Whether
10 131 implemented alone or jointly, nutrition-specific interventions improve health outcomes. Some
11 132 examples of nutrition-specific interventions are: counselling for mothers at the household level,
12 133 community-based nutrition education for spouses and in-laws, growth monitoring and promotion
13 134 sessions integrated with *Expanded Programme on Immunization* in communities, *Government of*
14 135 *Bangladesh* health facilities equipped with *severe acute malnutrition* service delivery, and support
15 136 for *National Nutrition Services* service delivery through community clinics, Union Health and
16 137 Family Welfare Centers, and Upazila health complexes.
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29 139 The primary objective of the *Suchana* programme was to reduce the prevalence of childhood
30 140 stunting in the intervention areas. The secondary objectives were to assess the changes in *Suchana*
31 141 beneficiaries' households, in terms of an increase and diversification of household income, food
32 142 security status, optimal IYCF practices, haemoglobin status of children, the empowerment of
33 143 women, and adolescents' nutritional knowledge and practices.²²
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39 145 The *Suchana* programme substantially improved nutritional behaviour, maternal healthcare
40 146 practices, women's empowerment, household income, and household food security in the
41 147 intervention area compared to the control area.²³ Contrary to predictions, however, *Suchana* did
42 148 not result in any significant reduction in the prevalence of childhood stunting. Therefore, although
43 149 most other factors related to childhood stunting improved, this raises the question of why the
44 150 prevalence of stunting did not reduce after the intervention. An important observation from the
45 151 *Suchana* survey was that the proportion of households in this study population using hygienic
46 152 latrines was quite low. This factor was associated with stunting in children,⁸ and did not
47 153 significantly improve by endline in the intervention areas compared to the control areas.
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3 155 In this study, we aimed to construct a predictive model to attempt to explain whether any
4 156 improvements in associated factors may promote a significant reduction in stunting among
5 157 children aged 12-23 months from poor and extremely poor households in the Sylhet region.
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10 159 **Methods**

11 160 **Study design and setting**

12 161 The *Suchana* programme was implemented in 157 *Unions* over 20 sub-districts in the Sylhet region
13 162 in the north-east of rural Bangladesh. The *Suchana* programme's protocol has been thoroughly
14 163 explained elsewhere.²² *Union*, the smallest local government and administrative entity in rural
15 164 Bangladesh, was considered as a cluster and divided into four phases at random. Phase-1 was
16 165 designated as the intervention group, while Phase-4 was the control group, and the other phases
17 166 were treated as learning phases.²² For implementation purposes, vulnerable villages were selected
18 167 within Phase-1 and Phase-4 areas. The staff of the programme chose vulnerable villages in each
19 168 *Union* based on their vulnerability (e.g., frequent floods or submerging, little or no intervention
20 169 from other development programmes, poverty or household living circumstances, remoteness and
21 170 accessibility issues, a high prevalence of superstitions and social taboos). After consultation with
22 171 the local government representatives, elected officials, and local elites as well as field visits, this
23 172 selection method was decided upon. The impacts of the intervention on livelihood, health, and
24 173 nutrition were measured using a pre-post design. A large dataset was collected from two cross-
25 174 sectional surveys (baseline and endline) under this study. The baseline survey was conducted in
26 175 November 2016 and February 2017, followed by the endline survey in the same months three years
27 176 later among the same population and different participants (Supplementary Figure 1).
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43 178 **Outcome variable**

44 179 The outcome variable in this study was childhood stunting, which was defined as a length-for-age
45 180 z-score (LAZ) <-2 .⁵
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50 182 **Independent variables**

51 183 Initially, a list of independent variables was finalized through results obtained from descriptive
52 184 and bi-variate analyses, as well as a comprehensive literature review (Table 1). These included at
53 185 least four antenatal care (ANC) visits by a skilled service provider, additional resting during
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3 186 pregnancy, additional food consumption during pregnancy, consumption of at least 100 IFA tablets
4 187 during pregnancy, receiving vitamin A capsule after last delivery, birth attendant/facility, mother
5 188 involved in income-generating activities, maternal BMI, maternal education, household food
6 189 insecurity, household monthly income >15000 BDT, involved with aquaculture, hygienic latrine,
7 190 water and soap available in handwashing place, household size, household dietary diversity, sex
8 191 of household head, religion, received any grant/allowance/stipend from the government, access of
9 192 mass media, child's age, child's sex, childhood illness in the last 15 days, minimum dietary
10 193 diversity, early initiation of breastfeeding, and received colostrum. Household food insecurity
11 194 access scale was measured using the Food and Nutrition Technical Assistance's Guideline, which
12 195 categorizes household food insecurity into four levels: a) food secure, b) mildly food insecure, c)
13 196 moderately food insecure, and d) severely food insecure.²⁴ In the analysis herein, this indicator
14 197 was redefined as a binary indicator: severely food insecure or not severely food insecure.
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199 **Sample size**

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27 200 The sample size for this study was calculated with the STATA "*clustersampsi*" command module,
28 201 considering the number of clusters in the surveys and considering the expected prevalence of
29 202 childhood stunting in the control group (Supplemental Appendix 1). It was estimated that the
30 203 expected prevalence of stunting was 47%, which was hypothesized to be reduced to 41% after
31 204 three years of intervention. A sample size of 1520 per arm was calculated based on a 5% level of
32 205 significance, 80% power, 40 clusters per arm, and an intra-cluster correlation coefficient (ICC) of
33 206 0.01. After rounding, the estimated sample size per arm was 1620, and the total sample size was
34 207 3200 at baseline, with an equal number of participants in the control and intervention groups. For
35 208 evaluation purposes, the sample size at endline was doubled to ensure a stratified intervention
36 209 component, resulting in a total sample size of 9600 mother-child pairs (baseline: 3200 and endline:
37 210 6400).²²
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48 212 **Sampling**

49 213 The baseline and endline surveys were conducted in a total of eight and twelve villages
50 214 respectively, which were randomly selected from each *Union* using a list of vulnerable villages
51 215 provided by Save the Children. The most vulnerable households were identified and verified using
52 216 the inclusion criteria of the *Suchana* programme (Supplementary Table 1). These households were
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3 217 then given an identification number to prepare the sampling frame and required households were
4 218 systematically selected for the surveys from the frame. The method of data collection is explained
5 219 in detail in the Supplemental Appendix 2.
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222 **Statistical analysis**

223 **Descriptive statistics:** Stata-14 software (StataCorp LP, College Station, TX, USA) and R 4.2.2
224 (*rpart*) were used to analyse the data. Several statistical plots were used for data visualization.
225 Descriptive statistics, such as frequency and proportions for categorical variables and mean and
226 standard deviations for quantitative variables, were used to summarize the data at baseline and
227 endline.
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229 **Predictive model:** Three statistical models were used as predictive models. Two parametric
230 models, such as Logistic and Probit regression models, and Decision Tree as a non-parametric
231 model. Logistic and Probit regression models were used as predictive models as well as classifier
232 models. The models were also used to investigate which factors were significantly associated with
233 childhood stunting, and estimate their effect size, in order to predict whether changes in
234 behavioural practices might potentially help to achieve targeted reductions in stunting. Using those
235 variables, a decision tree was applied, and the predictive performance was compared to other
236 models.
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238 For the parametric models, first, Chi-Square test was used to examine the bivariate associations
239 between stunting and all possible explanatory variables. In the second step, variables with p -values
240 <0.25 in the simple model were included in the multiple regression models.²⁵ In the final step, any
241 independent variables thought to be likely predictors were added to the multiple regression model
242 using the stepwise forward selection method. Some indicators, e.g., age, sex, and maternal
243 nutritional status were added regardless of their p -value due to their scientific plausibility. The
244 mathematical equation of logistic and probit regression models were given in the Supplemental
245 Appendix 3. As a cluster variable, *Union* was used to adjust the standard errors. Furthermore, for
246 the explanation of the regression model, a p -value <0.05 was considered as statistically significant,
247 and the confidence interval (CI) of 95% was also reviewed. From the fitted model, the adjusted
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248 effect size (adjusted prevalence difference) against all predictors was estimated using the “*adjrr*”
 249 package in Stata. The list of independent variables with the value labels used in the model is given
 250 in Table 1.

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253 **Table 1. List of all independent variables**

Indicators	Code	Stunting Status*	Selection in the model
At least four ANC visits by a skilled service provider			Selected
At least four ANC visits by a skilled service provider	0		
Less than four ANC visits by a skilled service provider	1	Higher prevalence ⁸	
Additional resting during pregnancy			Not selected
Took more rest	0		
Did not take more rest	1	Higher prevalence ⁸	
Additional food consumption during pregnancy			Not selected
Consumed more food	0		
Did not consumed more food	1	Higher prevalence ^{7,8}	
Consumption of at least 100 IFA tablets during pregnancy			Not selected
Consumed at least 100 IFA tablets	0		
Did not consumed at least 100 IFA tablets	1	Higher prevalence ⁹	
Received vitamin A capsule after last delivery			Not selected
Received	0		
Did not receive	1	Higher prevalence ⁸	
Birth attendant/facility			Selected
Skilled	0		
Unskilled	1	Higher prevalence ¹⁰	
Mother involved in income-generating activities			Selected
No	0		
Yes	1	Higher prevalence ^{6,13}	
Maternal BMI			Selected
BMI ≥ 18.5	0		
BMI < 18.5	1	Higher prevalence ^{6,11}	
Maternal education			Selected
At least one-year formal education	0		
No schooling	1	Higher prevalence ^{6,11}	
Access of mass media			Selected
Access	0		
No access	1	Higher prevalence ¹²	
Household food insecurity			Selected
Below severe	0		
Severe	1	Higher prevalence ⁸	
Household monthly income ≥ 15000 BDT			Selected
≥ 15000 BDT	0		
< 15000 BDT	1	Higher prevalence ¹¹	
Involved with aquaculture			Selected
Involved	0		
Did not involved	1	Higher prevalence ¹⁴	
Hygienic latrine			Selected
Hygienic latrine	0		

	Unhygienic latrine	1	Higher prevalence ^{6 11 15}	
	Water and soap available in handwashing place			
	Available	0		Selected
	Unavailable	1	Higher prevalence ¹⁵	
	Household size			
	Below seven	0		Selected
	Seven or above	1	Higher prevalence ¹¹	
	Household dietary diversity (HDDS)			
	HDDS ≥ 7	0		Selected
	HDDS < 7	1	Higher prevalence ⁸	
	Sex of household head			
	Female	0		Not selected
	Male	1	Higher prevalence ⁸	
	Household head education			
	At least one-year formal education	0		Not selected
	No schooling	1	Higher prevalence ⁶	
	Religion			
	Muslim	0		Not selected
	Non-Muslim	1	Lower prevalence ⁶	
	Received any grant/allowance/stipend from the government			
	Received	0		Not selected
	Did not receive	1	Higher prevalence ¹⁶	
	Child's age			
	Age ≤ 18 months	0		Selected
	Age > 18 months	1	Higher prevalence ⁸	
	Child's sex			
	Female	0		
	Male	1	Higher prevalence ⁸	
	Childhood illness in the last 15 days			
	No	0		Selected
	Yes	1	Higher prevalence ¹⁷	
	Minimum dietary diversity			
	Received	0		Not selected
	Did not receive	1	Higher prevalence ^{8 15}	
	Early initiation of breastfeeding			
	Received	0		Not selected
	Did not receive	1	Higher prevalence ⁸	
	Received colostrum			
	Received	0		Not selected
	Did not receive	1	Higher prevalence ⁸	

¹Expected effects based on findings of the literature

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256 **Model evaluation:** The predictive performance of the three statistical models was evaluated by
 257 computing model sensitivity and specificity, and calculating the area under the receiver operating
 258 curve (ROC) analysis. To ensure accurate results, the data was randomly split into a training set
 259 (75%) and a test set (25%) using a random-number seed 113843. The same training and test
 260 datasets were used for evaluating the performance of all algorithms to ensure consistency in the

261 results. The sensitivity and specificity values, as well as the area under the ROC curve, were used
262 to determine the overall accuracy of the algorithms in predicting childhood stunting.^{26 27}

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264 **Patient and public involvement**

265 Patients and public were not actively involved in formulating the research question and or protocol
266 development, including the outcome measures. To expedite the field implementation, however,
267 local elites e.g. teachers, religious persons, and local government council members were informed
268 about the study.

269

270 **Results**

271 **General characteristics:** Out of 9600 cases, 9501 cases were found to be available. The refusal
272 rate was around 1%. With respect to the outcome indicator, stunting in children aged 12-23 months,
273 52.7% of children were stunted at the baseline survey (intervention group: 52.6%; control group:
274 52.8%), whereas the proportion of children exhibiting stunting at endline was 50.0% (intervention:
275 49.9%; control: 50.1%; Figure 1). At both the baseline and endline surveys, there was no
276 significant difference in proportion between intervention and control areas. The *difference-in-*
277 *difference* in outcomes over time was also insignificant.

278

279 Figure 2 describes several other indicators related to maternal and child health, including the status
280 of consuming a minimum acceptable diet (intervention: 35.2%; control: 14.9%), minimum dietary
281 diversity (intervention: 42.8%; control: 20.4%), maternal decision-making (intervention: 45.0%;
282 control: 31.0%), at least four maternal ANC visits by a skilled service provider (intervention:
283 36.1%; control: 17.7%), minimum dietary diversity for women (intervention: 52.6%; control:
284 33.5%), a household dietary diversity score of at least seven (intervention: 88.9%; control: 78.3%),
285 and household food security status (intervention: 26.6%; control: 20.2%). Results from the endline
286 survey showed that these indicators were significantly improved in the intervention group
287 compared to the control group. However, the availability of hygienic latrines did not increase in
288 the intervention group (intervention: 44.0%; control: 44.0%). Table 2 shows the
289 households' socio-demographic characteristics, women's general characteristics, and children's
290 characteristics at baseline and endline.

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293 **Table 2. General characteristics of the *Suchana* beneficiaries**

Indicators, <i>n</i> (%)	Baseline <i>N</i> =3200	Endline <i>N</i> =6301	Total <i>N</i> =9501
At least four ANC visits by a skilled service provider			
Yes	408 (12.8)	1530 (24.3)	1938 (20.4)
No	2792 (87.2)	4771 (75.7)	7563 (79.6)
Delivery at skilled birth attendant/facility			
Yes	1000 (31.2)	2769 (44.0)	3769 (39.7)
No	2200 (68.8)	3532 (56.0)	5732 (60.3)
Access of mass media			
Access	563 (17.59)	1169 (18.55)	1732 (18.23)
No access	2637 (82.41)	5132 (81.45)	7769 (81.77)
Mother involved in income-generating activities			
No	3102 (96.9)	5665 (89.9)	8767 (92.2)
Yes	98 (3.1)	639 (10.1)	737 (7.8)
Maternal BMI			
BMI \geq 18.5	1859 (58.1)	4073 (64.6)	5932 (62.4)
BMI <18.5	1341 (41.9)	2231 (35.4)	3572 (37.6)
Mother completed primary education			
Yes	1721 (53.8)	3808 (60.4)	5529 (58.2)
No	1479 (46.2)	2496 (39.6)	3975 (41.8)
Maternal age			
Age <30 years	2145 (67.0)	3559 (56.5)	5704 (60.0)
Age \geq 30 years	1055 (33.0)	2745 (43.5)	3800 (40.0)
Type of delivery			
Normal	2879 (90.0)	5529 (87.8)	8408 (88.5)
Caesarean	321 (10.0)	772 (12.3)	1093 (11.5)
PNC			
No	2152 (67.3)	4128 (65.5)	6280 (66.1)
Yes	1048 (32.8)	2173 (34.5)	3221 (33.9)
Household severely food insecure			
Yes	912 (28.5)	1016 (16.1)	1928 (20.3)
No	2288 (71.5)	5285 (83.9)	7573 (79.7)
Household monthly income \geq15000 BDT			
Yes	424 (13.2)	1015 (16.1)	1439 (15.1)
No	2776 (86.8)	5289 (83.9)	8065 (84.9)
Household involved with aquaculture			
Yes	161 (5.0)	561 (8.9)	722 (7.6)
No	3039 (95.0)	5740 (91.1)	8779 (92.4)
Hygienic latrine			
Yes	1121 (35.0)	2782 (44.1)	3903 (41.1)
No	2079 (65.0)	3519 (55.9)	5598 (58.9)
Water and soap available in handwashing place			
Yes	862 (26.9)	3170 (50.3)	4032 (42.4)
No	2338 (73.1)	3131 (49.7)	5469 (57.6)
Household savings			
No	1080 (33.8)	2876 (45.6)	3956 (41.6)

	Yes	2120 (66.2)	3425 (54.4)	5545 (58.4)
Sex of household head				
	Female	110 (3.4)	501 (8.0)	611 (6.4)
	Male	3090 (96.6)	5799 (92.0)	8889 (93.6)
Source of drinking water				
	Tube well	2748 (85.9)	5713 (90.7)	8461 (89.0)
	Others	452 (14.1)	588 (9.3)	1040 (11.0)
Household dietary diversity score				
	HDDS ≥ 7	2182 (68.2)	5322 (84.5)	7504 (79.0)
	HDDS < 7	1018 (31.8)	979 (15.5)	1997 (21.0)
Household monthly income (Thousand BDT)¹				
Per capita income (Thousand)¹				
Household size¹				
Child's age in months²				
Length-for-age z-score²				
Weight-for-age z-score²				
Weight-for-length z-score²				
Child's age				
	Age < 18 months	1745 (54.5)	3710 (58.9)	5455 (57.4)
	Age ≥ 18 months	1455 (45.5)	2594 (41.1)	4049 (42.6)
Child's sex				
	Female	1567 (49.0)	3044 (48.3)	4611 (48.5)
	Male	1633 (51.0)	3257 (51.7)	4890 (51.5)
Childhood illness in the last 15 days				
	Yes	2867 (89.6)	5763 (91.5)	8630 (90.8)
	No	333 (10.4)	538 (8.5)	871 (9.2)

¹Median (IQR); ²Mean \pm SD

Associated factors: The study used two parametric predictive models to determine the correlates of childhood stunting. The results, presented in Table 3, showed the adjusted odds ratios (aOR) computed from multiple logistic regression and the adjusted coefficients computed from multiple probit regression. These results provide important insights into the factors that increase the odds of stunting in childhood, and can inform public health interventions aimed at reducing stunting and improving child health. The aORs provide a quantitative measure of the relationship between different factors and childhood stunting, adjusting for *Union* as cluster variable. Understanding the correlates of childhood stunting is critical for addressing this important public health issue and improving the health and well-being of children globally. The results of this study show that a number of maternal, household and children factors were correlated with an increased prevalence of stunting in children. Children of mothers who did not receive at least four ANC visits from a skilled service provider had 1.16 times higher odds of stunting (95% CI: 1.05, 1.30; p-value=0.005). Children of mothers who gave birth with an unskilled birth attendant or facility had

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3 309 1.11 times higher odds of stunting (95% CI: 1.02, 1.20; p-value=0.012). The odds of stunting were
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5 310 1.18 times higher in children whose mothers were involved in income-generating activities (95%
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7 311 CI: 1.02, 1.37; p-value=0.030), 1.23 times higher in children of underweight mothers (95% CI:
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9 312 1.12, 1.36; p-value<0.001), and 1.31 times higher in children of low-educated mothers (95% CI:
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11 313 1.20, 1.42; p-value<0.001). Furthermore, the lack of exposure to mass media was also found to be
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13 314 associated with stunting, with odds of 1.15 (95% CI: 1.02, 1.30; p-value=0.025) times higher.
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15 315 Children from households with severe food insecurity, lower-income households, households not
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17 316 involved in aquaculture, and households with low dietary diversity, were more likely to be stunted,
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19 317 with odds increasing by 1.12 (95% CI: 1.00, 1.24; p-value=0.041), 1.12 (95% CI: 1.01, 1.25; p-
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21 318 value=0.037), 1.19 (95% CI: 1.03, 1.38; p-value=0.018), and 1.17 (95% CI: 1.07, 1.29; p-
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23 319 value=0.001) times, respectively. The results also showed that the odds of stunting increased with
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25 320 increasing household size (95% CI: 1.11, 1.31; p-value<0.001), the absence of a hygienic latrine
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27 321 (95% CI: 1.10, 1.30; p-value<0.001), the absence of water and soap in the handwashing place
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29 322 (95% CI: 1.08, 1.30; p-value<0.001), increasing child age (95% CI: 1.39, 1.67; p-value<0.001),
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31 323 and being male (95% CI: 1.11, 1.34; p-value<0.001). The odds of stunting were also 1.20 times
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33 324 higher in children with acute illness (95% CI: 1.06, 1.36; p-value=0.003). The logistic and probit
34
35 325 regression models were employed to predict stunting in a sample of 9501 individuals. Both models
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37 326 were found to be significant, with log-likelihoods of -6387.94 and -6388.02, respectively, and
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39 327 significant Wald chi-square statistics (p-value < 0.001). The correlations of childhood stunting, as
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41 328 determined by using a decision tree as a non-parametric predictive model, are also presented in
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43 329 Figure 3. Predictive ability of various indicators for the adjusted prevalence of stunting and
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45 330 adjusted prevalence difference (effect size) are given in Supplementary Table 2a and 2b.
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Table 3. Factors influencing stunting in children aged 12-23 months, computed using logistic and probit regression analyses

Indicators	Logistic		Probit	
	Adjusted OR (95% CI)	p-value	Adjusted Coef. (95% CI)	p-value
At least four ANC visits by a skilled service provider				
Yes	Reference		Reference	
No	1.16 (1.05, 1.30)	0.005	0.09 (0.03, 0.16)	0.005
Birth attendant/facility				
Skilled	Reference		Reference	
Unskilled	1.11 (1.02, 1.20)	0.012	0.06 (0.01, 0.11)	0.012

Mother involved in income-generating activities					
	No	Reference		Reference	
	Yes	1.18 (1.02, 1.37)	0.030	0.10 (0.01, 0.19)	0.030
Maternal BMI					
	BMI \geq 18.5				
	BMI <18.5	1.23 (1.12, 1.36)	0.000	0.13 (0.07, 0.19)	0.000
Maternal education was primary completed					
	Yes	Reference		Reference	
	No	1.31 (1.20, 1.42)	0.000	0.17 (0.12, 0.22)	0.000
Access of mass media					
	Yes	Reference		Reference	
	No	1.15 (1.02, 1.30)	0.025	0.09 (0.01, 0.16)	0.025
Household food insecurity					
	Below severe				
	Severe	1.12 (1.00, 1.24)	0.041	0.07 (0.00, 0.13)	0.042
Household monthly income \geq15000 BDT					
	Yes	Reference		Reference	
	No	1.12 (1.01, 1.25)	0.037	0.07 (0.00, 0.14)	0.035
Involved with aquaculture					
	Yes	Reference		Reference	
	No	1.19 (1.03, 1.38)	0.018	0.11 (0.02, 0.20)	0.018
Household size					
	Below seven	Reference		Reference	
	Seven or above	1.20 (1.11, 1.31)	0.000	0.12 (0.06, 0.17)	0.000
Hygienic latrine					
	Yes	Reference		Reference	
	No	1.20 (1.10, 1.30)	0.000	0.11 (0.06, 0.16)	0.000
Water and soap available in handwashing place					
	Yes	Reference		Reference	
	No	1.19 (1.08, 1.30)	0.000	0.11 (0.05, 0.16)	0.000
Household dietary diversity					
	HDDS \geq 7	Reference		Reference	
	HDDS <7	1.17 (1.07, 1.29)	0.001	0.10 (0.04, 0.16)	0.001
Child's age					
	Age \leq 18 months	Reference		Reference	
	Age >18 months	1.52 (1.39, 1.67)	0.000	0.26 (0.2, 0.32)	0.000
Child's sex					
	Female	Reference		Reference	
	Male	1.22 (1.11, 1.34)	0.000	0.13 (0.07, 0.18)	0.000
Childhood illness in the last 15 days					
	No	Reference		Reference	
	Yes	1.20 (1.06, 1.36)	0.003	0.11 (0.04, 0.19)	0.003
Sample size and regression diagnostic values for logistic and probit regression analyses		n = 9501 Log-likelihood = -6387.94 Wald chi2(17) = 427.79 p-value<0.001 Pseudo R ² = 0.0298		n = 9501 Log-likelihood = -6388.02 Wald chi2(17) = 441.18 p-value<0.001 Pseudo R ² = 0.0298	

Unions were adjusted as clusters. Baseline and endline were adjusted as time variables

Predictive performance: Table 4 describes the model validation based on sensitivity, specificity, and whether the model was correctly classified for the overall dataset, as well as the training and

339 test datasets. The sensitivity and specificity of the model were around 60% and 55%, respectively
 340 for all models. The correctly classified rate was 59%, and the area under the ROC curve was around
 341 61%. We found that these values were approximately equal among the three datasets (main,
 342 training, and test datasets); however, the predictive performance of the model was low.

343

344 **Table 4. Predictive performance of the model for stunting based on classification, sensitivity,**
 345 **and specificity in the full, training and test datasets with area under the receiver operating**
 346 **characteristic curve analysis**

	Logistic regression	Probit regression	Decision tree
Full dataset			
Overall accuracy	58.46	58.38	56.51
Sensitivity	61.21	61.25	61.15
Specificity	55.61	55.41	51.70
Area under the curve	61.54	61.54	56.72
Training Dataset			
Overall accuracy	58.83	58.62	57.66
Sensitivity	61.59	61.70	63.93
Specificity	55.36	55.42	51.61
Area under the curve	61.37	61.37	58.44
Test Dataset			
Overall accuracy	58.11	58.19	56.67
Sensitivity	60.23	60.23	61.58
Specificity	55.90	56.07	51.94
Area under the curve	61.76	61.77	58.01

347

348

349 Discussion

350 In an effort to understand why the *Suchana* programme was not effective in reducing the
 351 prevalence of childhood stunting, this study analyzed data from both the baseline and endline
 352 surveys of the programme. The analysis aimed to identify the factors that were significantly
 353 correlated with stunting and to evaluate the model's predictive performance. After controlling for
 354 the *Union* as a cluster variable, the study found several indicators that were significantly related to
 355 stunting. These included the number of ANC visits by a skilled service provider, household dietary
 356 diversity, household food security, and household monthly income, which improved after the
 357 intervention. However, it was noted that the household food security status did not reach the target

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2
3 358 value of 50%, despite being an important factor associated with childhood stunting.^{8 28 29} On the
4
5 359 other hand, other outcome indicators of the *Suchana* programme, such as dietary diversity of
6
7 360 children, maternal dietary diversity, and maternal empowerment, despite reaching their target
8
9 361 values, were not found to be associated with stunting in this study.

10 362
11
12 363 The recent study found that while the *Suchana* programme showed improvement in certain
13
14 364 programme indicators, it did not lead to a significant reduction in childhood stunting. Despite
15
16 365 efforts to address key factors such as maternal nutrition and education, household food security,
17
18 366 and hygiene practices, these factors remained largely unchanged. However, the study suggests that
19
20 367 interventions aimed at adolescent mothers may be more effective in improving maternal nutrition
21
22 368 and education, since these are age-dependent variables. Additionally, the results of the study were
23
24 369 also impacted by natural disasters in 2017, including heavy rains and flooding in the Sylhet region,
25
26 370 which resulted in widespread damage to agriculture, aquaculture, and homes in the study
27
28 371 population.^{30 31}

29 372
30
31 373 The study found a contradictory relationship between stunting and maternal involvement in
32
33 374 income-generating activities, with higher stunting prevalence observed among children whose
34
35 375 mothers were engaged in various earning activities. Although there was a slight increase in the
36
37 376 proportion of mothers involved in income-generating activities after the intervention, the lack of
38
39 377 childcare support for working mothers resulted in a marked rise in childhood stunting among low-
40
41 378 income households. It is important to address this issue by providing adequate childcare support
42
43 379 measures for working mothers from poor families, to ensure that the essential needs of the child
44
45 380 are not impacted by the mother's employment status.¹³ Another important finding based on the
46
47 381 post-estimation findings as well as the value of the area under the ROC curve was that the
48
49 382 predictive performance of the model was low. Thus, we need to identify other indicators from
50
51 383 similar research contexts influencing childhood stunting that were not included in our model.

52 384
53
54 385 The literature suggests that environmental enteropathy may contribute to poor growth among
55
56 386 children in rural Bangladesh and may represent an important factor affecting the study population
57
58 387 in the *Suchana* programme.³² Although it was not specifically assessed in this study, indicators
59
60 388 such as unsanitary latrines, unimproved floors, lack of handwashing practices, and low education

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3 389 levels were available.^{18 33} Improving Water, Sanitation and Hygiene (WaSH) variables,
4 390 particularly latrine facilities and handwashing practices, may help reduce the burden of stunting in
5 391 young children. One of the components of the intervention was poultry, but our qualitative findings
6 392 revealed that many households shared living spaces with poultry, ducks, or other animals, which
7 393 could increase the risk of infections with *Campylobacter* species, a leading food-borne pathogen.¹⁸
8 394 ³⁴ Previous studies have shown a strong association between stunting and enteropathy among
9 395 children who do not respond to nutritional interventions, and findings from rural Bangladesh have
10 396 linked environmental conditions and stunting in children.³⁵⁻³⁷ While assessing environmental
11 397 enteropathy was beyond the scope of the *Suchana* evaluation, collecting data on indicators of
12 398 enteropathy in the intervention and control areas could help evaluate the impact of appropriate
13 399 interventions in the future. The failure to achieve the desired outcome may have been due to several
14 400 factors, including food insecurity and a lack of aquaculture involvement due to natural disasters,
15 401 poor WaSH status, a lack of focus on maternal education and nutrition, and a lack of focus on the
16 402 risk of enteropathogen burden.

17 403
18 404 This study will aid programme managers in prioritizing their focus and designing effective
19 405 interventions to reduce childhood stunting. Sustainable solutions should be based on the needs of
20 406 the beneficiaries. Implementing short-term initiatives such as attendance at healthcare-led
21 407 workshops and campaigns can increase ANC visits, skilled birth attendance, and handwashing
22 408 practices. Establishing women's healthcare services that focus on maternal and child health and
23 409 nutrition will also help reduce the incidence of stunting.²³ Improved access to media can help
24 410 vulnerable communities benefit from government welfare programmes. Food security, income,
25 411 sanitation, aquaculture, and illness are all time-sensitive factors. Increasing food production
26 412 through self-production or purchasing can improve household food security and nutrition.
27 413 However, household wealth and access to nearby markets can impact their ability to buy nutritious
28 414 food. Climate change adaptation in agriculture is crucial to minimize current risks and prepare for
29 415 future uncertainties. Using organic fertilizers instead of chemicals in agriculture has environmental
30 416 benefits, reducing the need for pesticides and protecting human health and biodiversity.
31 417 Aquaculture can provide a source of protein and improve nutrition, but establishing these facilities
32 418 takes time. Improving sanitation requires improving socioeconomic status, which is also a time-
33 419 intensive process. It takes time to improve stunting, as shown by national surveys such as BDHS

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2
3 420 and Food Security and National Surveillance Project (FSNSP).^{5 38} To improve maternal nutrition,
4 421 women need adequate food during adolescence and maternal education is a strong predictor of a
5 422 child's nutritional status. Emphasizing the education of female children can break the cycle of
6 423 poverty and stunting.^{6 11} To reduce childhood stunting in developing countries, comprehensive
7 424 interventions that include nutritional support, food security, maternal education, income-
8 425 generating activities for women, and addressing domestic violence against women should be
9 426 implemented.

10 427
11 428
12 429 **Recommendation:** The Suchana model offers a holistic and integrated approach to addressing
13 430 food and nutrition security, recognizing undernutrition as a complex problem caused by multiple
14 431 factors. The endline survey of Suchana showed significant improvement in programme indicators.
15 432 The multi-sector approach of Suchana is a meaningful solution to addressing undernutrition.
16 433 However, policy makers should consider implementing additional nutrition-sensitive and specific
17 434 activities, such as promoting climate-resilient agriculture and increasing water and sanitation
18 435 coverage. It is also important to have a sustainable mechanism for improving food security and to
19 436 promote awareness of seasonal diseases associated with livestock and poultry. To further improve
20 437 the programme, indicators such as child sex, maternal education, and nutrition could be adjusted
21 438 during the design stage. The Suchana programme is one of the largest global nutrition
22 439 interventions, leading to positive changes in critical indicators, with long-term benefits expected
23 440 for the health and livelihoods of the beneficiaries.

24 441
25 442 **Strength and limitation:** The study had several strengths, including a large sample size,
26 443 randomization, and appropriate sampling techniques. A dedicated quality control team was
27 444 involved in checking the data, and the use of precise anthropometry instruments and separate
28 445 training for the measurement team helped ensure accurate data collection. The study was also
29 446 designed to avoid seasonality by conducting the baseline and endline surveys at the same time of
30 447 the year. However, the study results may have been impacted by a lack of selection effect in the
31 448 implementation of the programme, as well as by the short time horizon of the study. The short
32 449 duration of the study may not have been enough to see a significant impact on stunting.
33 450 Additionally, changes in the study population between the baseline and endline surveys could also

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3 451 have contributed to the lack of differences observed in the results. Another limitation of this study
4
5 452 is that we did not collect food intake data but only recall data from the previous 24 hours. These
6
7 453 data may be subject to recall bias; thus, caution is necessary when drawing conclusions, especially
8
9 454 for indicators such as dietary diversity, household food insecurity, domestic violence, and maternal
10
11 455 healthcare.

12 456

13 457

15 458 **Conclusion**

17 459 Childhood stunting was heavily influenced by a number of factors, and majority of the factors
18
19 460 were found in poor status in our study area. Despite the implementation of an intervention
20
21 461 programme, the situation remained unchanged due to factors such as food insecurity, lack of
22
23 462 involvement in aquaculture, poor access to WaSH facilities, and a lack of focus on maternal
24
25 463 education and nutrition. The study did not include important indicators such as enteropathogen
26
27 464 and environmental enteric dysfunction, which might have contributed to the failure to achieve the
28
29 465 desired outcome. The results suggest that policy makers and programme planners should consider
30
31 466 enhancing collaboration and coordination between nutrition-sensitive and specific activities to
32
33 467 address nutritional deficiencies and family health programmes in vulnerable rural populations.

34 468

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37
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41
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43
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1
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11
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16 489
17 490 **Conflicts of Interest:** The authors declare no conflict of interest.
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20 491
21 492 **Author Contributions:** TA and NC originated the idea for the study and led the protocol design.
22 493 MAH conceptualized the manuscript. SMTA, SSR, MAH, NC, FDF, and TA contributed to the
23 494 survey design. MAH performed statistical analysis and drafted the manuscript. NC and ASGF
24 495 supervised the work, and critically reviewed and provided feedback for revising the manuscript.
25 496 MAH, NC, MA, FDF, FN, BZW, TJS, ASGF, TA, and SSR contributed to the revision of the final
26 497 draft for submission. All authors are responsible for the final content of the manuscript.
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31
32 499 **Ethics approval:** This study was approved by the Research Review Committee and Ethical
33 500 Review Committee, the two obligatory components of the Institutional Review Board (IRB) of
34 501 icddr,b. Ethics Committee's approval ID# 00001822. Informed written consent was obtained from
35 502 study participants.
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41 504 **Data availability statement:** The data that support the findings of this study are available on
42 505 request from the corresponding author. The data are not publicly available due to privacy and
43 506 ethical restrictions.
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3 631 Figure 1. Prevalence of childhood stunting in the intervention and control areas at baseline
4
5 632 compared to endline. The p-value of the *difference-in-difference* was estimated using interaction
6
7 633 analysis in the multiple logistic regression model.
8
9 634

10 635 Figure 2. Results framework and *Suchana* log frame indicators. ANC: antenatal care, HDDS:
11
12 636 household dietary diversity score, MDD-w: minimum dietary diversity for women.
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15 638 Figure 3. Factors influencing stunting in children aged 12-23 months, computed using decision
16
17 639 tree analysis.
18
19 640

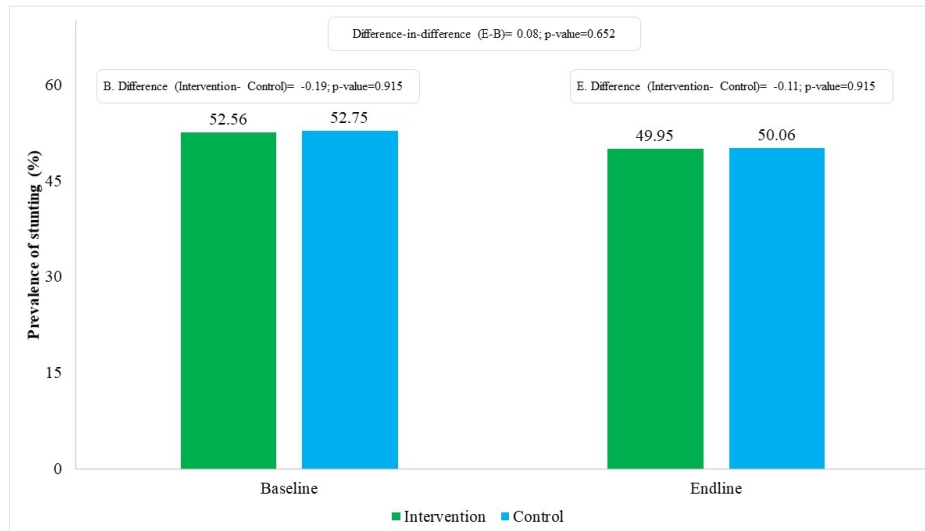


Figure 1. Prevalence of childhood stunting in the intervention and control areas at baseline compared to endline. The p-value of the difference-in-difference was estimated using interaction analysis in the multiple logistic regression model.

338x190mm (96 x 96 DPI)

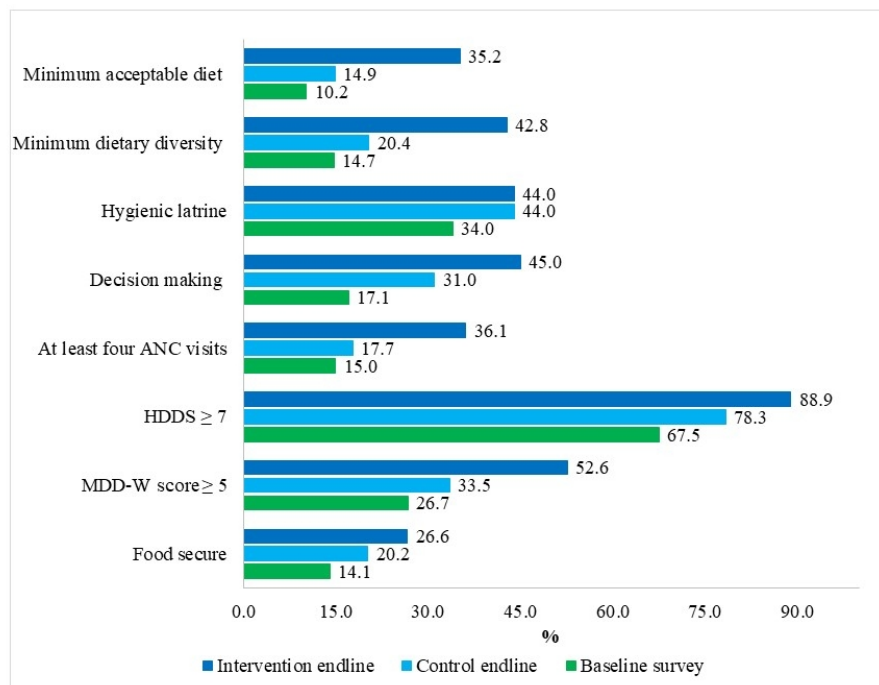


Figure 2. Results framework and Suchana log frame indicators. ANC: antenatal care, HDDS: household dietary diversity score, MDD-w: minimum dietary diversity for women

254x190mm (96 x 96 DPI)

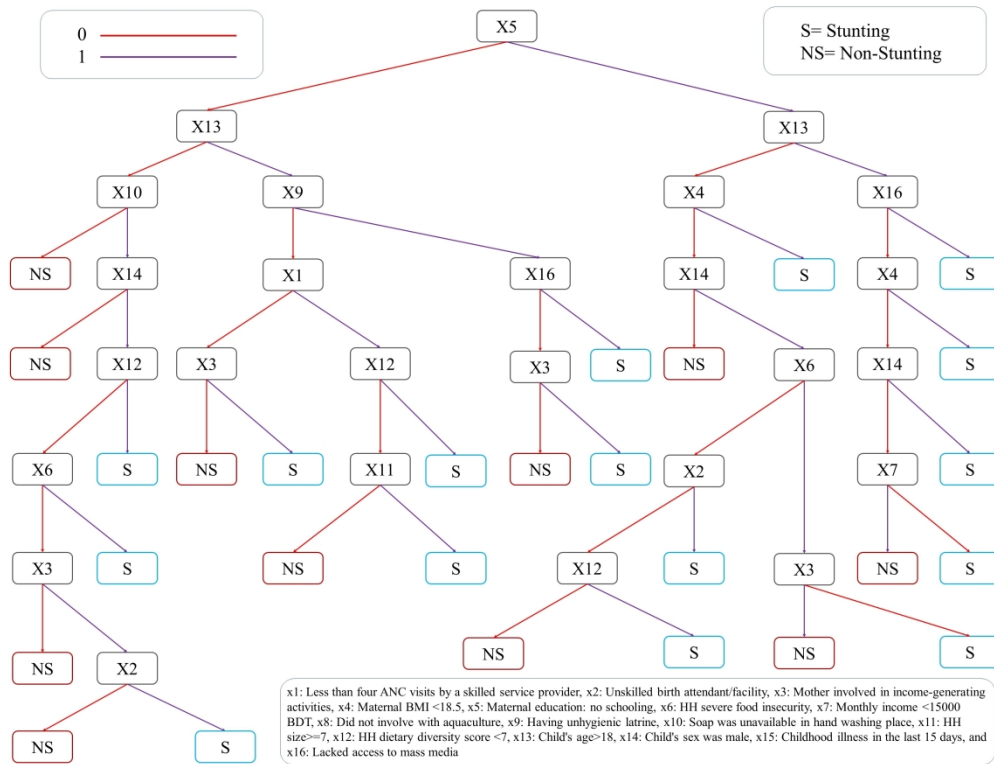


Figure 3. Factors influencing stunting in children aged 12-23 months, computed using decision tree analysis

325x254mm (300 x 300 DPI)

Appendix 1. Sample size calculation

```
clustersampsi, binomial samplesize p1(0.47) p2(0.41) k(40) rho(0.01)alpha(0.05) beta(0.8)
```

Output of the STATA command for sample size calculation

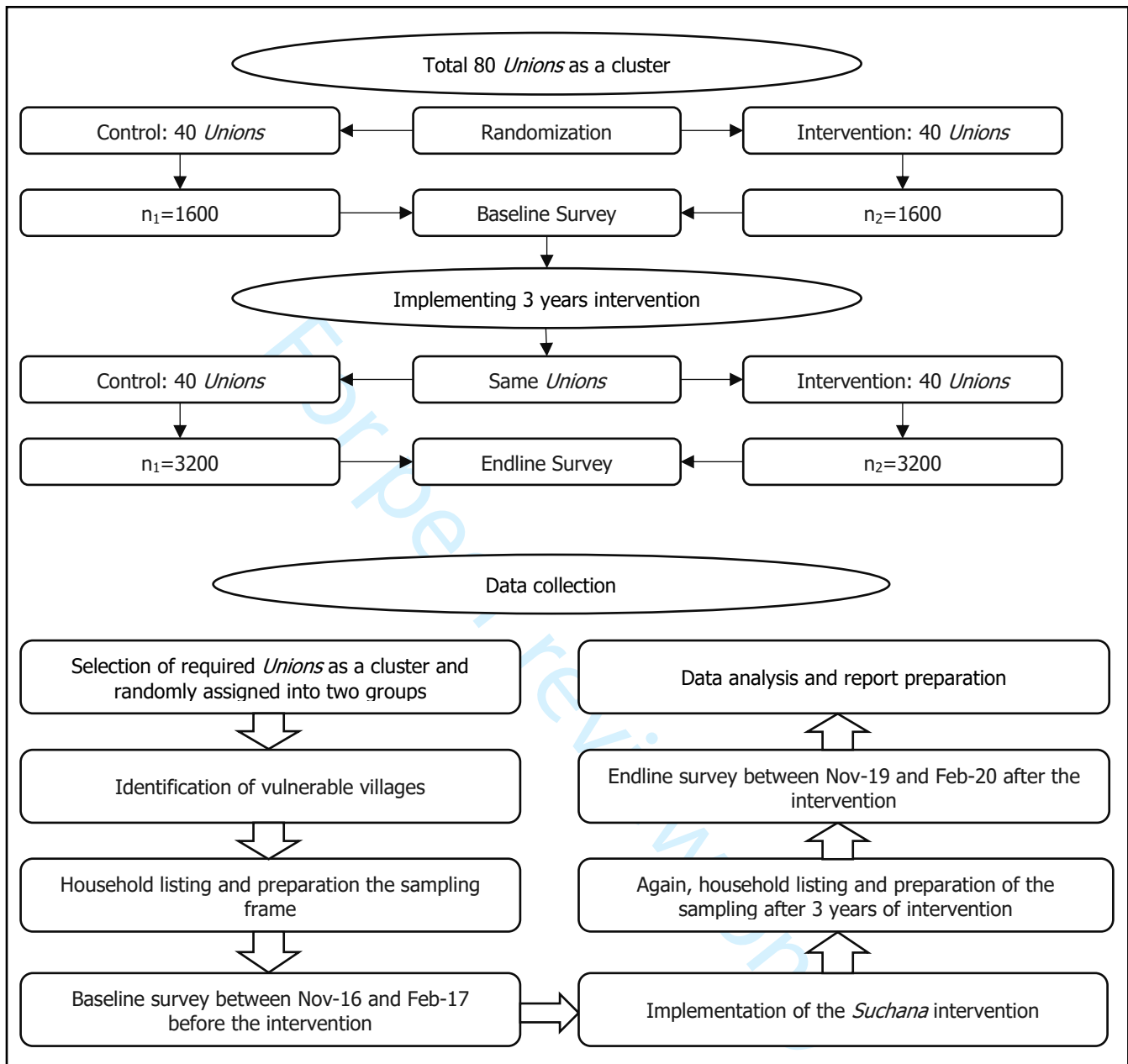
Sample size calculation to determine number of observations required per cluster, for a two-sample comparison of proportions (using normal approximations) without continuity correction.

For the user specified parameters:

```
p1: 0.4700  
p2: 0.4100  
significance level: 0.05  
power: 0.80  
number of clusters available: 40  
intra cluster correlation (ICC): 0.0100
```

clustersampsi estimated parameters:

```
Firstly, assuming individual randomisation: sample size per arm: 1071  
Then, allowing for cluster randomisation: average cluster size required: 38  
sample size per arm: 1520
```



Supplementary Figure 1. The evaluation diagram of *Suchana* programme

Appendix 2. Data collection

The Suchana data collection software contained built-in validation rules. As the data were entered at the interviewer level and the records were uploaded to a server at the icddr,b using the built-in internet connectivity of the devices, maximum validation rules were set in the data system to prevent errors during data entry, which reduced the data entry burden. This allowed the data analysis team to review the

consistency of the data every day. Data were synchronized to the central server “Web Service” developed in Asp.Net based on the C# (C Sharp) code. Activities such as editing (after receiving any feedback from field staff members), updating, range checks, duplication checks, consistency checks, frequency checks and cross tabulation were regularly performed during the data entry period. In case of any unusual observations, the issues were discussed and resolved.

Appendix 3. Equation of logistic and probit regression

$$\text{logit}(y) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 X_6 + \beta_7 X_7 + \beta_8 X_8 + \beta_9 X_9 + \beta_{10} X_{10} + \beta_{12} X_{12} + \beta_{13} X_{13} + \beta_{14} X_{14} + \beta_{15} X_{15} + \beta_{16} X_{16}$$

$$\text{probit}(y) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 X_6 + \beta_7 X_7 + \beta_8 X_8 + \beta_9 X_9 + \beta_{10} X_{10} + \beta_{12} X_{12} + \beta_{13} X_{13} + \beta_{14} X_{14} + \beta_{15} X_{15} + \beta_{16} X_{16}$$

Where,

x1: Less than four ANC visits by a skilled service provider	x9: Having unhygienic latrine
x2: Unskilled birth attendant/facility	x10: Soap was unavailable in hand washing place
x3: Mother involved in income-generating activities	x11: HH size ≥ 7
x4: Maternal BMI < 18.5	x12: HH dietary diversity score < 7
x5: Maternal education: no schooling	x13: Child's age > 18
x6: HH severe food insecurity	x14: Child's sex was male
x7: Monthly income < 15000 BDT	x15: Childhood illness in the last 15 days
x8: Did not involve with aquaculture	x16: Lacked access to mass media

and

$$\text{logit}(y) = \log[y/(1-y)]$$

Supplementary Table 1. Suchana inclusion criteria for registration of enrolling as vulnerable households

Vulnerable household verification questions	Inclusion criteria
Step 1	
<ul style="list-style-type: none"> Households currently participating/member of any livelihood, food security or asset transfer program 	If “NO” go ahead for next questions
Step 2	
<ul style="list-style-type: none"> Ability to afford three (3) full meals per day for all family members round the year Households monthly income BDT 7,500 or more Household productive asset value worth BDT 15,000 or more (excluding land, pond and homestead) Ownership of homestead land 10 decimals or more Ownership of cultivable land 50 decimals or more (excluding homestead or pond) 	If anyone is “NO” go ahead for next questions
Step 3	
<ul style="list-style-type: none"> Households have married women with in child bearing age (15 to 45 years) Households have pregnant women (including abandoned or widowed woman) Households have 0-23 months old children Households have adolescent girls (15-19 years) 	If anyone is ‘Yes’ go ahead for registration of enrolling as vulnerable Household
Sampling frame was prepared for collecting data from mother-child pair if the households had 0-23 months old children	

Supplementary Table 2a. Predictive ability of various indicators for the adjusted prevalence of stunting and adjusted prevalence difference (effect size) in the fitted multiple logistic regression model.

	Prediction of adjusted stunting [% (95% CI)]	Prediction of adjusted prevalence difference as effect size*	p-value
At least four ANC visits by a skilled service provider			
Yes	51.64 (50.05, 53.23)	Reference	
No	47.99 (45.46, 50.53)	3.65 (1.07, 6.22)	0.006
Birth attendant/facility			
Skilled	51.87 (50.23, 53.51)	Reference	
Unskilled	49.42 (47.48, 51.36)	2.45 (0.55, 4.35)	0.012
Mother involved in income-generating activities			
No	54.55 (50.90, 58.19)	Reference	
Yes	50.59 (49.08, 52.11)	3.95 (0.40, 7.51)	0.029
Maternal BMI			
BMI ≥ 18.5	54.04 (52.01, 56.07)	Reference	
BMI < 18.5	49.01 (47.21, 50.81)	5.03 (2.66, 7.41)	< 0.001
Maternal education was primary completed			
Yes	54.66 (52.58, 56.74)	Reference	
No	48.21 (46.67, 49.75)	6.45 (4.49, 8.40)	< 0.001
HH food insecurity			
Below severe	53.03 (50.91, 55.15)	Reference	
Severe	50.36 (48.63, 52.09)	2.66 (0.11, 5.22)	0.041
HH monthly income ≥ 15000 BDT			
Yes	51.31 (49.79, 52.84)	Reference	
No	48.58 (45.86, 51.30)	2.73 (0.17, 5.30)	0.037
Involved with aquaculture			
Yes	51.22 (49.72, 52.72)	Reference	
No	46.99 (43.30, 50.69)	4.23 (0.73, 7.73)	0.018
Hygienic latrine			
Yes	52.67 (50.94, 54.4)	Reference	
No	48.36 (46.5, 50.23)	4.31 (2.34, 6.28)	< 0.001
Water and soap available in handwashing place			
Yes	52.64 (50.71, 54.58)	Reference	
No	48.54 (46.74, 50.33)	4.10 (1.83, 6.38)	< 0.001
HH size			
Below seven	53.86 (51.98, 55.74)	Reference	
Seven or above	49.41 (47.70, 51.13)	4.44 (2.43, 6.46)	< 0.001
HH dietary diversity			
HDDS ≥ 7	53.92 (51.25, 56.60)	Reference	
HDDS < 7	50.10 (48.70, 51.50)	3.83 (1.63, 6.02)	< 0.001
Child's age			
Age ≤ 18 months	56.72 (54.77, 58.67)	Reference	
Age > 18 months	46.59 (44.82, 48.35)	10.1 (7.94, 12.32)	< 0.001
Child's sex			
Female	53.25 (51.17, 55.34)	Reference	
Male	48.40 (46.78, 50.03)	4.85 (2.59, 7.10)	< 0.001
Childhood illness in the last 15 days			
No	54.90 (52.04, 57.77)	Reference	
Yes	50.49 (48.94, 52.05)	4.41 (1.48, 7.34)	0.003
Access of mass media			
Yes	51.51 (49.88, 53.15)	Reference	
No	48.13 (45.39, 50.88)	3.38 (0.42, 6.34)	0.028

*Differences in the predicted values of stunting between the two groups were calculated using the Stata "adjrr" package

Supplementary Table 2b. Predictive ability of various indicators for the adjusted prevalence of stunting and adjusted prevalence difference (effect size) in the fitted multiple probit regression model.

	Prediction of adjusted stunting [% (95% CI)]	Prediction of adjusted prevalence difference as effect size*	p-value
At least four ANC visits by a skilled service provider			
Yes	51.64 (50.05, 53.23)	Reference	
No	47.99 (45.46, 50.53)	3.65 (1.08, 6.22)	0.007
Birth attendant/facility			
Skilled	51.87 (50.23, 53.51)	Reference	
Unskilled	49.42 (47.48, 51.36)	2.45 (0.54, 4.35)	0.011
Mother involved in income-generating activities			
No	54.55 (50.90, 58.16)	Reference	
Yes	50.59 (49.08, 52.11)	3.93 (0.39, 7.48)	0.024
Maternal BMI			
BMI ≥ 18.5	54.04 (52.01, 56.07)	Reference	
BMI < 18.5	49.01 (47.21, 50.81)	5.03 (2.66, 7.40)	<0.001
Maternal education was primary completed			
Yes	54.66 (52.58, 56.74)	Reference	
No	48.21 (46.67, 49.75)	6.45 (4.49, 8.41)	<0.001
HH food insecurity			
Below severe	53.01 (50.89, 55.12)	Reference	
Severe	50.37 (48.64, 52.10)	2.64 (0.09, 5.19)	0.042
HH monthly income ≥ 15000 BDT			
Yes	51.32 (49.79, 52.84)	Reference	
No	48.56 (45.84, 51.28)	2.75 (0.19, 5.32)	0.035
Involved with aquaculture			
Yes	51.22 (49.73, 52.71)	Reference	
No	46.99 (43.28, 50.69)	4.24 (0.73, 7.74)	0.018
Hygienic latrine			
Yes	52.67 (50.94, 54.4)	Reference	
No	48.36 (46.5, 50.23)	4.31 (2.34, 6.28)	<0.001
Water and soap available in handwashing place			
Yes	52.64 (50.71, 54.58)	Reference	
No	48.53 (46.74, 50.33)	4.11 (1.83, 6.39)	<0.001
HH size			
Below seven	53.86 (51.98, 55.73)	Reference	
Seven or above	49.41 (47.70, 51.13)	4.44 (2.43, 6.46)	<0.001
HH dietary diversity			
HDDS ≥ 7	53.90 (51.23, 56.57)	Reference	
HDDS < 7	50.10 (48.71, 51.50)	3.79 (1.60, 5.98)	<0.001
Child's age			
Age ≤ 18 months	56.72 (54.76, 58.67)	Reference	
Age > 18 months	46.59 (44.83, 48.35)	10.1 (7.93, 12.3)	<0.001
Child's sex			
Female	53.25 (51.17, 55.33)	Reference	
Male	48.41 (46.78, 50.03)	4.85 (2.60, 7.10)	<0.001
Childhood illness in the last 15 days			
No	54.90 (52.04, 57.75)	Reference	
Yes	50.50 (48.94, 52.05)	4.40 (1.47, 7.33)	0.003
Access of mass media			
Yes	51.51 (49.88, 53.15)	Reference	
No	48.13 (45.40, 50.86)	3.38 (0.42, 6.34)	0.028

*Differences in the predicted values of stunting between the two groups were calculated using the Stata "adjrr" package

STROBE Statement—Checklist of items that should be included in reports of *cross-sectional studies*

	Item No	Recommendation	Page No
Title and abstract	1	(a) Indicate the study's design with a commonly used term in the title or the abstract	1-2
		(b) Provide in the abstract an informative and balanced summary of what was done and what was found	1-2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	3-6
Objectives	3	State specific objectives, including any prespecified hypotheses	6
Methods			
Study design	4	Present key elements of study design early in the paper	6
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	6
Participants	6	(a) Give the eligibility criteria, and the sources and methods of selection of participants	6
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	6-7
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	6-7
Bias	9	Describe any efforts to address potential sources of bias	19
Study size	10	Explain how the study size was arrived at	7
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	7
Statistical methods	12	(a) Describe all statistical methods, including those used to control for confounding	8-9
		(b) Describe any methods used to examine subgroups and interactions	
		(c) Explain how missing data were addressed	
		(d) If applicable, describe analytical methods taking account of sampling strategy	8-9
		(e) Describe any sensitivity analyses	
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	11
		(b) Give reasons for non-participation at each stage	
		(c) Consider use of a flow diagram	
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	11
		(b) Indicate number of participants with missing data for each variable of interest	
Outcome data	15*	Report numbers of outcome events or summary measures	11
Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	11-14

		(b) Report category boundaries when continuous variables were categorized	
		(c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	11-15
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	
Discussion			
Key results	18	Summarise key results with reference to study objectives	16
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	19
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	16
Generalisability	21	Discuss the generalisability (external validity) of the study results	16-18
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	20

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at <http://www.plosmedicine.org/>, Annals of Internal Medicine at <http://www.annals.org/>, and Epidemiology at <http://www.epidem.com/>). Information on the STROBE Initiative is available at www.strobe-statement.org.

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A predictive modelling approach to illustrate factors correlating with stunting among children aged 12-23 months: a cluster randomized pre-post study

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3 1 **A predictive modelling approach to illustrate factors correlating with stunting among**
4 **children aged 12-23 months: a cluster randomized pre-post study**
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23 16 Word count: 4977
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29 22 **Abstract**

30 23 **Objective** The aim of this study was to construct a predictive model in order to develop an
31 24 intervention study to reduce the prevalence of stunting among children aged 12-23 months.
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34 27 **Design** The study followed a cluster randomized pre-post design and measured the impacts on
35 28 various indicators of livelihood, health, and nutrition. The study was based on a large dataset
36 29 collected from two cross-sectional studies (baseline and endline).
37 30
38 31

39 32 **Setting** The study was conducted in the north-eastern region of Bangladesh under the Sylhet
40 33 division, which is vulnerable to both natural disasters and poverty. The study specifically targeted
41 34 children between the ages of 12 and 23 months.
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44 37

45 38 **Main outcome measures** Childhood stunting, defined as a length-for-age z-score (LAZ) <-2 , was
46 39 the outcome variable in this study. Logistic and probit regression models and a decision tree were
47 40 constructed to predict the factors associated with childhood stunting. The predictive performance
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32 of the models was evaluated by computing the area under the receiver operating characteristic
33 (ROC) curve analysis.

34
35 **Results** The baseline survey showed a prevalence of 52.7% stunting, while 50.0% were stunted at
36 endline. Several factors were found to be associated with childhood stunting. The model's
37 sensitivity was 61% and specificity was 56%, with a correctly classified rate of 59% and an area
38 under the ROC curve of 0.615.

39
40 **Conclusion** The study showed that childhood stunting in the study area was largely influenced by
41 factors such as maternal nutrition and education, food insecurity, and hygiene practices. Despite
42 efforts to address these factors, they remain largely unchanged. The study suggests that a more
43 effective approach may be developed in future to target adolescent mothers, as maternal nutrition
44 and education are age-dependent variables. Policymakers and programme planners need to
45 consider incorporating both nutrition-sensitive and specific activities and enhancing collaboration
46 in their efforts to improve the health of vulnerable rural populations.

47
48 **Study registration:** RIDIE-STUDY-ID-5d5678361809b

49
50 **Keywords:** Childhood stunting, Chronic malnutrition, Global public health, Logistic regression,
51 Probit regression, Decision tree

52 53 **Strengths and limitations of this study**

- 54 • The study used a combination of parametric and non-parametric predictive models to
55 estimate the effect size of the independent variables and identify significant correlates of
56 childhood stunting
- 57 • The study was designed to mitigate the potential impact of seasonal factors by conducting
58 the baseline and endline surveys at the same time of the year
- 59 • A binary indicator of stunting based on a single LAZ cut-off point (<-2) may not provide
60 a complete evaluation of the severity of malnutrition among children as it does not
61 consider micronutrient deficiencies

- 62 • Use of recall data from the previous 24 hours for dietary diversity, household food
63 insecurity, domestic violence, and maternal healthcare may be subject to recall bias
- 64 • Biological data has not been collected such as enteropathogen and environmental enteric
65 dysfunction, which could have been related to childhood stunting

67 **Introduction**

68 Childhood stunting, which is defined as length-for-age z-score (LAZ)<-2, is a major concern for
69 public health and has been widely used as an indicator of chronic malnutrition in children.[1, 2]
70 Although childhood stunting scenarios have much improved globally, the prevalence of childhood
71 stunting is still very high in low-resource settings, including countries such as Bangladesh.
72 According to the 2018 Global Nutrition Report, 150.8 million children (22.2%) under five years-
73 of-age are stunted globally, compared to 198.4 million (32.6%) and 165 million children in 2000
74 and 2011, respectively.[3, 4] Between 2000 and 2018, Asian countries have experienced a decrease
75 in the rate of stunting among children under five from 38.1% to 23.2%. However, South Asia still
76 has the highest prevalence of stunting in the region, with a rate of 38.9% in 2018.[3] In Bangladesh,
77 about 5.5 million (36%) children under five were stunted in 2014,[5] however by 2018, childhood
78 stunting has reduced to about 31%.[2] As the World Health Organization (WHO) considers a
79 childhood stunting rate of 15% to be an emergency situation, the current prevalence of childhood
80 stunting in Bangladesh reflects an alarming situation of chronic undernutrition.[6]

81
82 Literature suggests that children are at a higher prevalence of stunting if their mothers do not
83 receive adequate antenatal care, fail to rest sufficiently, do not consume additional food, and
84 neglect to take iron-folic acid (IFA) tablets during pregnancy.[7-9] Mass media exposure, receive
85 a vitamin A capsule; have a skilled birth attendant; and have maternal nutritional status and
86 maternal education, both of which are linked to childhood stunting.[6, 8, 10-12] Children in poor
87 households in Bangladesh are more likely to experience stunted growth if their mothers are
88 employed, as there are inadequate day-care centres available for the children, leading to
89 insufficient breastfeeding.[13] Moreover, evidence suggests that a number of characteristics at the
90 household level, which relate to both children and mothers, can influence childhood stunting. The
91 characteristics of the household head, household food insecurity and lower dietary diversity,
92 household lower-income, household involvement in several earning activities, availability of

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3 93 sanitation facility at home, hand-washing status, family size, religion, and receive several types of
4 94 allowance from government are most often reported to be associated with stunting in the
5 95 literature.[6, 8, 11, 14-16]
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10 97 Based on child characteristics, several indicators are associated with stunting. This status is
11 98 associated with two basic characteristics: a child's gender and age.[8] Children are commonly
12 99 affected by the co-occurrence of illness in low- and middle-income countries, which is one of the
13 100 most common causes of stunting.[17] Inadequate infant and young child feeding (IYCF) practices
14 101 also reduce child growth.[8, 15] However, these findings are mostly based on nationally
15 102 representative cross-sectional and cohort studies, or studies conducted in urban settings.[18, 19]
16 103 Therefore, a knowledge gap exists on whether similar results would be obtained when nationwide
17 104 data are compared with data for study populations from poor or very poor rural households in
18 105 specific vulnerable regions.
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27 107 Sylhet is one such vulnerable region of north-east Bangladesh, comprising diverse terrains such as
28 108 plain land, hilly land, *Haor* (wetland), and flash flood-prone areas. This region is reported to
29 109 perform poorly for all important maternal healthcare indicators,[20] despite the fact that
30 110 Bangladesh has made substantial progress in improving the overall health of the population.[21]
31 111 Moreover, the socio-economic profile of the inhabitants in Sylhet region includes both very rich
32 112 and extremely poor people. This scenario may worsen without the implementation of appropriate
33 113 strategies in the near future. Sylhet region is also performing poorly compared to the national
34 114 averages for a number of health and nutritional indicators. Critical indicators such as the infant
35 115 mortality rate and unemployment status of women are high.[19] In comparison to the overall
36 116 situation of Bangladesh, where stunting among children under five has decreased, the Bangladesh
37 117 Demographic and Health Survey (BDHS) 2014 indicates the prevalence of childhood stunting in
38 118 Sylhet is astonishingly high, at 50%.[19] This alarming figure provided the rationale for
39 119 implementation of a comprehensive intervention programme in this region. A large-scale nutrition
40 120 programme, *Suchana: Ending the Cycle of Undernutrition in Bangladesh; a multi-sectoral*
41 121 *nutrition programme*, was undertaken with the aim to prevent chronic malnutrition in Sylhet.
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3 123 In general, *Suchana* nutrition interventions can be divided into two types: nutrition-sensitive and
4 124 nutrition-specific.[22] The concept of nutrition-sensitive intervention refers to an intervention that
5 125 benefits the beneficiaries in terms of food and nutrition security, and also influences the underlying
6 126 determinants of nutrition. This type of intervention is largely delivered through the agricultural
7 127 sector (homestead vegetable and fruit production, pro-poor nutrition-sensitive aquaculture),
8 128 improved technology (mono-sex tilapia and carp-tilapia polyculture, subsistence fishing, fish
9 129 drying), demonstrations (village model farms and demo ponds, livestock, food security, promotion
10 130 of climate-smart technologies), and supported income-generating activities (skill development in
11 131 business management, engagement with the private sector and other sectors). As nutrition-specific
12 132 interventions were delivered through nutrition-sensitive interventions, their coverage,
13 133 effectiveness, and scale can be increased. It can meet the targets by lowering them and
14 134 implementing nutrition-specific interventions. A nutrition-specific intervention addresses the
15 135 immediate cause of malnutrition. Direct determinants of nutrition are the focus of this intervention.
16 136 There is a strong focus on nutrition-specific interventions in the health sector. Whether
17 137 implemented alone or jointly, nutrition-specific interventions improve health outcomes. Some
18 138 examples of nutrition-specific interventions are: counselling for mothers at the household level,
19 139 community-based nutrition education for spouses and in-laws, growth monitoring and promotion
20 140 sessions integrated with *Expanded Programme on Immunization* in communities, *Government of*
21 141 *Bangladesh* health facilities equipped with *severe acute malnutrition* service delivery, and support
22 142 for *National Nutrition Services* service delivery through community clinics, Union Health and
23 143 Family Welfare Centers, and Upazila health complexes.
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41 145 The primary objective of the *Suchana* programme was to reduce the prevalence of childhood
42 146 stunting in the intervention areas. The secondary objectives were to assess the changes in *Suchana*
43 147 beneficiaries' households, in terms of an increase and diversification of household income, food
44 148 security status, optimal IYCF practices, haemoglobin status of children, the empowerment of
45 149 women, and adolescents' nutritional knowledge and practices.[22]
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50 150
51 151 The *Suchana* programme substantially improved nutritional behaviour, maternal healthcare
52 152 practices, women's empowerment, household income, and household food security in the
53 153 intervention area compared to the control area.[23] Contrary to predictions, however, *Suchana* did
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154 not result in any significant reduction in the prevalence of childhood stunting. Therefore, although
155 most other factors related to childhood stunting improved, this raises the question of why the
156 prevalence of stunting did not reduce after the intervention. An important observation from the
157 *Suchana* survey was that the proportion of households in this study population using hygienic
158 latrines was quite low. This factor was associated with stunting in children,[8] and did not
159 significantly improve by endline in the intervention areas compared to the control areas.

160
161 In this study, we aimed to construct a predictive model to attempt to explain whether any
162 improvements in associated factors may promote a significant reduction in stunting among
163 children aged 12-23 months from poor and extremely poor households in the Sylhet region.

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165

166 **Methods**

167 **Study design and setting**

168 The *Suchana* programme was implemented in 157 Unions over 20 sub-districts in the Sylhet region
169 in the north-east of rural Bangladesh. The *Suchana* programme's protocol has been thoroughly
170 explained elsewhere.[22] *Union*, the smallest local government and administrative entity in rural
171 Bangladesh, was considered as a cluster and divided into four phases at random. Phase-1 was
172 designated as the intervention group, while Phase-4 was the control group, and the other phases
173 were treated as learning phases.[22] For implementation purposes, vulnerable villages were
174 selected within Phase-1 and Phase-4 areas. The staff of the programme chose vulnerable villages
175 in each *Union* based on their vulnerability (e.g., frequent floods or submerging, little or no
176 intervention from other development programmes, poverty or household living circumstances,
177 remoteness and accessibility issues, a high prevalence of superstitions and social taboos). After
178 consultation with the local government representatives, elected officials, and local elites as well as
179 field visits, this selection method was decided upon. The impacts of the intervention on livelihood,
180 health, and nutrition were measured using a pre-post design. A large dataset was collected from
181 two cross-sectional surveys (baseline and endline) under this study. The baseline survey was
182 conducted in November 2016 and February 2017, followed by the endline survey in the same
183 months three years later among the same population and different participants (Supplementary
184 Figure 1).

185

186 Outcome variable

187 The outcome variable in this study was childhood stunting, which was defined as a length-for-age
188 z-score (LAZ) <-2 .^[2]

189

190 Independent variables

191 Initially, a list of independent variables was finalized through results obtained from descriptive
192 and bi-variate analyses, as well as a comprehensive literature review (Table 1). These included at
193 least four antenatal care (ANC) visits by a skilled service provider, additional resting during
194 pregnancy, additional food consumption during pregnancy, consumption of at least 100 IFA tablets
195 during pregnancy, receiving vitamin A capsule after last delivery, birth attendant/facility, mother
196 involved in income-generating activities, maternal BMI, maternal education, household food
197 insecurity, household monthly income >15000 BDT, involved with aquaculture, hygienic latrine,
198 water and soap available in handwashing place, household size, household dietary diversity, sex
199 of household head, religion, received any grant/allowance/stipend from the government, access of
200 mass media, child's age, child's sex, childhood illness in the last 15 days, minimum dietary
201 diversity, early initiation of breastfeeding, and received colostrum. Household food insecurity
202 access scale was measured using the Food and Nutrition Technical Assistance's Guideline, which
203 categorizes household food insecurity into four levels: a) food secure, b) mildly food insecure, c)
204 moderately food insecure, and d) severely food insecure.^[24] In the analysis herein, this indicator
205 was redefined as a binary indicator: severely food insecure or not severely food insecure.

206

207 Sample size

208 The sample size for this study was calculated with the STATA "*clustersampsi*" command module,
209 considering the number of clusters in the surveys and considering the expected prevalence of
210 childhood stunting in the control group (Supplemental Appendix 1). It was estimated that the
211 expected prevalence of stunting was 47%, which was hypothesized to be reduced to 41% after
212 three years of intervention. A sample size of 1520 per arm was calculated based on a 5% level of
213 significance, 80% power, 40 clusters per arm, and an intra-cluster correlation coefficient (ICC) of
214 0.01. After rounding, the estimated sample size per arm was 1620, and the total sample size was
215 3200 at baseline, with an equal number of participants in the control and intervention groups. For

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3 216 evaluation purposes, the sample size at endline was doubled to ensure a stratified intervention
4 217 component, resulting in a total sample size of 9600 mother-child pairs (baseline: 3200 and endline:
5 218 6400).[22]
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220 **Sampling**

221 The baseline and endline surveys were conducted in a total of eight and twelve villages
222 respectively, which were randomly selected from each *Union* using a list of vulnerable villages
223 provided by Save the Children. The most vulnerable households were identified and verified using
224 the inclusion criteria of the *Suchana* programme (Supplementary Table 1). These households were
225 then given an identification number to prepare the sampling frame and required households were
226 systematically selected for the surveys from the frame. The method of data collection is explained
227 in detail in the Supplemental Appendix 2.
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229 **Statistical analysis**

230 **General characteristics:** Stata-14 software (StataCorp LP, College Station, TX, USA) and R 4.2.2
231 (*rpart*)[25] were used to analyse the data. Bar diagram was used for data visualization. Descriptive
232 statistics, such as frequency and proportions for categorical variables and mean and standard
233 deviations for quantitative variables, were used to summarize the data at baseline and endline.
234 Cross-tabulation was used to present that outcome variable segregated by intervention and control
235 group at baseline survey as well as the endline survey. The *difference in difference* method was
236 used to estimate the contrast of an intervention by comparing the difference in the outcomes
237 between an intervention group and a control group before and after the intervention.[26]
238

239

239 **Predictive model:** Three statistical models were used as predictive models. Two parametric
240 models, such as Logistic and Probit regression models, and Decision Tree as a non-parametric
241 model. Logistic and Probit regression models were used as predictive models as well as classifier
242 models. The models were also used to investigate which factors were significantly associated with
243 childhood stunting, and estimate their effect size, in order to predict whether changes in
244 behavioural practices might potentially help to achieve targeted reductions in stunting. Using those
245 variables, a decision tree was applied, and the predictive performance was compared to other
246 models.
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 248 For the parametric models, first, Chi-Square test was used to examine the bivariate associations
 249 between stunting and all possible explanatory variables. In the second step, variables with p -values
 250 <0.25 in the simple model were included in the multiple regression models.[27] In the final step,
 251 any independent variables thought to be likely predictors were added to the multiple regression
 252 model using the stepwise forward selection method. Some indicators, e.g., age, sex, and maternal
 253 nutritional status were added regardless of their p -value due to their scientific plausibility. The
 254 mathematical equation of logistic and probit regression models were given in the Supplemental
 255 Appendix 3. As a cluster variable, *Union* was used to adjust the standard errors. Furthermore, for
 256 the explanation of the regression model, a p -value <0.05 was considered as statistically significant,
 257 and the confidence interval (CI) of 95% was also reviewed. From the fitted model, the adjusted
 258 effect size (adjusted prevalence difference) against all predictors was estimated using the “*adjrr*”
 259 package in Stata. The list of independent variables with the value labels used in the model is given
 260 in Table 1.

261

262 **Table 1. List of all independent variables**

Indicators	Code	Stunting Status*	Selection in the model
At least four ANC visits by a skilled service provider			
At least four ANC visits by a skilled service provider	0		Selected
Less than four ANC visits by a skilled service provider	1	Higher prevalence[8]	
Additional resting during pregnancy			
Took more rest	0		Not selected
Did not take more rest	1	Higher prevalence[8]	
Additional food consumption during pregnancy			
Consumed more food	0		Not selected
Did not consumed more food	1	Higher prevalence[7, 8]	
Consumption of at least 100 IFA tablets during pregnancy			
Consumed at least 100 IFA tablets	0		Not selected
Did not consumed at least 100 IFA tablets	1	Higher prevalence[9]	
Received vitamin A capsule after last delivery			
Received	0		Not selected
Did not receive	1	Higher prevalence[8]	
Birth attendant/facility			
Skilled	0		Selected
Unskilled	1	Higher prevalence[10]	
Mother involved in income-generating activities			
No	0		Selected
Yes	1	Higher prevalence[6, 13]	
Maternal BMI			
BMI ≥ 18.5	0		Selected
BMI <18.5	1	Higher prevalence[6, 11]	

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Maternal education			
At least one-year formal education	0		Selected
No schooling	1	Higher prevalence[6, 11]	
Access of mass media			
Access	0		Selected
No access	1	Higher prevalence[12]	
Household food insecurity			
Below severe	0		Selected
Severe	1	Higher prevalence[8]	
Household monthly income \geq15000 BDT			
\geq 15000 BDT	0		Selected
<15000 BDT	1	Higher prevalence[11]	
Involved with aquaculture			
Involved	0		Selected
Did not involved	1	Higher prevalence[14]	
Hygienic latrine			
Hygienic latrine	0		Selected
Unhygienic latrine	1	Higher prevalence[6, 11, 15]	
Water and soap available in handwashing place			
Available	0		Selected
Unavailable	1	Higher prevalence[15]	
Household size			
Below seven	0		Selected
Seven or above	1	Higher prevalence[11]	
Household dietary diversity (HDDS)			
HDDS \geq 7	0		Selected
HDDS <7	1	Higher prevalence[8]	
Sex of household head			
Female	0		Not selected
Male	1	Higher prevalence[8]	
Household head education			
At least one-year formal education	0		Not selected
No schooling	1	Higher prevalence[6]	
Religion			
Muslim	0		Not selected
Non-Muslim	1	Lower prevalence[6]	
Received any grant/allowance/stipend from the government			
Received	0		Not selected
Did not receive	1	Higher prevalence[16]	
Child's age			
Age \leq 18 months	0		Selected
Age >18 months	1	Higher prevalence[8]	
Child's sex			
Female	0		
Male	1	Higher prevalence[8]	
Childhood illness in the last 15 days			
No	0		Selected
Yes	1	Higher prevalence[17]	
Minimum dietary diversity			
Received	0		Not selected
Did not receive	1	Higher prevalence[8, 15]	
Early initiation of breastfeeding			
Received	0		Not selected

	Did not receive	1	Higher prevalence[8]	
	Received colostrum			Not selected
	Received	0		
	Did not receive	1	Higher prevalence[8]	

¹Expected effects based on findings of the literature

Model evaluation: The predictive performance of the three statistical models was evaluated by computing model sensitivity and specificity, and calculating the area under the receiver operating curve (ROC) analysis. To ensure accurate results, the data was randomly split into a training set (75%) and a test set (25%) using a random-number seed 113843. The same training and test datasets were used for evaluating the performance of all algorithms to ensure consistency in the results. The sensitivity and specificity values, as well as the area under the ROC curve, were used to determine the overall accuracy of the algorithms in predicting childhood stunting.[28, 29]

Patient and public involvement

Patients and public were not actively involved in formulating the research question and or protocol development, including the outcome measures. To expedite the field implementation, however, local elites e.g. teachers, religious persons, and local government council members were informed about the study.

Results

General characteristics: Out of 9600 cases, 9501 cases were found to be available. The refusal rate was around 1%. With respect to the outcome indicator, stunting in children aged 12-23 months, 52.7% of children were stunted at the baseline survey (intervention group: 52.6%; control group: 52.8%), whereas the proportion of children exhibiting stunting at endline was 50.0% (intervention: 49.9%; control: 50.1%; Figure 1). At both the baseline and endline surveys, there was no significant difference in proportion between intervention and control areas. The *difference-in-difference* in outcomes over time was also insignificant.

Figure 2 describes several other indicators related to maternal and child health, including the status of consuming a minimum acceptable diet (intervention: 35.2%; control: 14.9%), minimum dietary diversity (intervention: 42.8%; control: 20.4%), maternal decision-making (intervention: 45.0%; control: 31.0%), at least four maternal ANC visits by a skilled service provider (intervention:

292 36.1%; control: 17.7%), minimum dietary diversity for women (intervention: 52.6%; control:
 293 33.5%), a household dietary diversity score of at least seven (intervention: 88.9%; control: 78.3%),
 294 and household food security status (intervention: 26.6%; control: 20.2%). Results from the endline
 295 survey showed that these indicators were significantly improved in the intervention group
 296 compared to the control group. However, the availability of hygienic latrines did not increase in
 297 the intervention group (intervention: 44.0%; control: 44.0%). Table 2 shows the
 298 households' socio-demographic characteristics, women's general characteristics, and children's
 299 characteristics at baseline and endline.

301 **Table 2. General characteristics of the *Suchana* beneficiaries**

Indicators, n (%)		Baseline N=3200	Endline N=6301	Total N=9501
At least four ANC visits by a skilled service provider				
	Yes	408 (12.8)	1530 (24.3)	1938 (20.4)
	No	2792 (87.2)	4771 (75.7)	7563 (79.6)
Delivery at skilled birth attendant/facility				
	Yes	1000 (31.2)	2769 (44.0)	3769 (39.7)
	No	2200 (68.8)	3532 (56.0)	5732 (60.3)
Access of mass media				
	Access	563 (17.59)	1169 (18.55)	1732 (18.23)
	No access	2637 (82.41)	5132 (81.45)	7769 (81.77)
Mother involved in income-generating activities				
	No	3102 (96.9)	5665 (89.9)	8767 (92.2)
	Yes	98 (3.1)	639 (10.1)	737 (7.8)
Maternal BMI				
	BMI \geq 18.5	1859 (58.1)	4073 (64.6)	5932 (62.4)
	BMI <18.5	1341 (41.9)	2231 (35.4)	3572 (37.6)
Mother completed primary education				
	Yes	1721 (53.8)	3808 (60.4)	5529 (58.2)
	No	1479 (46.2)	2496 (39.6)	3975 (41.8)
Maternal age				
	Age <30 years	2145 (67.0)	3559 (56.5)	5704 (60.0)
	Age \geq 30 years	1055 (33.0)	2745 (43.5)	3800 (40.0)
Type of delivery				
	Normal	2879 (90.0)	5529 (87.8)	8408 (88.5)
	Caesarean	321 (10.0)	772 (12.3)	1093 (11.5)
PNC				
	No	2152 (67.3)	4128 (65.5)	6280 (66.1)
	Yes	1048 (32.8)	2173 (34.5)	3221 (33.9)
Household severely food insecure				
	Yes	912 (28.5)	1016 (16.1)	1928 (20.3)
	No	2288 (71.5)	5285 (83.9)	7573 (79.7)
Household monthly income \geq15000 BDT				

	Yes	424 (13.2)	1015 (16.1)	1439 (15.1)
	No	2776 (86.8)	5289 (83.9)	8065 (84.9)
Household involved with aquaculture				
	Yes	161 (5.0)	561 (8.9)	722 (7.6)
	No	3039 (95.0)	5740 (91.1)	8779 (92.4)
Hygienic latrine				
	Yes	1121 (35.0)	2782 (44.1)	3903 (41.1)
	No	2079 (65.0)	3519 (55.9)	5598 (58.9)
Water and soap available in handwashing place				
	Yes	862 (26.9)	3170 (50.3)	4032 (42.4)
	No	2338 (73.1)	3131 (49.7)	5469 (57.6)
Household savings				
	No	1080 (33.8)	2876 (45.6)	3956 (41.6)
	Yes	2120 (66.2)	3425 (54.4)	5545 (58.4)
Sex of household head				
	Female	110 (3.4)	501 (8.0)	611 (6.4)
	Male	3090 (96.6)	5799 (92.0)	8889 (93.6)
Source of drinking water				
	Tube well	2748 (85.9)	5713 (90.7)	8461 (89.0)
	Others	452 (14.1)	588 (9.3)	1040 (11.0)
Household dietary diversity score				
	HDDS ≥ 7	2182 (68.2)	5322 (84.5)	7504 (79.0)
	HDDS < 7	1018 (31.8)	979 (15.5)	1997 (21.0)
Household monthly income (Thousand BDT)¹				
Per capita income (Thousand)¹				
Household size¹				
Child's age in months²				
Length-for-age z-score²				
Weight-for-age z-score²				
Weight-for-length z-score²				
Child's age				
	Age < 18 months	1745 (54.5)	3710 (58.9)	5455 (57.4)
	Age ≥ 18 months	1455 (45.5)	2594 (41.1)	4049 (42.6)
Child's sex				
	Female	1567 (49.0)	3044 (48.3)	4611 (48.5)
	Male	1633 (51.0)	3257 (51.7)	4890 (51.5)
Childhood illness in the last 15 days				
	Yes	2867 (89.6)	5763 (91.5)	8630 (90.8)
	No	333 (10.4)	538 (8.5)	871 (9.2)

¹Median (IQR); ²Mean \pm SD

Correlated factors: The study used two parametric predictive models to determine the correlates of childhood stunting. The results, presented in Table 3, showed the adjusted odds ratios (aOR) computed from multiple logistic regression and the adjusted coefficients computed from multiple probit regression. These results provide important insights into the factors that increase the odds of stunting in childhood, and can inform public health interventions aimed at reducing stunting

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3 309 and improving child health. The aORs provide a quantitative measure of the relationship between
4 310 different factors and childhood stunting, adjusting for *Union* as cluster variable. Understanding the
5 311 correlates of childhood stunting is critical for addressing this important public health issue and
6 312 improving the health and well-being of children globally. The results of this study show that a
7 313 number of maternal, household and children factors were correlated with an increased prevalence
8 314 of stunting in children. Children of mothers who did not receive at least four ANC visits from a
9 315 skilled service provider had 1.16 times higher odds of stunting (95% CI: 1.05, 1.30; p-
10 316 value=0.005). Children of mothers who gave birth with an unskilled birth attendant or facility had
11 317 1.11 times higher odds of stunting (95% CI: 1.02, 1.20; p-value=0.012). The odds of stunting were
12 318 1.18 times higher in children whose mothers were involved in income-generating activities (95%
13 319 CI: 1.02, 1.37; p-value=0.030), 1.23 times higher in children of underweight mothers (95% CI:
14 320 1.12, 1.36; p-value<0.001), and 1.31 times higher in children of low-educated mothers (95% CI:
15 321 1.20, 1.42; p-value<0.001). Furthermore, the lack of exposure to mass media was also found to be
16 322 associated with stunting, with odds of 1.15 (95% CI: 1.02, 1.30; p-value=0.025) times higher.
17 323 Children from households with severe food insecurity, lower-income households, households not
18 324 involved in aquaculture, and households with low dietary diversity, were more likely to be stunted,
19 325 with odds increasing by 1.12 (95% CI: 1.00, 1.24; p-value=0.041), 1.12 (95% CI: 1.01, 1.25; p-
20 326 value=0.037), 1.19 (95% CI: 1.03, 1.38; p-value=0.018), and 1.17 (95% CI: 1.07, 1.29; p-
21 327 value=0.001) times, respectively. The results also showed that the odds of stunting increased with
22 328 increasing household size (95% CI: 1.11, 1.31; p-value<0.001), the absence of a hygienic latrine
23 329 (95% CI: 1.10, 1.30; p-value<0.001), the absence of water and soap in the handwashing place
24 330 (95% CI: 1.08, 1.30; p-value<0.001), increasing child age (95% CI: 1.39, 1.67; p-value<0.001),
25 331 and being male (95% CI: 1.11, 1.34; p-value<0.001). The odds of stunting were also 1.20 times
26 332 higher in children with acute illness (95% CI: 1.06, 1.36; p-value=0.003). The logistic and probit
27 333 regression models were employed to predict stunting in a sample of 9501 individuals. Both models
28 334 were found to be significant, with log-likelihoods of -6387.94 and -6388.02, respectively, and
29 335 significant Wald chi-square statistics (p-value < 0.001). Predictive ability of various indicators for
30 336 the adjusted prevalence of stunting and adjusted prevalence difference (effect size) are given in
31 337 Supplementary Table 2a and 2b. The Factors correlating with childhood stunting, as determined
32 338 by using a decision tree as a non-parametric predictive model, are also presented in Figure 3. The
33 339 decision tree result suggests that maternal education was the most important variable in predicting

childhood stunting, as it was the main root node. The other variables, such as maternal nutrition, hand washing indicators, and hygienic latrine, were also important, as they were next root node variables. This tree model can be used to predict the childhood stunting status with relative ease.

Table 3. Factors correlating with stunting in children aged 12-23 months, computed using logistic and probit regression analyses

Indicators	Logistic		Probit	
	Adjusted OR (95% CI)	p-value	Adjusted Coef. (95% CI)	p-value
At least four ANC visits by a skilled service provider				
Yes	Reference		Reference	
No	1.16 (1.05, 1.30)	0.005	0.09 (0.03, 0.16)	0.005
Birth attendant/facility				
Skilled	Reference		Reference	
Unskilled	1.11 (1.02, 1.20)	0.012	0.06 (0.01, 0.11)	0.012
Mother involved in income-generating activities				
No	Reference		Reference	
Yes	1.18 (1.02, 1.37)	0.030	0.10 (0.01, 0.19)	0.030
Maternal BMI				
BMI \geq 18.5				
BMI $<$ 18.5	1.23 (1.12, 1.36)	0.000	0.13 (0.07, 0.19)	0.000
Maternal education was primary completed				
Yes	Reference		Reference	
No	1.31 (1.20, 1.42)	0.000	0.17 (0.12, 0.22)	0.000
Access of mass media				
Yes	Reference		Reference	
No	1.15 (1.02, 1.30)	0.025	0.09 (0.01, 0.16)	0.025
Household food insecurity				
Below severe				
Severe	1.12 (1.00, 1.24)	0.041	0.07 (0.00, 0.13)	0.042
Household monthly income \geq15000 BDT				
Yes	Reference		Reference	
No	1.12 (1.01, 1.25)	0.037	0.07 (0.00, 0.14)	0.035
Involved with aquaculture				
Yes	Reference		Reference	
No	1.19 (1.03, 1.38)	0.018	0.11 (0.02, 0.20)	0.018
Household size				
Below seven	Reference		Reference	
Seven or above	1.20 (1.11, 1.31)	0.000	0.12 (0.06, 0.17)	0.000
Hygienic latrine				
Yes	Reference		Reference	
No	1.20 (1.10, 1.30)	0.000	0.11 (0.06, 0.16)	0.000
Water and soap available in handwashing place				
Yes	Reference		Reference	
No	1.19 (1.08, 1.30)	0.000	0.11 (0.05, 0.16)	0.000
Household dietary diversity				
HDDS \geq 7	Reference		Reference	
HDDS $<$ 7	1.17 (1.07, 1.29)	0.001	0.10 (0.04, 0.16)	0.001
Child's age				

	Age ≤18 months	Reference		Reference	
	Age >18 months	1.52 (1.39, 1.67)	0.000	0.26 (0.2, 0.32)	0.000
Child's sex					
	Female	Reference		Reference	
	Male	1.22 (1.11, 1.34)	0.000	0.13 (0.07, 0.18)	0.000
Childhood illness in the last 15 days					
	No	Reference		Reference	
	Yes	1.20 (1.06, 1.36)	0.003	0.11 (0.04, 0.19)	0.003
Sample size and regression diagnostic values for logistic and probit regression analyses		n = 9501 Log-likelihood = -6387.94 Wald chi2(17) = 427.79 p-value<0.001 Pseudo R ² = 0.0298		n = 9501 Log-likelihood = -6388.02 Wald chi2(17) = 441.18 p-value<0.001 Pseudo R ² = 0.0298	

Unions were adjusted as clusters. Baseline and endline were adjusted as time variables

Predictive performance: Table 4 describes the model validation based on sensitivity, specificity, and whether the model was correctly classified for the overall dataset, as well as the training and test datasets. The sensitivity and specificity of the model were around 60% and 55%, respectively for all models. The correctly classified rate was 59%, and the area under the ROC curve was around 61%. We found that these values were approximately equal among the three datasets (main, training, and test datasets); however, the predictive performance of the model was low.

Table 4. Predictive performance of the model for stunting based on classification, sensitivity, and specificity in the full, training and test datasets with area under the receiver operating characteristic curve analysis

	Logistic regression	Probit regression	Decision tree
Full dataset			
Overall accuracy	58.46	58.38	56.51
Sensitivity	61.21	61.25	61.15
Specificity	55.61	55.41	51.70
Area under the curve	61.54	61.54	56.72
Training Dataset			
Overall accuracy	58.83	58.62	57.66
Sensitivity	61.59	61.70	63.93
Specificity	55.36	55.42	51.61
Area under the curve	61.37	61.37	58.44
Test Dataset			
Overall accuracy	58.11	58.19	56.67
Sensitivity	60.23	60.23	61.58
Specificity	55.90	56.07	51.94

Area under the curve	61.76	61.77	58.01
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360 Discussion

361 In an effort to understand why the *Suchana* programme was not effective in reducing the
 362 prevalence of childhood stunting, this study analyzed data from both the baseline and endline
 363 surveys of the programme. The analysis aimed to identify the factors that were significantly
 364 correlated with stunting and to evaluate the model's predictive performance. After controlling for
 365 the *Union* as a cluster variable, the study found several indicators that were significantly related to
 366 stunting. These included the number of ANC visits by a skilled service provider, household dietary
 367 diversity, household food security, and household monthly income, all of which improved after
 368 the intervention. However, it was noted that the household food security status did not reach the
 369 target value of 50%, despite being an important factor associated with childhood stunting.[8, 30,
 370 31] On the other hand, other outcome indicators of the *Suchana* programme, such as the dietary
 371 diversity of children, maternal dietary diversity, and maternal empowerment, despite reaching their
 372 target values, were not found to be associated with stunting in this study.

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374 The study found that while the *Suchana* programme showed improvement in certain programme
 375 indicators, it did not lead to a significant reduction in childhood stunting. Despite efforts to address
 376 key factors such as maternal nutrition and education, household food security, and hygiene
 377 practices, these factors remained largely unchanged. However, the study suggests that
 378 interventions aimed at adolescent mothers may be more effective in improving maternal nutrition
 379 and education, since these are age-dependent variables. Additionally, the results of the study were
 380 also impacted by natural disasters in 2017, including heavy rains and flooding in the Sylhet region,
 381 which resulted in widespread damage to agriculture, aquaculture, and homes in the study
 382 population.[32, 33]

383

384 The study found a contradictory relationship between stunting and maternal involvement in
 385 income-generating activities, with a higher prevalence of stunting observed among children whose
 386 mothers were engaged in various earning activities. Although there was a slight increase in the
 387 proportion of mothers involved in income-generating activities after the intervention, the lack of

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3 388 childcare support for working mothers resulted in a marked rise in childhood stunting among low-
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5 389 income households. It is important to address this issue by providing adequate childcare support
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7 390 measures for working mothers from poor families to ensure that the child's essential needs are not
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9 391 impacted by the mother's employment status.[13] Additionally, efforts should be made to increase
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11 392 awareness among working mothers regarding the importance of child health and nutrition. This
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13 393 can be achieved through targeted education and outreach programmes that provide information on
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15 394 proper child feeding practices, hygiene, and health-seeking behaviours.

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16
17 396 The literature suggests that environmental enteropathy may contribute to poor growth among
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19 397 children in rural Bangladesh and may represent an important factor affecting the study population
20
21 398 in the *Suchana* programme.[34] Although it was not specifically assessed in this study, indicators
22
23 399 such as unsanitary latrines, unimproved floors, a lack of handwashing practices, and low education
24
25 400 levels were available.[18, 35] Improving Water, Sanitation and Hygiene (WaSH) variables,
26
27 401 particularly latrine facilities and handwashing practices, may help reduce the burden of stunting in
28
29 402 young children. One of the components of the intervention was poultry, but our qualitative findings
30
31 403 revealed that many households shared living spaces with poultry, ducks, or other animals, which
32
33 404 could increase the risk of infections with *Campylobacter* species, a leading food-borne
34
35 405 pathogen.[18, 36] Previous studies have shown a strong association between stunting and
36
37 406 enteropathy among children who do not respond to nutritional interventions, and findings from
38
39 407 rural Bangladesh have linked environmental conditions and stunting in children.[37-39] While
40
41 408 assessing environmental enteropathy was beyond the scope of the *Suchana* evaluation, collecting
42
43 409 data on indicators of enteropathy in the intervention and control areas could help evaluate the
44
45 410 impact of appropriate interventions in the future. The failure to achieve the desired outcome may
46
47 411 have been due to several factors, including food insecurity and a lack of aquaculture involvement
48
49 412 due to natural disasters, poor WaSH status, a lack of focus on maternal education and nutrition,
50
51 413 and a lack of focus on the risk of enteropathogen burden.

48 414
49
50 415 Another important finding based on the post-estimation findings as well as the value of the area
51
52 416 under the ROC curve was that the predictive performance of the model was low. Thus, we need to
53
54 417 identify other indicators from similar research contexts that influence childhood stunting but were
55
56 418 not included in our model. Future research in the field of childhood stunting should give priority

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2
3 419 to the development of more suitable methods for monitoring and identifying effective
4
5 420 interventions. It is also essential to collect data that considers biological and environmental factors
6
7 421 related to childhood stunting, following the literature. By considering these diverse factors, we can
8
9 422 improve the accuracy and predictive performance of statistical models. This, in turn, can help draw
10
11 423 more reliable conclusions about the effectiveness of interventions aimed at reducing childhood
12
13 424 stunting in similar contexts. Additionally, evaluating the model on an independent dataset or
14
15 425 conducting external validation could help to determine the generalizability of the model to new
16
17 426 data.

18
19 428 This study will aid programme managers in prioritizing their focus and designing effective
20
21 429 interventions to reduce childhood stunting. Sustainable solutions should be based on the needs of
22
23 430 the beneficiaries. Implementing short-term initiatives such as attendance at healthcare-led
24
25 431 workshops and campaigns can increase ANC visits, skilled birth attendance, and handwashing
26
27 432 practices. Establishing women's healthcare services that focus on maternal and child health and
28
29 433 nutrition will also help reduce the incidence of stunting.[23] Improved access to media can help
30
31 434 vulnerable communities benefit from government welfare programmes. Food security, income,
32
33 435 sanitation, aquaculture, and illness are all time-sensitive factors. Increasing food production
34
35 436 through self-production or purchasing can improve household food security and nutrition.
36
37 437 However, household wealth and access to nearby markets can impact their ability to buy nutritious
38
39 438 food. Climate change adaptation in agriculture is crucial to minimize current risks and prepare for
40
41 439 future uncertainties. Using organic fertilizers instead of chemicals in agriculture has environmental
42
43 440 benefits, reducing the need for pesticides and protecting human health and biodiversity.
44
45 441 Aquaculture can provide a source of protein and improve nutrition, but establishing these facilities
46
47 442 takes time. Improving sanitation requires improving socioeconomic status, which is also a time-
48
49 443 intensive process. It takes time to improve stunting, as shown by national surveys such as the
50
51 444 BDHS and the Food Security and National Surveillance Project (FSNSP).[2, 40] Improving
52
53 445 maternal nutrition and education is crucial for promoting the optimal growth and development of
54
55 446 children. Adequate food, good environmental conditions, and access to schooling facilities during
56
57 447 adolescence are necessary for women to maintain their own health and to positively impact the
58
59 448 health of their children. Emphasizing the education of female children can break the cycle of
60
61 449 poverty and stunting, as it can lead to improved knowledge and decision-making skills related to

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2
3 450 nutrition and health.[6, 11] To reduce childhood stunting in developing countries, comprehensive
4 451 interventions that include nutritional support, food security, maternal education, income-
5 452 generating activities for women with childcare support, and addressing domestic violence against
6
7 453 women should be implemented. These interventions should be tailored to the specific needs and
8
9 454 cultural context of the community in which they are implemented, and community participation
10
11 455 and engagement are essential for their success. By addressing the underlying factors contributing
12
13 456 to childhood stunting, we can make significant progress towards reducing its prevalence and
14
15 457 improving the health and well-being of children in developing countries. Furthermore, continued
16
17 458 monitoring and evaluation of these interventions is essential to ensure their effectiveness and to
18
19 459 identify areas for improvement.
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21 460
22 461 **Recommendation:** The *Suchana* model offers a holistic and integrated approach to addressing
23
24 462 food and nutrition security, recognizing undernutrition as a complex problem caused by multiple
25
26 463 factors. The endline survey of *Suchana* showed significant improvement in programme indicators.
27
28 464 The multi-sector approach of *Suchana* is a meaningful solution to addressing undernutrition.
29
30 465 However, policy makers should consider implementing additional nutrition-sensitive and specific
31
32 466 activities, such as promoting climate-resilient agriculture and increasing water and sanitation
33
34 467 coverage. It is also important to have a sustainable mechanism for improving food security and to
35
36 468 promote awareness of seasonal diseases associated with livestock and poultry. To further improve
37
38 469 the programme, indicators such as child sex, maternal education, and nutrition could be adjusted
39
40 470 during the design stage. The *Suchana* programme is one of the largest global nutrition
41
42 471 interventions, leading to positive changes in critical indicators, with long-term benefits expected
43
44 472 for the health and livelihoods of the beneficiaries.
45

46 473
47 474 **Strength and limitation:** The study had several strengths, including a large sample size,
48
49 475 randomization, and appropriate sampling techniques. A dedicated quality control team was
50
51 476 involved in checking the data, and the use of precise anthropometry instruments and separate
52
53 477 training for the measurement team helped ensure accurate data collection. The study was also
54
55 478 designed to avoid seasonality by conducting the baseline and endline surveys at the same time of
56
57 479 the year. However, the study results may have been impacted by a lack of selection effect in the
58
59 480 implementation of the programme, as well as by the short time horizon of the study. The short
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1
2
3 481 duration of the study may not have been enough to see a significant impact on stunting.
4
5 482 Additionally, changes in the study population between the baseline and endline surveys could also
6
7 483 have contributed to the lack of differences observed in the results. Another limitation of this study
8
9 484 is that we did not collect food intake data but only recall data from the previous 24 hours. These
10
11 485 data may be subject to recall bias; thus, caution is necessary when drawing conclusions, especially
12
13 486 for indicators such as dietary diversity, household food insecurity, domestic violence, and maternal
14
15 487 healthcare. Finally, using a binary indicator of stunting based on a single LAZ cut-off point, which
16
17 488 was defined as <-2 , may not provide a comprehensive assessment of the severity of malnutrition
18
19 489 among children, as it fails to account for micronutrient deficiencies
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21 490
22 491

22 492 **Conclusion**

23
24 493 Childhood stunting was heavily influenced by a number of factors, and majority of the factors
25
26 494 were found in poor status in our study area. Despite the implementation of an intervention
27
28 495 programme, the situation remained unchanged due to factors such as food insecurity, lack of
29
30 496 involvement in aquaculture, poor access to WaSH facilities, and a lack of focus on maternal
31
32 497 education and nutrition. The study did not include important indicators such as enteropathogen
33
34 498 and environmental enteric dysfunction, which might have contributed to the failure to achieve the
35
36 499 desired outcome. The results suggest that policy makers and programme planners should consider
37
38 500 enhancing collaboration and coordination between nutrition-sensitive and specific activities to
39
40 501 address nutritional deficiencies and family health programmes in vulnerable rural populations.
41
42 502

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42
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46
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48
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23
24 524 **Conflicts of Interest:** The authors declare no conflict of interest.
25
26 525

27 526 **Author Contributions:** TA and NC originated the idea for the study and led the protocol design.
28 527 MAH conceptualized the manuscript. SMTA, SSR, MAH, NC, FDF, and TA contributed to the
29 528 survey design. MAH performed statistical analysis and drafted the manuscript. NC and ASGF
30 529 supervised the work, and critically reviewed and provided feedback for revising the manuscript.
31 530 MAH, NC, MA, FDF, FN, BZW, TJS, ASGF, TA, and SSR contributed to the revision of the final
32 531 draft for submission. All authors are responsible for the final content of the manuscript.
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39 533 **Ethics approval:** This study was approved by the Research Review Committee and Ethical
40 534 Review Committee, the two obligatory components of the Institutional Review Board (IRB) of
41 535 icddr,b. Ethics Committee's approval ID# 00001822. Informed written consent was obtained from
42 536 study participants.
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48 538 **Data availability statement:** The data that support the findings of this study are available on
49 539 request from the corresponding author. The data are not publicly available due to privacy and
50 540 ethical restrictions.
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3 651 Figure 1. Prevalence of childhood stunting in the intervention and control areas at baseline
4 652 compared to endline. The p-value of the *difference-in-difference* was estimated using interaction
5 653 analysis in the multiple logistic regression model.
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10 654
11 655 Figure 2. Results framework and *Suchana* log frame indicators. ANC: antenatal care, HDDS:
12 656 household dietary diversity score, MDD-w: minimum dietary diversity for women.
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15 657
16 658 Figure 3. Factors correlating with stunting in children aged 12-23 months, computed using decision
17 659 tree analysis. (X₁: Less than four ANC visits by a skilled service provider, X₂: Unskilled birth
18 660 attendant/facility, X₃: Mother involved in income-generating activities, X₄: Maternal BMI <18.5,
19 661 X₅: Maternal education: no schooling, X₆: Household severe food insecurity, X₇: Monthly income
20 662 <15000 BDT, X₈: Did not involve with aquaculture, X₉: Having unhygienic latrine, X₁₀: Soap was
21 663 unavailable in hand washing place, X₁₁: HH size ≥7, X₁₂: HH dietary diversity score <7, X₁₃:
22 664 Child's age >18, X₁₄: Child's sex was male, X₁₅: Childhood illness in the last 15 days, and X₁₆:
23 665 Lacked access to mass media)
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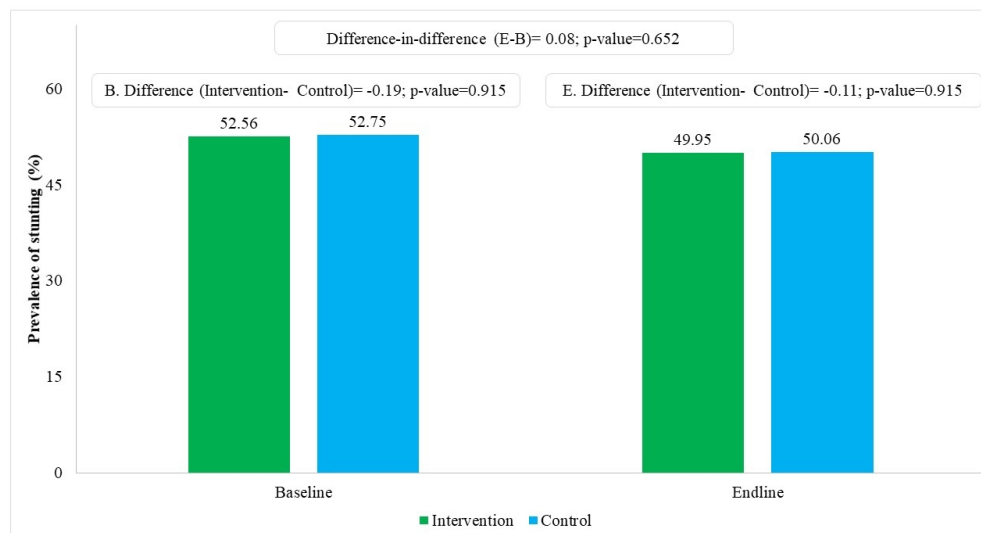


Figure 1. Prevalence of childhood stunting in the intervention and control areas at baseline compared to endline. The p-value of the difference-in-difference was estimated using interaction analysis in the multiple logistic regression model.

108x60mm (300 x 300 DPI)

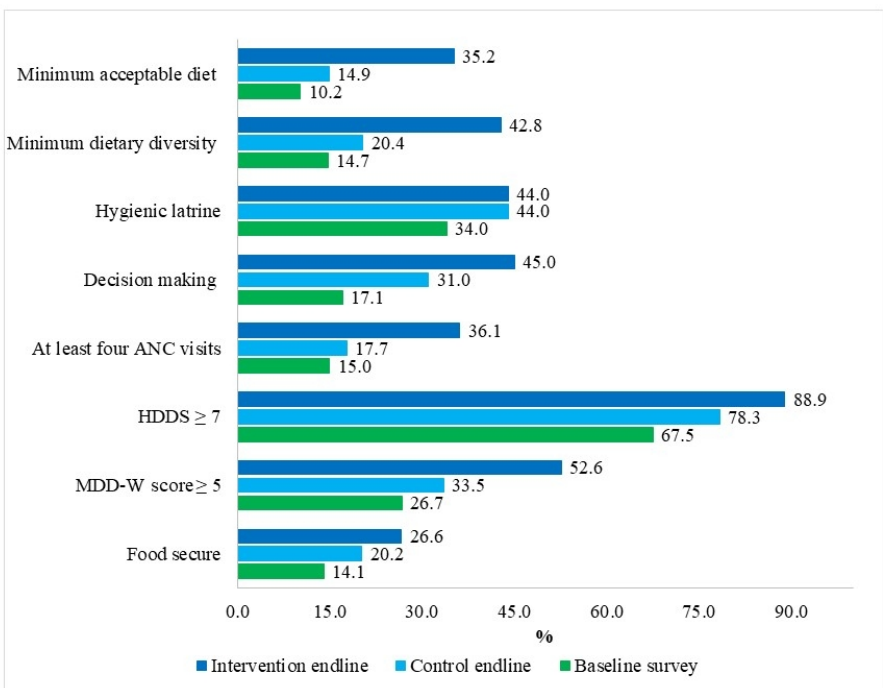


Figure 2. Results framework and Suchana log frame indicators. ANC: antenatal care, HDDS: household dietary diversity score, MDD-w: minimum dietary diversity for women.

254x190mm (96 x 96 DPI)

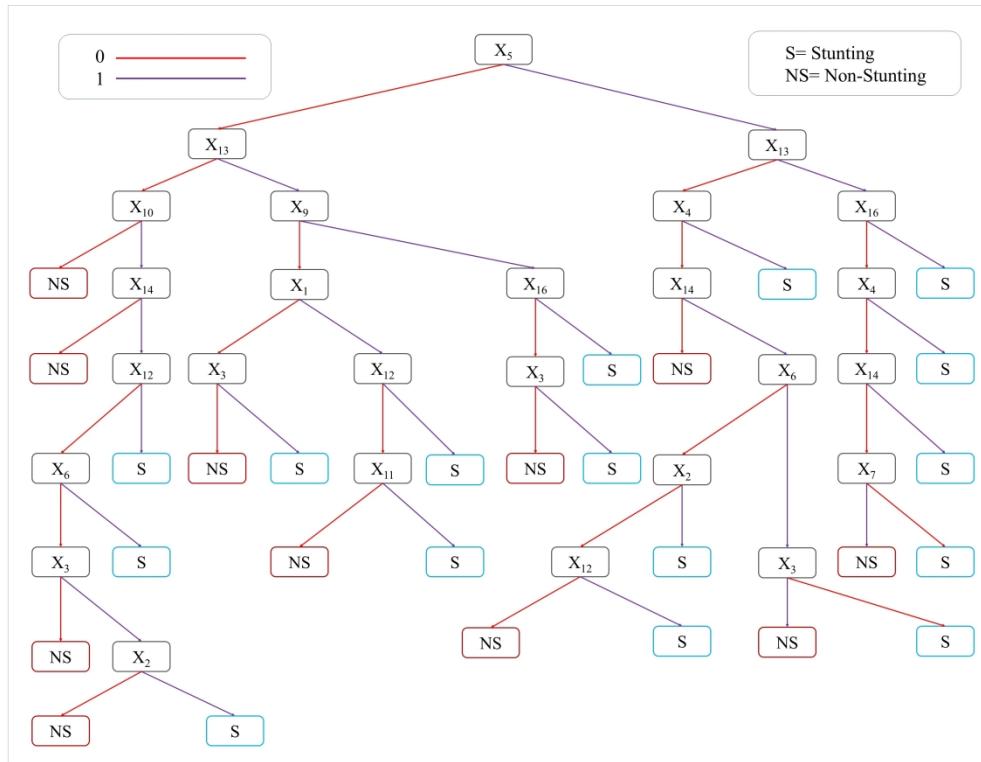


Figure 3. Factors correlating with stunting in children aged 12-23 months, computed using decision tree analysis. (X1: Less than four ANC visits by a skilled service provider, X2: Unskilled birth attendant/facility, X3: Mother involved in income-generating activities, X4: Maternal BMI <18.5, X5: Maternal education: no schooling, X6: Household severe food insecurity, X7: Monthly income <15000 BDT, X8: Did not involve with aquaculture, X9: Having unhygienic latrine, X10: Soap was unavailable in hand washing place, X11: HH size>7, X12: HH dietary diversity score <7, X13: Child's age>18, X14: Child's sex was male, X15: Childhood illness in the last 15 days, and X16: Lacked access to mass media)

325x254mm (300 x 300 DPI)

Appendix 1. Sample size calculation

```
clustersampsi, binomial samplesize p1(0.47) p2(0.41) k40) rho0.01)alpha(0.05) beta(0.8)
```

Output of the STATA command for sample size calculation

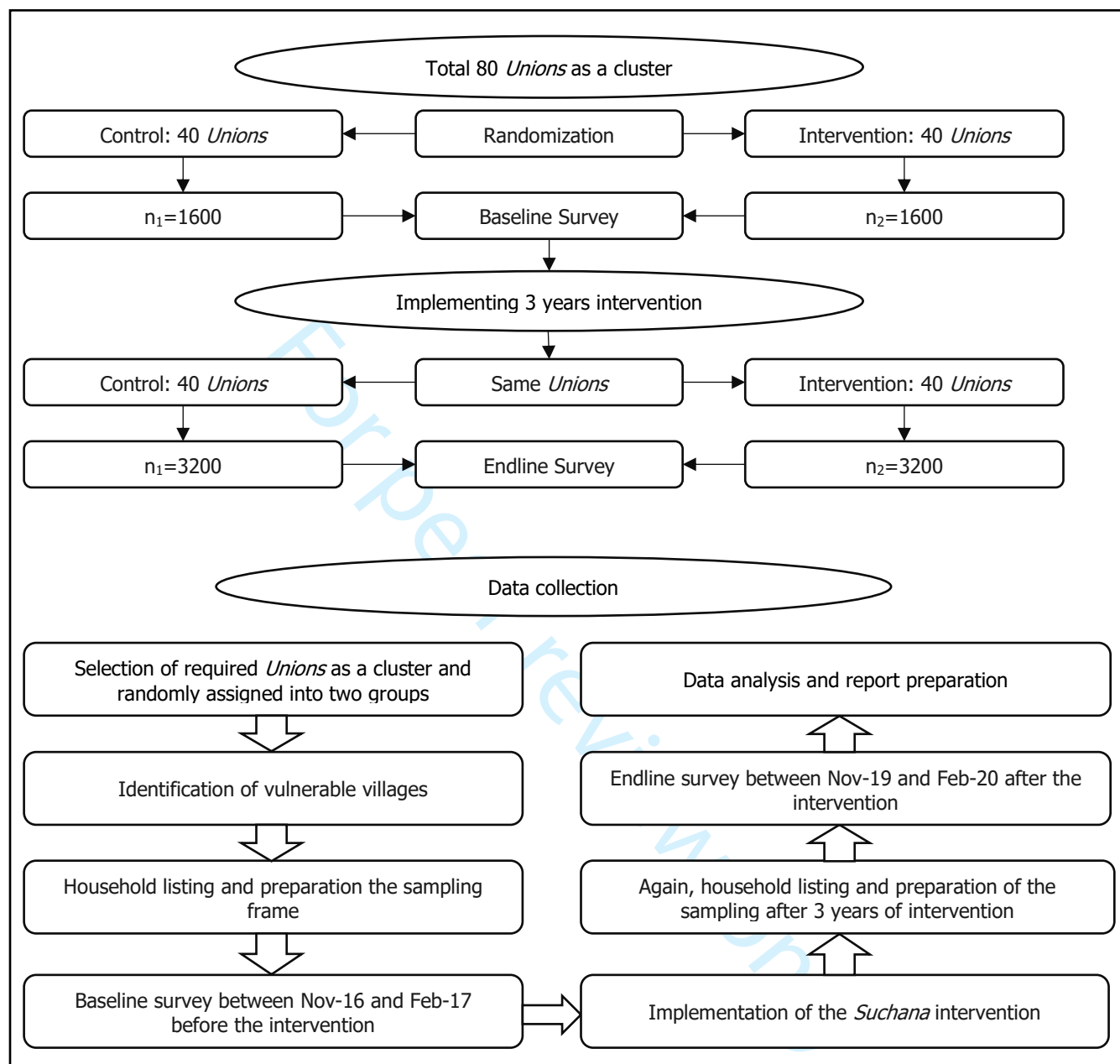
Sample size calculation to determine number of observations required per cluster, for a two-sample comparison of proportions (using normal approximations) without continuity correction.

For the user specified parameters:

```
p1: 0.4700
p2: 0.4100
significance level: 0.05
power: 0.80
number of clusters available: 40
intra cluster correlation (ICC): 0.0100
```

clustersampsi estimated parameters:

```
Firstly, assuming individual randomisation: sample size per arm: 1071
Then, allowing for cluster randomisation: average cluster size required: 38
sample size per arm: 1520
```



Supplementary Figure 1. The evaluation diagram of *Suchana* programme

Appendix 2. Data collection

The Suchana data collection software contained built-in validation rules. As the data were entered at the interviewer level and the records were uploaded to a server at the icddr,b using the built-in internet connectivity of the devices, maximum validation rules were set in the data system to prevent errors during data entry, which reduced the data entry burden. This allowed the data analysis team to review the

consistency of the data every day. Data were synchronized to the central server “Web Service” developed in Asp.Net based on the C# (C Sharp) code. Activities such as editing (after receiving any feedback from field staff members), updating, range checks, duplication checks, consistency checks, frequency checks and cross tabulation were regularly performed during the data entry period. In case of any unusual observations, the issues were discussed and resolved.

Appendix 3. Equation of logistic and probit regression

$$\text{logit}(y) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 X_6 + \beta_7 X_7 + \beta_8 X_8 + \beta_9 X_9 + \beta_{10} X_{10} + \beta_{12} X_{12} + \beta_{13} X_{13} + \beta_{14} X_{14} + \beta_{15} X_{15} + \beta_{16} X_{16}$$

$$\text{probit}(y) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 X_6 + \beta_7 X_7 + \beta_8 X_8 + \beta_9 X_9 + \beta_{10} X_{10} + \beta_{12} X_{12} + \beta_{13} X_{13} + \beta_{14} X_{14} + \beta_{15} X_{15} + \beta_{16} X_{16}$$

Where,

x1: Less than four ANC visits by a skilled service provider	x9: Having unhygienic latrine
x2: Unskilled birth attendant/facility	x10: Soap was unavailable in hand washing place
x3: Mother involved in income-generating activities	x11: HH size ≥ 7
x4: Maternal BMI < 18.5	x12: HH dietary diversity score < 7
x5: Maternal education: no schooling	x13: Child's age > 18
x6: HH severe food insecurity	x14: Child's sex was male
x7: Monthly income < 15000 BDT	x15: Childhood illness in the last 15 days
x8: Did not involve with aquaculture	x16: Lacked access to mass media

and

$$\text{logit}(y) = \log[y/(1-y)]$$

Supplementary Table 1. Suchana inclusion criteria for registration of enrolling as vulnerable households

Vulnerable household verification questions	Inclusion criteria
Step 1	
<ul style="list-style-type: none"> Households currently participating/member of any livelihood, food security or asset transfer program 	If “NO” go ahead for next questions
Step 2	
<ul style="list-style-type: none"> Ability to afford three (3) full meals per day for all family members round the year Households monthly income BDT 7,500 or more Household productive asset value worth BDT 15,000 or more (excluding land, pond and homestead) Ownership of homestead land 10 decimals or more Ownership of cultivable land 50 decimals or more (excluding homestead or pond) 	If anyone is “NO” go ahead for next questions
Step 3	
<ul style="list-style-type: none"> Households have married women with in child bearing age (15 to 45 years) Households have pregnant women (including abandoned or widowed woman) Households have 0-23 months old children Households have adolescent girls (15-19 years) 	If anyone is ‘Yes’ go ahead for registration of enrolling as vulnerable Household
Sampling frame was prepared for collecting data from mother-child pair if the households had 0-23 months old children	

Supplementary Table 2a. Predictive ability of various indicators for the adjusted prevalence of stunting and adjusted prevalence difference (effect size) in the fitted multiple logistic regression model.

	Prediction of adjusted stunting [% (95% CI)]	Prediction of adjusted prevalence difference as effect size*	p-value
At least four ANC visits by a skilled service provider			
Yes	51.64 (50.05, 53.23)	Reference	
No	47.99 (45.46, 50.53)	3.65 (1.07, 6.22)	0.006
Birth attendant/facility			
Skilled	51.87 (50.23, 53.51)	Reference	
Unskilled	49.42 (47.48, 51.36)	2.45 (0.55, 4.35)	0.012
Mother involved in income-generating activities			
No	54.55 (50.90, 58.19)	Reference	
Yes	50.59 (49.08, 52.11)	3.95 (0.40, 7.51)	0.029
Maternal BMI			
BMI \geq 18.5	54.04 (52.01, 56.07)	Reference	
BMI <18.5	49.01 (47.21, 50.81)	5.03 (2.66, 7.41)	<0.001
Maternal education was primary completed			
Yes	54.66 (52.58, 56.74)	Reference	
No	48.21 (46.67, 49.75)	6.45 (4.49, 8.40)	<0.001
HH food insecurity			
Below severe	53.03 (50.91, 55.15)	Reference	
Severe	50.36 (48.63, 52.09)	2.66 (0.11, 5.22)	0.041
HH monthly income \geq15000 BDT			
Yes	51.31 (49.79, 52.84)	Reference	
No	48.58 (45.86, 51.30)	2.73 (0.17, 5.30)	0.037
Involved with aquaculture			
Yes	51.22 (49.72, 52.72)	Reference	
No	46.99 (43.30, 50.69)	4.23 (0.73, 7.73)	0.018
Hygienic latrine			
Yes	52.67 (50.94, 54.4)	Reference	
No	48.36 (46.5, 50.23)	4.31 (2.34, 6.28)	<0.001
Water and soap available in handwashing place			
Yes	52.64 (50.71, 54.58)	Reference	
No	48.54 (46.74, 50.33)	4.10 (1.83, 6.38)	<0.001
HH size			
Below seven	53.86 (51.98, 55.74)	Reference	
Seven or above	49.41 (47.70, 51.13)	4.44 (2.43, 6.46)	<0.001
HH dietary diversity			
HDDS \geq 7	53.92 (51.25, 56.60)	Reference	
HDDS <7	50.10 (48.70, 51.50)	3.83 (1.63, 6.02)	<0.001
Child's age			
Age \leq 18 months	56.72 (54.77, 58.67)	Reference	
Age >18 months	46.59 (44.82, 48.35)	10.1 (7.94, 12.32)	<0.001
Child's sex			
Female	53.25 (51.17, 55.34)	Reference	
Male	48.40 (46.78, 50.03)	4.85 (2.59, 7.10)	<0.001
Childhood illness in the last 15 days			
No	54.90 (52.04, 57.77)	Reference	
Yes	50.49 (48.94, 52.05)	4.41 (1.48, 7.34)	0.003
Access of mass media			
Yes	51.51 (49.88, 53.15)	Reference	
No	48.13 (45.39, 50.88)	3.38 (0.42, 6.34)	0.028

*Differences in the predicted values of stunting between the two groups were calculated using the Stata "adjrr" package

Supplementary Table 2b. Predictive ability of various indicators for the adjusted prevalence of stunting and adjusted prevalence difference (effect size) in the fitted multiple probit regression model.

	Prediction of adjusted stunting [% (95% CI)]	Prediction of adjusted prevalence difference as effect size*	p-value
At least four ANC visits by a skilled service provider			
Yes	51.64 (50.05, 53.23)	Reference	
No	47.99 (45.46, 50.53)	3.65 (1.08, 6.22)	0.007
Birth attendant/facility			
Skilled	51.87 (50.23, 53.51)	Reference	
Unskilled	49.42 (47.48, 51.36)	2.45 (0.54, 4.35)	0.011
Mother involved in income-generating activities			
No	54.55 (50.90, 58.16)	Reference	
Yes	50.59 (49.08, 52.11)	3.93 (0.39, 7.48)	0.024
Maternal BMI			
BMI \geq 18.5	54.04 (52.01, 56.07)	Reference	
BMI <18.5	49.01 (47.21, 50.81)	5.03 (2.66, 7.40)	<0.001
Maternal education was primary completed			
Yes	54.66 (52.58, 56.74)	Reference	
No	48.21 (46.67, 49.75)	6.45 (4.49, 8.41)	<0.001
HH food insecurity			
Below severe	53.01 (50.89, 55.12)	Reference	
Severe	50.37 (48.64, 52.10)	2.64 (0.09, 5.19)	0.042
HH monthly income \geq15000 BDT			
Yes	51.32 (49.79, 52.84)	Reference	
No	48.56 (45.84, 51.28)	2.75 (0.19, 5.32)	0.035
Involved with aquaculture			
Yes	51.22 (49.73, 52.71)	Reference	
No	46.99 (43.28, 50.69)	4.24 (0.73, 7.74)	0.018
Hygienic latrine			
Yes	52.67 (50.94, 54.4)	Reference	
No	48.36 (46.5, 50.23)	4.31 (2.34, 6.28)	<0.001
Water and soap available in handwashing place			
Yes	52.64 (50.71, 54.58)	Reference	
No	48.53 (46.74, 50.33)	4.11 (1.83, 6.39)	<0.001
HH size			
Below seven	53.86 (51.98, 55.73)	Reference	
Seven or above	49.41 (47.70, 51.13)	4.44 (2.43, 6.46)	<0.001
HH dietary diversity			
HDDS \geq 7	53.90 (51.23, 56.57)	Reference	
HDDS <7	50.10 (48.71, 51.50)	3.79 (1.60, 5.98)	<0.001
Child's age			
Age \leq 18 months	56.72 (54.76, 58.67)	Reference	
Age >18 months	46.59 (44.83, 48.35)	10.1 (7.93, 12.3)	<0.001
Child's sex			
Female	53.25 (51.17, 55.33)	Reference	
Male	48.41 (46.78, 50.03)	4.85 (2.60, 7.10)	<0.001
Childhood illness in the last 15 days			
No	54.90 (52.04, 57.75)	Reference	
Yes	50.50 (48.94, 52.05)	4.40 (1.47, 7.33)	0.003
Access of mass media			
Yes	51.51 (49.88, 53.15)	Reference	
No	48.13 (45.40, 50.86)	3.38 (0.42, 6.34)	0.028

*Differences in the predicted values of stunting between the two groups were calculated using the Stata "adjrr" package

STROBE Statement—Checklist of items that should be included in reports of *cross-sectional studies*

	Item No	Recommendation	Page No
Title and abstract	1	(a) Indicate the study's design with a commonly used term in the title or the abstract	1-2
		(b) Provide in the abstract an informative and balanced summary of what was done and what was found	1-2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	3-6
Objectives	3	State specific objectives, including any prespecified hypotheses	6
Methods			
Study design	4	Present key elements of study design early in the paper	6
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	6
Participants	6	(a) Give the eligibility criteria, and the sources and methods of selection of participants	6
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	6-7
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	6-7
Bias	9	Describe any efforts to address potential sources of bias	20
Study size	10	Explain how the study size was arrived at	7
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	7
Statistical methods	12	(a) Describe all statistical methods, including those used to control for confounding	8-9
		(b) Describe any methods used to examine subgroups and interactions	
		(c) Explain how missing data were addressed	
		(d) If applicable, describe analytical methods taking account of sampling strategy	8-9
		(e) Describe any sensitivity analyses	
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	11
		(b) Give reasons for non-participation at each stage	
		(c) Consider use of a flow diagram	
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	11
		(b) Indicate number of participants with missing data for each variable of interest	
Outcome data	15*	Report numbers of outcome events or summary measures	11
Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	11-14

		(b) Report category boundaries when continuous variables were categorized	
		(c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	11-15
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	
Discussion			
Key results	18	Summarise key results with reference to study objectives	17
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	20
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	17
Generalisability	21	Discuss the generalisability (external validity) of the study results	17-18
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	22

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at <http://www.plosmedicine.org/>, Annals of Internal Medicine at <http://www.annals.org/>, and Epidemiology at <http://www.epidem.com/>). Information on the STROBE Initiative is available at www.strobe-statement.org.

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A predictive modelling approach to illustrate factors correlating with stunting among children aged 12-23 months: a cluster randomized pre-post study

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1 A predictive modelling approach to illustrate factors correlating with stunting among 2 children aged 12-23 months: a cluster randomized pre-post study

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15 Word count: 4977

17 **Abstract**

18 **Objective** The aim of this study was to construct a predictive model in order to develop an
19 intervention study to reduce the prevalence of stunting among children aged 12-23 months.

20
21 **Design** The study followed a cluster randomized pre-post design and measured the impacts on
22 various indicators of livelihood, health, and nutrition. The study was based on a large dataset
23 collected from two cross-sectional studies (baseline and endline).

24
25 **Setting** The study was conducted in the north-eastern region of Bangladesh under the Sylhet
26 division, which is vulnerable to both natural disasters and poverty. The study specifically targeted
27 children between the ages of 12 and 23 months.

28
29 **Main outcome measures** Childhood stunting, defined as a length-for-age z-score (LAZ) <-2 , was
30 the outcome variable in this study. Logistic and probit regression models and a decision tree were
31 constructed to predict the factors associated with childhood stunting. The predictive performance

32 of the models was evaluated by computing the area under the receiver operating characteristic
33 (ROC) curve analysis.

34
35 **Results** The baseline survey showed a prevalence of 52.7% stunting, while 50.0% were stunted at
36 endline. Several factors were found to be associated with childhood stunting. The model's
37 sensitivity was 61% and specificity was 56%, with a correctly classified rate of 59% and an area
38 under the ROC curve of 0.615.

39
40 **Conclusion** The study found that childhood stunting in the study area was correlated with several
41 factors, including maternal nutrition and education, food insecurity, and hygiene practices. Despite
42 efforts to address these factors, they remain largely unchanged. The study suggests that a more
43 effective approach may be developed in future to target adolescent mothers, as maternal nutrition
44 and education are age-dependent variables. Policymakers and programme planners need to
45 consider incorporating both nutrition-sensitive and specific activities and enhancing collaboration
46 in their efforts to improve the health of vulnerable rural populations.

47
48 **Study registration:** RIDIE-STUDY-ID-5d5678361809b

49
50 **Keywords:** Childhood stunting, Chronic malnutrition, Global public health, Logistic regression,
51 Probit regression, Decision tree

52 53 **Strengths and limitations of this study**

- 54 • The study used a combination of parametric and non-parametric predictive models to
55 estimate the effect size of the independent variables and identify significant correlates of
56 childhood stunting
- 57 • The study was designed to mitigate the potential impact of seasonal factors by conducting
58 the baseline and endline surveys at the same time of the year
- 59 • A binary indicator of stunting based on a single LAZ cut-off point (<-2) may not provide
60 a complete evaluation of the severity of malnutrition among children as it does not
61 consider micronutrient deficiencies

- 62 • Use of recall data from the previous 24 hours for dietary diversity, household food
63 insecurity, domestic violence, and maternal healthcare may be subject to recall bias
- 64 • Biological data has not been collected such as enteropathogen and environmental enteric
65 dysfunction, which could have been related to childhood stunting

67 Introduction

68 Childhood stunting, which is defined as length-for-age z-score (LAZ) <-2 , is a major concern for
69 public health and has been widely used as an indicator of chronic malnutrition in children.^{1 2}
70 Although childhood stunting scenarios have much improved globally, the prevalence of childhood
71 stunting is still very high in low-resource settings, including countries such as Bangladesh.
72 According to the 2018 Global Nutrition Report, 150.8 million children (22.2%) under five years-
73 of-age are stunted globally, compared to 198.4 million (32.6%) and 165 million children in 2000
74 and 2011, respectively.^{3 4} Between 2000 and 2018, Asian countries have experienced a decrease
75 in the rate of stunting among children under five from 38.1% to 23.2%. However, South Asia still
76 has the highest prevalence of stunting in the region, with a rate of 38.9% in 2018.³ In Bangladesh,
77 about 5.5 million (36%) children under five were stunted in 2014,⁵ however by 2018, childhood
78 stunting has reduced to about 31%.² As the World Health Organization (WHO) considers a
79 childhood stunting rate of 15% to be an emergency situation, the current prevalence of childhood
80 stunting in Bangladesh reflects an alarming situation of chronic undernutrition.⁶

81
82 Literature suggests that children are at a higher prevalence of stunting if their mothers do not
83 receive adequate antenatal care, fail to rest sufficiently, do not consume additional food, and
84 neglect to take iron-folic acid (IFA) tablets during pregnancy.⁷⁻⁹ Additionally, maternal and child
85 health are correlated with mass media exposure, receiving a vitamin A capsule, having a skilled
86 birth attendant, and maternal education.^{6 8 10-12} Children in poor households in Bangladesh are more
87 likely to experience stunted growth if their mothers are employed, as there are inadequate day-care
88 centres available for the children, leading to insufficient breastfeeding.¹³ Moreover, evidence
89 suggests that a number of characteristics at the household level, which relate to both children and
90 mothers, can influence childhood stunting. The characteristics of the household head, household
91 food insecurity and lower dietary diversity, household lower-income, household involvement in
92 several earning activities, availability of sanitation facility at home, hand-washing status, family

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3 93 size, religion, and receive several types of allowance from government are most often reported to
4 be associated with stunting in the literature.^{6 8 11 14-16}
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8 96 Based on child characteristics, several indicators are associated with stunting. This status is
9 associated with two basic characteristics: a child's gender and age.⁸ Children are commonly
10 affected by the co-occurrence of illness in low- and middle-income countries, which is one of the
11 most common causes of stunting.¹⁷ Inadequate infant and young child feeding (IYCF) practices
12 also reduce child growth.^{8 15} However, these findings are mostly based on nationally representative
13 cross-sectional and cohort studies, or studies conducted in urban settings.^{18 19} Therefore, a
14 knowledge gap exists on whether similar results would be obtained when nationwide data are
15 compared with data for study populations from poor or very poor rural households in specific
16 vulnerable regions.
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26 106 Sylhet is one such vulnerable region of north-east Bangladesh, comprising diverse terrains such as
27 plain land, hilly land, *Haor* (wetland), and flash flood-prone areas. This region is reported to
28 perform poorly for all important maternal healthcare indicators,²⁰ despite the fact that Bangladesh
29 has made substantial progress in improving the overall health of the population.²¹ Moreover, the
30 socio-economic profile of the inhabitants in Sylhet region includes both very rich and extremely
31 poor people. This scenario may worsen without the implementation of appropriate strategies in the
32 near future. Sylhet region is also performing poorly compared to the national averages for a number
33 of health and nutritional indicators. Critical indicators such as the infant mortality rate and
34 unemployment status of women are high.¹⁹ In comparison to the overall situation of Bangladesh,
35 where stunting among children under five has decreased, the Bangladesh Demographic and Health
36 Survey (BDHS) 2014 indicates the prevalence of childhood stunting in Sylhet is astonishingly
37 high, at 50%.¹⁹ This alarming figure provided the rationale for implementation of a comprehensive
38 intervention programme in this region. A large-scale nutrition programme, *Suchana: Ending the*
39 *Cycle of Undernutrition in Bangladesh; a multi-sectoral nutrition programme*, was undertaken
40 with the aim to prevent chronic malnutrition in Sylhet.
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53 122 In general, *Suchana* nutrition interventions can be divided into two types: nutrition-sensitive and
54 nutrition-specific.²² The concept of nutrition-sensitive intervention refers to an intervention that
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3 124 benefits the beneficiaries in terms of food and nutrition security, and also influences the underlying
4 125 determinants of nutrition. This type of intervention is largely delivered through the agricultural
5 126 sector (homestead vegetable and fruit production, pro-poor nutrition-sensitive aquaculture),
6 127 improved technology (mono-sex tilapia and carp-tilapia polyculture, subsistence fishing, fish
7 128 drying), demonstrations (village model farms and demo ponds, livestock, food security, promotion
8 129 of climate-smart technologies), and supported income-generating activities (skill development in
9 130 business management, engagement with the private sector and other sectors). As nutrition-specific
10 131 interventions were delivered through nutrition-sensitive interventions, their coverage,
11 132 effectiveness, and scale can be increased. It can meet the targets by lowering them and
12 133 implementing nutrition-specific interventions. A nutrition-specific intervention addresses the
13 134 immediate cause of malnutrition. Direct determinants of nutrition are the focus of this intervention.
14 135 There is a strong focus on nutrition-specific interventions in the health sector. Whether
15 136 implemented alone or jointly, nutrition-specific interventions improve health outcomes. Some
16 137 examples of nutrition-specific interventions are: counselling for mothers at the household level,
17 138 community-based nutrition education for spouses and in-laws, growth monitoring and promotion
18 139 sessions integrated with *Expanded Programme on Immunization* in communities, *Government of*
19 140 *Bangladesh* health facilities equipped with *severe acute malnutrition* service delivery, and support
20 141 for *National Nutrition Services* service delivery through community clinics, Union Health and
21 142 Family Welfare Centers, and Upazila health complexes.

22 143
23
24 144 The primary objective of the *Suchana* programme was to reduce the prevalence of childhood
25 145 stunting in the intervention areas. The secondary objectives were to assess the changes in *Suchana*
26 146 beneficiaries' households, in terms of an increase and diversification of household income, food
27 147 security status, optimal IYCF practices, haemoglobin status of children, the empowerment of
28 148 women, and adolescents' nutritional knowledge and practices.²²

29 149
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31 150 The *Suchana* programme substantially improved nutritional behaviour, maternal healthcare
32 151 practices, women's empowerment, household income, and household food security in the
33 152 intervention area compared to the control area.²³ Contrary to predictions, however, *Suchana* did
34 153 not result in any significant reduction in the prevalence of childhood stunting. Therefore, although
35 154 most other factors related to childhood stunting improved, this raises the question of why the

155 prevalence of stunting did not reduce after the intervention. An important observation from the
156 *Suchana* survey was that the proportion of households in this study population using hygienic
157 latrines was quite low. This factor was associated with stunting in children,⁸ and did not
158 significantly improve by endline in the intervention areas compared to the control areas.

159
160 In this study, we aimed to construct a predictive model to attempt to explain whether any
161 improvements in associated factors may promote a significant reduction in stunting among
162 children aged 12-23 months from poor and extremely poor households in the Sylhet region.

165 **Methods**

166 **Study design and setting**

167 The *Suchana* programme was implemented in 157 *Unions* over 20 sub-districts in the Sylhet region
168 in the north-east of rural Bangladesh. The *Suchana* programme's protocol has been thoroughly
169 explained elsewhere.²² *Union*, the smallest local government and administrative entity in rural
170 Bangladesh, was considered as a cluster and divided into four phases at random. Phase-1 was
171 designated as the intervention group, while Phase-4 was the control group, and the other phases
172 were treated as learning phases.²² For implementation purposes, vulnerable villages were selected
173 within Phase-1 and Phase-4 areas. The staff of the programme chose vulnerable villages in each
174 *Union* based on their vulnerability (e.g., frequent floods or submerging, little or no intervention
175 from other development programmes, poverty or household living circumstances, remoteness and
176 accessibility issues, a high prevalence of superstitions and social taboos). After consultation with
177 the local government representatives, elected officials, and local elites as well as field visits, this
178 selection method was decided upon. The impacts of the intervention on livelihood, health, and
179 nutrition were measured using a pre-post design. A large dataset was collected from two cross-
180 sectional surveys (baseline and endline) under this study. The baseline survey was conducted in
181 November 2016 and February 2017, followed by the endline survey in the same months three years
182 later among the same population and different participants (Supplementary Figure 1).

184 **Outcome variable**

185 The outcome variable in this study was childhood stunting, which was defined as a length-for-age
186 z-score (LAZ) <-2 .²

188 **Independent variables**

189 Initially, a list of independent variables was finalized through results obtained from descriptive
190 and bi-variate analyses, as well as a comprehensive literature review (Table 1). These included at
191 least four antenatal care (ANC) visits by a skilled service provider, additional resting during
192 pregnancy, additional food consumption during pregnancy, consumption of at least 100 IFA tablets
193 during pregnancy, receiving vitamin A capsule after last delivery, birth attendant/facility, mother
194 involved in income-generating activities, maternal BMI, maternal education, household food
195 insecurity, household monthly income >15000 BDT, involved with aquaculture, hygienic latrine,
196 water and soap available in handwashing place, household size, household dietary diversity, sex
197 of household head, religion, received any grant/allowance/stipend from the government, access of
198 mass media, child's age, child's sex, childhood illness in the last 15 days, minimum dietary
199 diversity, early initiation of breastfeeding, and received colostrum. Household food insecurity
200 access scale was measured using the Food and Nutrition Technical Assistance's Guideline, which
201 categorizes household food insecurity into four levels: a) food secure, b) mildly food insecure, c)
202 moderately food insecure, and d) severely food insecure.²⁴ In the analysis herein, this indicator
203 was redefined as a binary indicator: severely food insecure or not severely food insecure.

205 **Sample size**

206 The sample size for this study was calculated with the STATA "*clustersampsi*" command module,
207 considering the number of clusters in the surveys and considering the expected prevalence of
208 childhood stunting in the control group (Supplemental Appendix 1). It was estimated that the
209 expected prevalence of stunting was 47%, which was hypothesized to be reduced to 41% after
210 three years of intervention. A sample size of 1520 per arm was calculated based on a 5% level of
211 significance, 80% power, 40 clusters per arm, and an intra-cluster correlation coefficient (ICC) of
212 0.01. After rounding, the estimated sample size per arm was 1620, and the total sample size was
213 3200 at baseline, with an equal number of participants in the control and intervention groups. For
214 evaluation purposes, the sample size at endline was doubled to ensure a stratified intervention

1
2
3 215 component, resulting in a total sample size of 9600 mother-child pairs (baseline: 3200 and endline:
4 216 6400).²²

6 217

8 218 **Sampling**

10 219 The baseline and endline surveys were conducted in a total of eight and twelve villages
11 220 respectively, which were randomly selected from each *Union* using a list of vulnerable villages
12 221 provided by Save the Children. The most vulnerable households were identified and verified using
13 222 the inclusion criteria of the *Suchana* programme (Supplementary Table 1). These households were
14 223 then given an identification number to prepare the sampling frame and required households were
15 224 systematically selected for the surveys from the frame. The method of data collection is explained
16 225 in detail in the Supplemental Appendix 2.

22 226

24 227 **Statistical analysis**

26 228 **General characteristics:** Stata-14 software (StataCorp LP, College Station, TX, USA) and R 4.2.2
27 229 (*rpart*)²⁵ were used to analyse the data. Bar diagram was used for data visualization. Descriptive
28 230 statistics, such as frequency and proportions for categorical variables and mean and standard
29 231 deviations for quantitative variables, were used to summarize the data at baseline and endline.
30 232 Cross-tabulation was used to present that outcome variable segregated by intervention and control
31 233 group at baseline survey as well as the endline survey. The *difference in difference* method was
32 234 used to estimate the contrast of an intervention by comparing the difference in the outcomes
33 235 between an intervention group and a control group before and after the intervention.²⁶

39 236

41 237 **Predictive model:** Three statistical models were used as predictive models. Two parametric
42 238 models, such as Logistic and Probit regression models, and Decision Tree as a non-parametric
43 239 model. Logistic and Probit regression models were used as predictive models as well as classifier
44 240 models. The models were also used to investigate which factors were significantly associated with
45 241 childhood stunting, and estimate their effect size, in order to predict whether changes in
46 242 behavioural practices might potentially help to achieve targeted reductions in stunting. Using those
47 243 variables, a decision tree was applied, and the predictive performance was compared to other
48 244 models.

55 245

246 For the parametric models, first, Chi-Square test was used to examine the bivariate associations
 247 between stunting and all possible explanatory variables. In the second step, variables with p -values
 248 <0.25 in the simple model were included in the multiple regression models.²⁷ In the final step, any
 249 independent variables thought to be likely predictors were added to the multiple regression model
 250 using the stepwise forward selection method. Some indicators, e.g., age, sex, and maternal
 251 nutritional status were added regardless of their p -value due to their scientific plausibility. The
 252 mathematical equation of logistic and probit regression models were given in the Supplemental
 253 Appendix 3. As a cluster variable, *Union* was used to adjust the standard errors. Furthermore, for
 254 the explanation of the regression model, a p -value <0.05 was considered as statistically significant,
 255 and the confidence interval (CI) of 95% was also reviewed. From the fitted model, the adjusted
 256 effect size (adjusted prevalence difference) against all predictors was estimated using the “*adjrr*”
 257 package in Stata. The list of independent variables with the value labels used in the model is given
 258 in Table 1.

259
 260 **Table 1. List of all independent variables**

Indicators	Code	Stunting Status*	Selection in the model
At least four ANC visits by a skilled service provider			
At least four ANC visits by a skilled service provider	0		Selected
Less than four ANC visits by a skilled service provider	1	Higher prevalence ⁸	
Additional resting during pregnancy			
Took more rest	0		Not selected
Did not take more rest	1	Higher prevalence ⁸	
Additional food consumption during pregnancy			
Consumed more food	0		Not selected
Did not consumed more food	1	Higher prevalence ^{7,8}	
Consumption of at least 100 IFA tablets during pregnancy			
Consumed at least 100 IFA tablets	0		Not selected
Did not consumed at least 100 IFA tablets	1	Higher prevalence ⁹	
Received vitamin A capsule after last delivery			
Received	0		Not selected
Did not receive	1	Higher prevalence ⁸	
Birth attendant/facility			
Skilled	0		Selected
Unskilled	1	Higher prevalence ¹⁰	
Mother involved in income-generating activities			
No	0		Selected
Yes	1	Higher prevalence ^{6,13}	
Maternal BMI			
BMI ≥ 18.5	0		Selected
BMI < 18.5	1	Higher prevalence ^{6,11}	
Maternal education			
			Selected

	At least one-year formal education	0		
	No schooling	1	Higher prevalence ^{6 11}	
	Access of mass media			
	Access	0		Selected
	No access	1	Higher prevalence ¹²	
	Household food insecurity			
	Below severe	0		Selected
	Severe	1	Higher prevalence ⁸	
	Household monthly income \geq15000 BDT			
	\geq 15000 BDT	0		Selected
	<15000 BDT	1	Higher prevalence ¹¹	
	Involved with aquaculture			
	Involved	0		Selected
	Did not involved	1	Higher prevalence ¹⁴	
	Hygienic latrine			
	Hygienic latrine	0		Selected
	Unhygienic latrine	1	Higher prevalence ^{6 11 15}	
	Water and soap available in handwashing place			
	Available	0		Selected
	Unavailable	1	Higher prevalence ¹⁵	
	Household size			
	Below seven	0		Selected
	Seven or above	1	Higher prevalence ¹¹	
	Household dietary diversity (HDDS)			
	HDDS \geq 7	0		Selected
	HDDS <7	1	Higher prevalence ⁸	
	Sex of household head			
	Female	0		Not selected
	Male	1	Higher prevalence ⁸	
	Household head education			
	At least one-year formal education	0		Not selected
	No schooling	1	Higher prevalence ⁶	
	Religion			
	Muslim	0		Not selected
	Non-Muslim	1	Lower prevalence ⁶	
	Received any grant/allowance/stipend from the government			
	Received	0		Not selected
	Did not receive	1	Higher prevalence ¹⁶	
	Child's age			
	Age \leq 18 months	0		Selected
	Age >18 months	1	Higher prevalence ⁸	
	Child's sex			
	Female	0		
	Male	1	Higher prevalence ⁸	
	Childhood illness in the last 15 days			
	No	0		Selected
	Yes	1	Higher prevalence ¹⁷	
	Minimum dietary diversity			
	Received	0		Not selected
	Did not receive	1	Higher prevalence ^{8 15}	
	Early initiation of breastfeeding			
	Received	0		Not selected
	Did not receive	1	Higher prevalence ⁸	

Received colostrum				Not selected
	Received	0		
	Did not receive	1	Higher prevalence ⁸	

¹Expected effects based on findings of the literature

Model evaluation: The predictive performance of the three statistical models was evaluated by computing model sensitivity and specificity, and calculating the area under the receiver operating curve (ROC) analysis. To ensure accurate results, the data was randomly split into a training set (75%) and a test set (25%) using a random-number seed 113843. The same training and test datasets were used for evaluating the performance of all algorithms to ensure consistency in the results. The sensitivity and specificity values, as well as the area under the ROC curve, were used to determine the overall accuracy of the algorithms in predicting childhood stunting.^{28 29}

Patient and public involvement

Patients and public were not actively involved in formulating the research question and or protocol development, including the outcome measures. To expedite the field implementation, however, local elites e.g. teachers, religious persons, and local government council members were informed about the study.

Results

General characteristics: Out of 9600 cases, 9501 cases were found to be available. The refusal rate was around 1%. With respect to the outcome indicator, stunting in children aged 12-23 months, 52.7% of children were stunted at the baseline survey (intervention group: 52.6%; control group: 52.8%), whereas the proportion of children exhibiting stunting at endline was 50.0% (intervention: 49.9%; control: 50.1%; Figure 1). At both the baseline and endline surveys, there was no significant difference in proportion between intervention and control areas. The *difference-in-difference* in outcomes over time was also insignificant.

Figure 2 describes several other indicators related to maternal and child health, including the status of consuming a minimum acceptable diet (intervention: 35.2%; control: 14.9%), minimum dietary diversity (intervention: 42.8%; control: 20.4%), maternal decision-making (intervention: 45.0%; control: 31.0%), at least four maternal ANC visits by a skilled service provider (intervention: 36.1%; control: 17.7%), minimum dietary diversity for women (intervention: 52.6%; control:

33.5%), a household dietary diversity score of at least seven (intervention: 88.9%; control: 78.3%), and household food security status (intervention: 26.6%; control: 20.2%). Results from the endline survey showed that these indicators were significantly improved in the intervention group compared to the control group. However, the availability of hygienic latrines did not increase in the intervention group (intervention: 44.0%; control: 44.0%). Table 2 shows the households' socio-demographic characteristics, women's general characteristics, and children's characteristics at baseline and endline.

Table 2. General characteristics of the *Suchana* beneficiaries

Indicators, <i>n</i> (%)	Baseline N=3200	Endline N=6301	Total N=9501
At least four ANC visits by a skilled service provider			
Yes	408 (12.8)	1530 (24.3)	1938 (20.4)
No	2792 (87.2)	4771 (75.7)	7563 (79.6)
Delivery at skilled birth attendant/facility			
Yes	1000 (31.2)	2769 (44.0)	3769 (39.7)
No	2200 (68.8)	3532 (56.0)	5732 (60.3)
Access of mass media			
Access	563 (17.59)	1169 (18.55)	1732 (18.23)
No access	2637 (82.41)	5132 (81.45)	7769 (81.77)
Mother involved in income-generating activities			
No	3102 (96.9)	5665 (89.9)	8767 (92.2)
Yes	98 (3.1)	639 (10.1)	737 (7.8)
Maternal BMI			
BMI \geq 18.5	1859 (58.1)	4073 (64.6)	5932 (62.4)
BMI <18.5	1341 (41.9)	2231 (35.4)	3572 (37.6)
Mother completed primary education			
Yes	1721 (53.8)	3808 (60.4)	5529 (58.2)
No	1479 (46.2)	2496 (39.6)	3975 (41.8)
Maternal age			
Age <30 years	2145 (67.0)	3559 (56.5)	5704 (60.0)
Age \geq 30 years	1055 (33.0)	2745 (43.5)	3800 (40.0)
Type of delivery			
Normal	2879 (90.0)	5529 (87.8)	8408 (88.5)
Caesarean	321 (10.0)	772 (12.3)	1093 (11.5)
PNC			
No	2152 (67.3)	4128 (65.5)	6280 (66.1)
Yes	1048 (32.8)	2173 (34.5)	3221 (33.9)
Household severely food insecure			
Yes	912 (28.5)	1016 (16.1)	1928 (20.3)
No	2288 (71.5)	5285 (83.9)	7573 (79.7)
Household monthly income \geq15000 BDT			
Yes	424 (13.2)	1015 (16.1)	1439 (15.1)
No	2776 (86.8)	5289 (83.9)	8065 (84.9)

Household involved with aquaculture				
	Yes	161 (5.0)	561 (8.9)	722 (7.6)
	No	3039 (95.0)	5740 (91.1)	8779 (92.4)
Hygienic latrine				
	Yes	1121 (35.0)	2782 (44.1)	3903 (41.1)
	No	2079 (65.0)	3519 (55.9)	5598 (58.9)
Water and soap available in handwashing place				
	Yes	862 (26.9)	3170 (50.3)	4032 (42.4)
	No	2338 (73.1)	3131 (49.7)	5469 (57.6)
Household savings				
	No	1080 (33.8)	2876 (45.6)	3956 (41.6)
	Yes	2120 (66.2)	3425 (54.4)	5545 (58.4)
Sex of household head				
	Female	110 (3.4)	501 (8.0)	611 (6.4)
	Male	3090 (96.6)	5799 (92.0)	8889 (93.6)
Source of drinking water				
	Tube well	2748 (85.9)	5713 (90.7)	8461 (89.0)
	Others	452 (14.1)	588 (9.3)	1040 (11.0)
Household dietary diversity score				
	HDDS ≥ 7	2182 (68.2)	5322 (84.5)	7504 (79.0)
	HDDS < 7	1018 (31.8)	979 (15.5)	1997 (21.0)
Household monthly income (Thousand BDT)¹				
Per capita income (Thousand)¹				
Household size¹				
Child's age in months²				
Length-for-age z-score²				
Weight-for-age z-score²				
Weight-for-length z-score²				
Child's age				
	Age < 18 months	1745 (54.5)	3710 (58.9)	5455 (57.4)
	Age ≥ 18 months	1455 (45.5)	2594 (41.1)	4049 (42.6)
Child's sex				
	Female	1567 (49.0)	3044 (48.3)	4611 (48.5)
	Male	1633 (51.0)	3257 (51.7)	4890 (51.5)
Childhood illness in the last 15 days				
	Yes	2867 (89.6)	5763 (91.5)	8630 (90.8)
	No	333 (10.4)	538 (8.5)	871 (9.2)

¹Median (IQR); ²Mean \pm SD

Correlated factors: The study used two parametric predictive models to determine the correlates of childhood stunting. The results, presented in Table 3, showed the adjusted odds ratios (aOR) computed from multiple logistic regression and the adjusted coefficients computed from multiple probit regression. These results provide important insights into the factors that increase the odds of stunting in childhood, and can inform public health interventions aimed at reducing stunting and improving child health. The aORs provide a quantitative measure of the relationship between

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2
3 308 different factors and childhood stunting, adjusting for *Union* as cluster variable. Understanding the
4
5 309 correlates of childhood stunting is critical for addressing this important public health issue and
6
7 310 improving the health and well-being of children globally. The results of this study show that a
8
9 311 number of maternal, household and children factors were correlated with an increased prevalence
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11 312 of stunting in children. Children of mothers who did not receive at least four ANC visits from a
12
13 313 skilled service provider had 1.16 times higher odds of stunting (95% CI: 1.05, 1.30; p-
14
15 314 value=0.005). Children of mothers who gave birth with an unskilled birth attendant or facility had
16
17 315 1.11 times higher odds of stunting (95% CI: 1.02, 1.20; p-value=0.012). The odds of stunting were
18
19 316 1.18 times higher in children whose mothers were involved in income-generating activities (95%
20
21 317 CI: 1.02, 1.37; p-value=0.030), 1.23 times higher in children of underweight mothers (95% CI:
22
23 318 1.12, 1.36; p-value<0.001), and 1.31 times higher in children of low-educated mothers (95% CI:
24
25 319 1.20, 1.42; p-value<0.001). Furthermore, the lack of exposure to mass media was also found to be
26
27 320 associated with stunting, with odds of 1.15 (95% CI: 1.02, 1.30; p-value=0.025) times higher.
28
29 321 Children from households with severe food insecurity, lower-income households, households not
30
31 322 involved in aquaculture, and households with low dietary diversity, were more likely to be stunted,
32
33 323 with odds increasing by 1.12 (95% CI: 1.00, 1.24; p-value=0.041), 1.12 (95% CI: 1.01, 1.25; p-
34
35 324 value=0.037), 1.19 (95% CI: 1.03, 1.38; p-value=0.018), and 1.17 (95% CI: 1.07, 1.29; p-
36
37 325 value=0.001) times, respectively. The results also showed that the odds of stunting increased with
38
39 326 increasing household size (95% CI: 1.11, 1.31; p-value<0.001), the absence of a hygienic latrine
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41 327 (95% CI: 1.10, 1.30; p-value<0.001), the absence of water and soap in the handwashing place
42
43 328 (95% CI: 1.08, 1.30; p-value<0.001), increasing child age (95% CI: 1.39, 1.67; p-value<0.001),
44
45 329 and being male (95% CI: 1.11, 1.34; p-value<0.001). The odds of stunting were also 1.20 times
46
47 330 higher in children with acute illness (95% CI: 1.06, 1.36; p-value=0.003). The logistic and probit
48
49 331 regression models were employed to predict stunting in a sample of 9501 individuals. Both models
50
51 332 were found to be significant, with log-likelihoods of -6387.94 and -6388.02, respectively, and
52
53 333 significant Wald chi-square statistics (p-value < 0.001). Predictive ability of various indicators for
54
55 334 the adjusted prevalence of stunting and adjusted prevalence difference (effect size) are given in
56
57 335 Supplementary Table 2a and 2b. The Factors correlating with childhood stunting, as determined
58
59 336 by using a decision tree as a non-parametric predictive model, are also presented in Figure 3. The
60
337 decision tree result suggests that maternal education was the most important variable in predicting
338 childhood stunting, as it was the main root node. The other variables, such as maternal nutrition,

339 hand washing indicators, and hygienic latrine, were also important, as they were next root node
340 variables. This tree model can be used to predict the childhood stunting status with relative ease.

341
342 **Table 3. Factors correlating with stunting in children aged 12-23 months, computed using**
343 **logistic and probit regression analyses**

Indicators	Logistic		Probit	
	Adjusted OR (95% CI)	p-value	Adjusted Coef. (95% CI)	p-value
At least four ANC visits by a skilled service provider				
Yes	Reference		Reference	
No	1.16 (1.05, 1.30)	0.005	0.09 (0.03, 0.16)	0.005
Birth attendant/facility				
Skilled	Reference		Reference	
Unskilled	1.11 (1.02, 1.20)	0.012	0.06 (0.01, 0.11)	0.012
Mother involved in income-generating activities				
No	Reference		Reference	
Yes	1.18 (1.02, 1.37)	0.030	0.10 (0.01, 0.19)	0.030
Maternal BMI				
BMI ≥ 18.5	Reference		Reference	
BMI < 18.5	1.23 (1.12, 1.36)	0.000	0.13 (0.07, 0.19)	0.000
Maternal education was primary completed				
Yes	Reference		Reference	
No	1.31 (1.20, 1.42)	0.000	0.17 (0.12, 0.22)	0.000
Access of mass media				
Yes	Reference		Reference	
No	1.15 (1.02, 1.30)	0.025	0.09 (0.01, 0.16)	0.025
Household food insecurity				
Below severe	Reference		Reference	
Severe	1.12 (1.00, 1.24)	0.041	0.07 (0.00, 0.13)	0.042
Household monthly income ≥ 15000 BDT				
Yes	Reference		Reference	
No	1.12 (1.01, 1.25)	0.037	0.07 (0.00, 0.14)	0.035
Involved with aquaculture				
Yes	Reference		Reference	
No	1.19 (1.03, 1.38)	0.018	0.11 (0.02, 0.20)	0.018
Household size				
Below seven	Reference		Reference	
Seven or above	1.20 (1.11, 1.31)	0.000	0.12 (0.06, 0.17)	0.000
Hygienic latrine				
Yes	Reference		Reference	
No	1.20 (1.10, 1.30)	0.000	0.11 (0.06, 0.16)	0.000
Water and soap available in handwashing place				
Yes	Reference		Reference	
No	1.19 (1.08, 1.30)	0.000	0.11 (0.05, 0.16)	0.000
Household dietary diversity				
HDDS ≥ 7	Reference		Reference	
HDDS < 7	1.17 (1.07, 1.29)	0.001	0.10 (0.04, 0.16)	0.001
Child's age				
Age ≤ 18 months	Reference		Reference	
Age > 18 months	1.52 (1.39, 1.67)	0.000	0.26 (0.2, 0.32)	0.000

Child's sex					
	Female	Reference		Reference	
	Male	1.22 (1.11, 1.34)	0.000	0.13 (0.07, 0.18)	0.000
Childhood illness in the last 15 days					
	No	Reference		Reference	
	Yes	1.20 (1.06, 1.36)	0.003	0.11 (0.04, 0.19)	0.003
Sample size and regression diagnostic values for logistic and probit regression analyses		n = 9501 Log-likelihood = -6387.94 Wald chi2(17) = 427.79 p-value<0.001 Pseudo R ² = 0.0298		n = 9501 Log-likelihood = -6388.02 Wald chi2(17) = 441.18 p-value<0.001 Pseudo R ² = 0.0298	

Unions were adjusted as clusters. Baseline and endline were adjusted as time variables

Predictive performance: Table 4 describes the model validation based on sensitivity, specificity, and whether the model was correctly classified for the overall dataset, as well as the training and test datasets. The sensitivity and specificity of the model were around 60% and 55%, respectively for all models. The correctly classified rate was 59%, and the area under the ROC curve was around 61%. We found that these values were approximately equal among the three datasets (main, training, and test datasets); however, the predictive performance of the model was low.

Table 4. Predictive performance of the model for stunting based on classification, sensitivity, and specificity in the full, training and test datasets with area under the receiver operating characteristic curve analysis

	Logistic regression	Probit regression	Decision tree
Full dataset			
Overall accuracy	58.46	58.38	56.51
Sensitivity	61.21	61.25	61.15
Specificity	55.61	55.41	51.70
Area under the curve	61.54	61.54	56.72
Training Dataset			
Overall accuracy	58.83	58.62	57.66
Sensitivity	61.59	61.70	63.93
Specificity	55.36	55.42	51.61
Area under the curve	61.37	61.37	58.44
Test Dataset			
Overall accuracy	58.11	58.19	56.67
Sensitivity	60.23	60.23	61.58
Specificity	55.90	56.07	51.94
Area under the curve	61.76	61.77	58.01

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5 358 **Discussion**

6 359 In an effort to understand why the *Suchana* programme was not effective in reducing the
7 prevalence of childhood stunting, this study analyzed data from both the baseline and endline
8 360 surveys of the programme. The analysis aimed to identify the factors that were significantly
9 361 correlated with stunting and to evaluate the model's predictive performance. After controlling for
10 362 the *Union* as a cluster variable, the study found several indicators that were significantly related to
11 363 stunting. These included the number of ANC visits by a skilled service provider, household dietary
12 364 diversity, household food security, and household monthly income, all of which improved after
13 365 the intervention. However, it was noted that the household food security status did not reach the
14 366 target value of 50%, despite being an important factor associated with childhood stunting.^{8,30,31} On
15 367 the other hand, other outcome indicators of the *Suchana* programme, such as the dietary diversity
16 368 of children, maternal dietary diversity, and maternal empowerment, despite reaching their target
17 369 values, were not found to be associated with stunting in this study.
18 370

19 371
20 372 The study found that while the *Suchana* programme showed improvement in certain programme
21 373 indicators, it did not lead to a significant reduction in childhood stunting. Despite efforts to address
22 374 key factors such as maternal nutrition and education, household food security, and hygiene
23 375 practices, these factors remained largely unchanged. However, the study suggests that
24 376 interventions aimed at adolescent mothers may be more effective in improving maternal nutrition
25 377 and education, since these are age-dependent variables. Additionally, the results of the study were
26 378 also impacted by natural disasters in 2017, including heavy rains and flooding in the Sylhet region,
27 379 which resulted in widespread damage to agriculture, aquaculture, and homes in the study
28 380 population.^{32,33}

29 381
30 382 The study found a contradictory relationship between stunting and maternal involvement in
31 383 income-generating activities, with a higher prevalence of stunting observed among children whose
32 384 mothers were engaged in various earning activities. Although there was a slight increase in the
33 385 proportion of mothers involved in income-generating activities after the intervention, the lack of
34 386 childcare support for working mothers resulted in a marked rise in childhood stunting among low-
35 387 income households. It is important to address this issue by providing adequate childcare support

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3 388 measures for working mothers from poor families to ensure that the child's essential needs are not
4 389 impacted by the mother's employment status.¹³ Additionally, efforts should be made to increase
5 390 awareness among working mothers regarding the importance of child health and nutrition. This
6 391 can be achieved through targeted education and outreach programmes that provide information on
7 392 proper child feeding practices, hygiene, and health-seeking behaviours.
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12

13 394 The literature suggests that environmental enteropathy may contribute to poor growth among
14 395 children in rural Bangladesh and may represent an important factor affecting the study population
15 396 in the *Suchana* programme.³⁴ Although it was not specifically assessed in this study, indicators
16 397 such as unsanitary latrines, unimproved floors, a lack of handwashing practices, and low education
17 398 levels were available.^{18 35} Improving Water, Sanitation and Hygiene (WaSH) variables,
18 399 particularly latrine facilities and handwashing practices, may help reduce the burden of stunting in
19 400 young children. One of the components of the intervention was poultry, but our qualitative findings
20 401 revealed that many households shared living spaces with poultry, ducks, or other animals, which
21 402 could increase the risk of infections with *Campylobacter* species, a leading food-borne pathogen.¹⁸

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26 403 ³⁶ Previous studies have shown a strong association between stunting and enteropathy among
27 404 children who do not respond to nutritional interventions, and findings from rural Bangladesh have
28 405 linked environmental conditions and stunting in children.³⁷⁻³⁹ While assessing environmental
29 406 enteropathy was beyond the scope of the *Suchana* evaluation, collecting data on indicators of
30 407 enteropathy in the intervention and control areas could help evaluate the impact of appropriate
31 408 interventions in the future. The failure to achieve the desired outcome may have been due to several
32 409 factors, including food insecurity and a lack of aquaculture involvement due to natural disasters,
33 410 poor WaSH status, a lack of focus on maternal education and nutrition, and a lack of focus on the
34 411 risk of enteropathogen burden.
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45 413 Another important finding based on the post-estimation findings as well as the value of the area
46 414 under the ROC curve was that the predictive performance of the model was low. Thus, we need to
47 415 identify other indicators from similar research contexts that influence childhood stunting but were
48 416 not included in our model. Future research in the field of childhood stunting should give priority
49 417 to the development of more suitable methods for monitoring and identifying effective
50 418 interventions. It is also essential to collect data that considers biological and environmental factors
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3 419 related to childhood stunting, following the literature. By considering these diverse factors, we can
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5 420 improve the accuracy and predictive performance of statistical models. This, in turn, can help draw
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7 421 more reliable conclusions about the effectiveness of interventions aimed at reducing childhood
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9 422 stunting in similar contexts. Additionally, evaluating the model on an independent dataset or
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11 423 conducting external validation could help to determine the generalizability of the model to new
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13 424 data.

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15 426 This study will aid programme managers in prioritizing their focus and designing effective
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17 427 interventions to reduce childhood stunting. Sustainable solutions should be based on the needs of
18
19 428 the beneficiaries. Implementing short-term initiatives such as attendance at healthcare-led
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21 429 workshops and campaigns can increase ANC visits, skilled birth attendance, and handwashing
22
23 430 practices. Establishing women's healthcare services that focus on maternal and child health and
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25 431 nutrition will also help reduce the incidence of stunting.²³ Improved access to media can help
26
27 432 vulnerable communities benefit from government welfare programmes. Food security, income,
28
29 433 sanitation, aquaculture, and illness are all time-sensitive factors. Increasing food production
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31 434 through self-production or purchasing can improve household food security and nutrition.
32
33 435 However, household wealth and access to nearby markets can impact their ability to buy nutritious
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35 436 food. Climate change adaptation in agriculture is crucial to minimize current risks and prepare for
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37 437 future uncertainties. Using organic fertilizers instead of chemicals in agriculture has environmental
38
39 438 benefits, reducing the need for pesticides and protecting human health and biodiversity.
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41 439 Aquaculture can provide a source of protein and improve nutrition, but establishing these facilities
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43 440 takes time. Improving sanitation requires improving socioeconomic status, which is also a time-
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45 441 intensive process. It takes time to improve stunting, as shown by national surveys such as the
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47 442 BDHS and the Food Security and National Surveillance Project (FSNSP).^{2,40} Improving maternal
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49 443 nutrition and education is crucial for promoting the optimal growth and development of children.
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51 444 Adequate food, good environmental conditions, and access to schooling facilities during
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53 445 adolescence are necessary for women to maintain their own health and to positively impact the
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55 446 health of their children. Emphasizing the education of female children can break the cycle of
56
57 447 poverty and stunting, as it can lead to improved knowledge and decision-making skills related to
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59 448 nutrition and health.^{6 11} To reduce childhood stunting in developing countries, comprehensive
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61 449 interventions that include nutritional support, food security, maternal education, income-

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3 450 generating activities for women with childcare support, and addressing domestic violence against
4 451 women should be implemented. These interventions should be tailored to the specific needs and
5 452 cultural context of the community in which they are implemented, and community participation
6 453 and engagement are essential for their success. By addressing the underlying factors contributing
7 454 to childhood stunting, we can make significant progress towards reducing its prevalence and
8 455 improving the health and well-being of children in developing countries. Furthermore, continued
9 456 monitoring and evaluation of these interventions is essential to ensure their effectiveness and to
10 457 identify areas for improvement.
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19 459 **Recommendation:** The *Suchana* model offers a holistic and integrated approach to addressing
20 460 food and nutrition security, recognizing undernutrition as a complex problem caused by multiple
21 461 factors. The endline survey of *Suchana* showed significant improvement in programme indicators.
22 462 The multi-sector approach of *Suchana* is a meaningful solution to addressing undernutrition.
23 463 However, policy makers should consider implementing additional nutrition-sensitive and specific
24 464 activities, such as promoting climate-resilient agriculture and increasing water and sanitation
25 465 coverage. It is also important to have a sustainable mechanism for improving food security and to
26 466 promote awareness of seasonal diseases associated with livestock and poultry. To further improve
27 467 the programme, indicators such as child sex, maternal education, and nutrition could be adjusted
28 468 during the design stage. The *Suchana* programme is one of the largest global nutrition
29 469 interventions, leading to positive changes in critical indicators, with long-term benefits expected
30 470 for the health and livelihoods of the beneficiaries.
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41 472 **Strength and limitation:** The study had several strengths, including a large sample size,
42 473 randomization, and appropriate sampling techniques. A dedicated quality control team was
43 474 involved in checking the data, and the use of precise anthropometry instruments and separate
44 475 training for the measurement team helped ensure accurate data collection. The study was also
45 476 designed to avoid seasonality by conducting the baseline and endline surveys at the same time of
46 477 the year. However, the study results may have been impacted by a lack of selection effect in the
47 478 implementation of the programme, as well as by the short time horizon of the study. The short
48 479 duration of the study may not have been enough to see a significant impact on stunting.
49 480 Additionally, changes in the study population between the baseline and endline surveys could also
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3 481 have contributed to the lack of differences observed in the results. Another limitation of this study
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5 482 is that we did not collect food intake data but only recall data from the previous 24 hours. These
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7 483 data may be subject to recall bias; thus, caution is necessary when drawing conclusions, especially
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9 484 for indicators such as dietary diversity, household food insecurity, domestic violence, and maternal
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11 485 healthcare. Finally, using a binary indicator of stunting based on a single LAZ cut-off point, which
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13 486 was defined as <-2 , may not provide a comprehensive assessment of the severity of malnutrition
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15 487 among children, as it fails to account for micronutrient deficiencies
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19 **Conclusion**

20 491 Childhood stunting was heavily influenced by a number of factors, and majority of the factors
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22 492 were found in poor status in our study area. Despite the implementation of an intervention
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24 493 programme, the situation remained unchanged due to factors such as food insecurity, lack of
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26 494 involvement in aquaculture, poor access to WaSH facilities, and a lack of focus on maternal
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28 495 education and nutrition. The study did not include important indicators such as enteropathogen
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30 496 and environmental enteric dysfunction, which might have contributed to the failure to achieve the
31
32 497 desired outcome. The results suggest that policy makers and programme planners should consider
33
34 498 enhancing collaboration and coordination between nutrition-sensitive and specific activities to
35
36 499 address nutritional deficiencies and family health programmes in vulnerable rural populations.
37

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39
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41
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43
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9 518

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12 521

13 522 **Conflicts of Interest:** The authors declare no conflict of interest.
14 523

15 524 **Author Contributions:** TA and NC originated the idea for the study and led the protocol design.
16 525 MAH conceptualized the manuscript. SMTA, SSR, MAH, NC, FDF, and TA contributed to the
17 526 survey design. MAH performed statistical analysis and drafted the manuscript. NC and ASGF
18 527 supervised the work, and critically reviewed and provided feedback for revising the manuscript.
19 528 MAH, NC, MA, FDF, FN, BZW, TJS, ASGF, TA, and SSR contributed to the revision of the final
20 529 draft for submission. All authors are responsible for the final content of the manuscript.
21 530

22 531 **Ethics approval:** This study was approved by the Research Review Committee and Ethical
23 532 Review Committee, the two obligatory components of the Institutional Review Board (IRB) of
24 533 icddr,b. Ethics Committee's approval ID# 00001822. Informed written consent was obtained from
25 534 study participants.
26 535

27 536 **Data availability statement:** The data that support the findings of this study are available on
28 537 request from the corresponding author. The data are not publicly available due to privacy and
29 538 ethical restrictions.
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For peer review only

668 Figure 1. Prevalence of childhood stunting in the intervention and control areas at baseline
669 compared to endline. The p-value of the *difference-in-difference* was estimated using interaction
670 analysis in the multiple logistic regression model.

671
672 Figure 2. Results framework and *Suchana* log frame indicators. ANC: antenatal care, HDDS:
673 household dietary diversity score, MDD-w: minimum dietary diversity for women.

674
675 Figure 3. Factors correlating with stunting in children aged 12-23 months, computed using decision
676 tree analysis. (X₁: Less than four ANC visits by a skilled service provider, X₂: Unskilled birth
677 attendant/facility, X₃: Mother involved in income-generating activities, X₄: Maternal BMI <18.5,
678 X₅: Maternal education: no schooling, X₆: Household severe food insecurity, X₇: Monthly income
679 <15000 BDT, X₈: Did not involve with aquaculture, X₉: Having unhygienic latrine, X₁₀: Soap was
680 unavailable in hand washing place, X₁₁: HH size ≥7, X₁₂: HH dietary diversity score <7, X₁₃:
681 Child's age >18, X₁₄: Child's sex was male, X₁₅: Childhood illness in the last 15 days, and X₁₆:
682 Lacked access to mass media)

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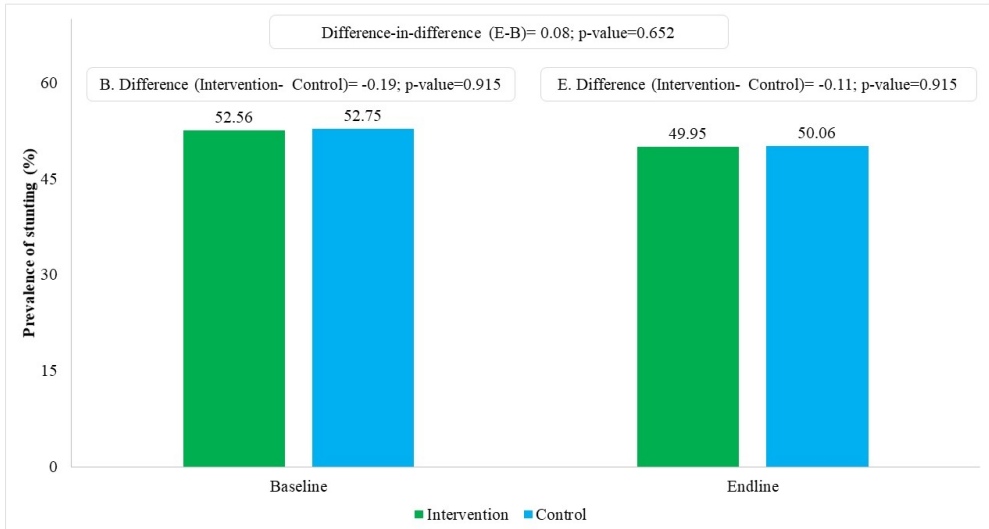


Figure 1. Prevalence of childhood stunting in the intervention and control areas at baseline compared to endline. The p-value of the difference-in-difference was estimated using interaction analysis in the multiple logistic regression model.

108x60mm (300 x 300 DPI)

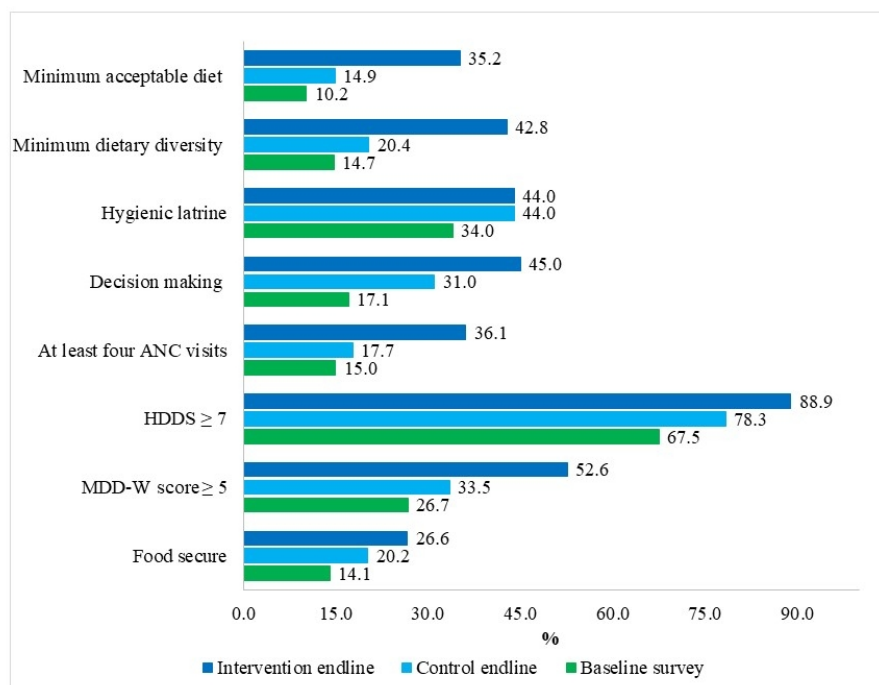


Figure 2. Results framework and Suchana log frame indicators. ANC: antenatal care, HDDS: household dietary diversity score, MDD-w: minimum dietary diversity for women.

254x190mm (96 x 96 DPI)

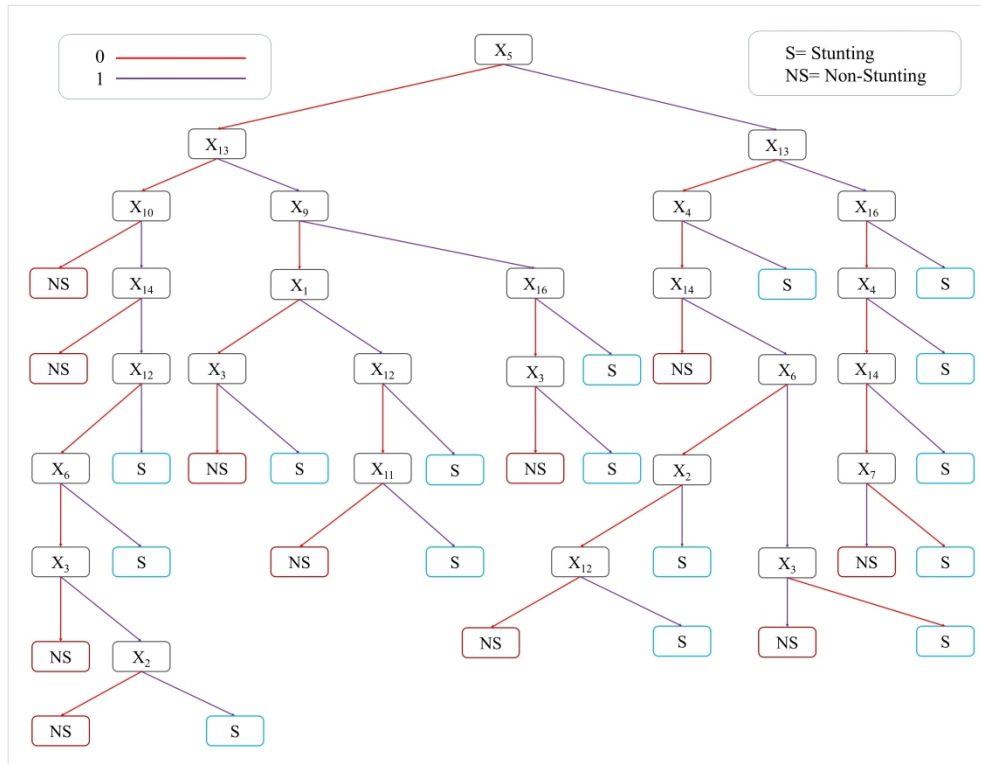


Figure 3. Factors correlating with stunting in children aged 12-23 months, computed using decision tree analysis. (X1: Less than four ANC visits by a skilled service provider, X2: Unskilled birth attendant/facility, X3: Mother involved in income-generating activities, X4: Maternal BMI <18.5, X5: Maternal education: no schooling, X6: Household severe food insecurity, X7: Monthly income <15000 BDT, X8: Did not involve with aquaculture, X9: Having unhygienic latrine, X10: Soap was unavailable in hand washing place, X11: HH size>7, X12: HH dietary diversity score <7, X13: Child's age>18, X14: Child's sex was male, X15: Childhood illness in the last 15 days, and X16: Lacked access to mass media)

325x254mm (300 x 300 DPI)

Appendix 1. Sample size calculation

```
clustersampsi, binomial samplesize p1(0.47) p2(0.41) k(40) rho(0.01)alpha(0.05) beta(0.8)
```

Output of the STATA command for sample size calculation

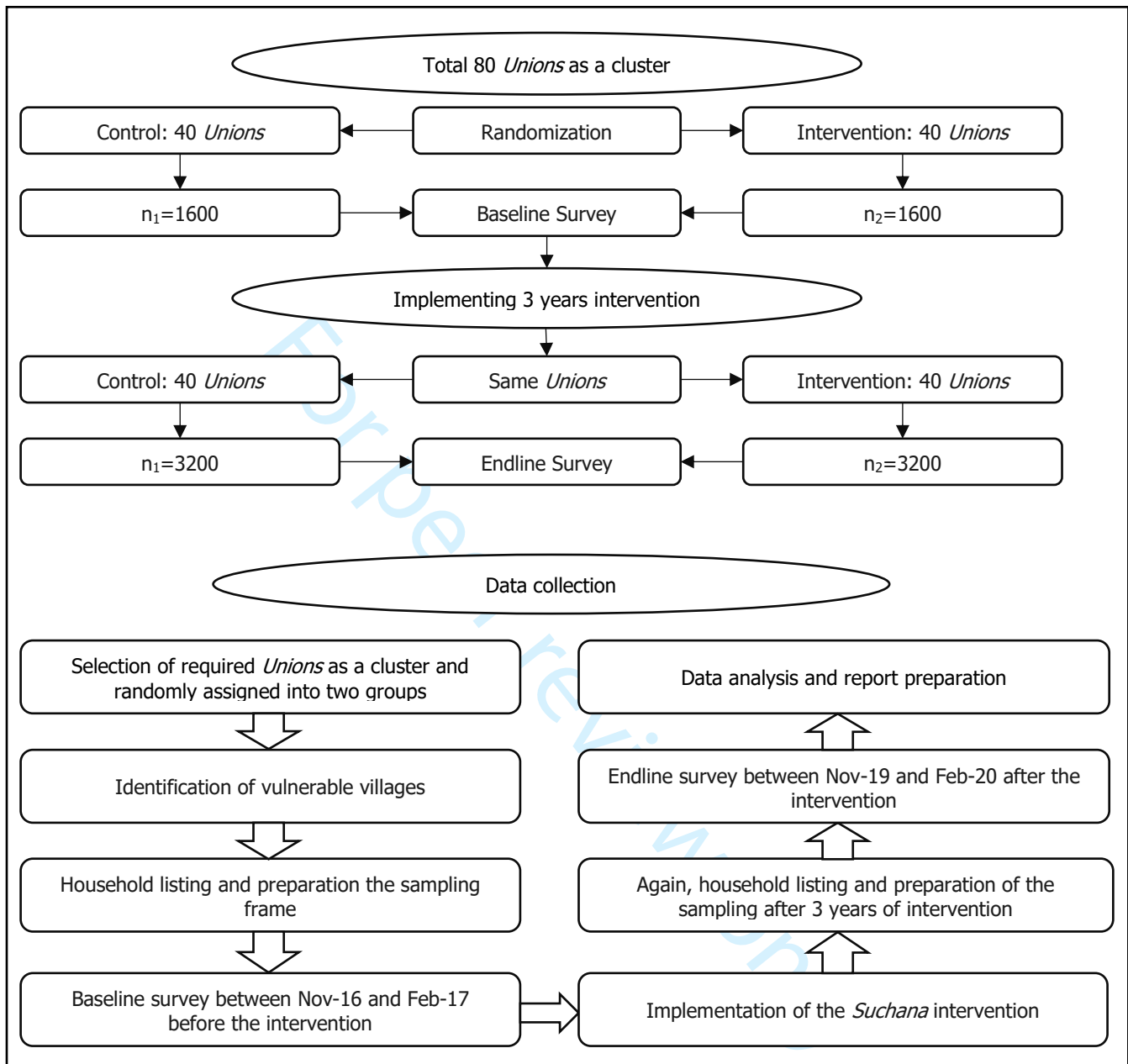
Sample size calculation to determine number of observations required per cluster, for a two-sample comparison of proportions (using normal approximations) without continuity correction.

For the user specified parameters:

```
p1: 0.4700
p2: 0.4100
significance level: 0.05
power: 0.80
number of clusters available: 40
intra cluster correlation (ICC): 0.0100
```

clustersampsi estimated parameters:

```
Firstly, assuming individual randomisation: sample size per arm: 1071
Then, allowing for cluster randomisation: average cluster size required: 38
sample size per arm: 1520
```

Supplementary Figure 1. The evaluation diagram of *Suchana* programme

Appendix 2. Data collection

The Suchana data collection software contained built-in validation rules. As the data were entered at the interviewer level and the records were uploaded to a server at the icddr,b using the built-in internet connectivity of the devices, maximum validation rules were set in the data system to prevent errors during data entry, which reduced the data entry burden. This allowed the data analysis team to review the

consistency of the data every day. Data were synchronized to the central server “Web Service” developed in Asp.Net based on the C# (C Sharp) code. Activities such as editing (after receiving any feedback from field staff members), updating, range checks, duplication checks, consistency checks, frequency checks and cross tabulation were regularly performed during the data entry period. In case of any unusual observations, the issues were discussed and resolved.

Appendix 3. Equation of logistic and probit regression

$$\text{logit}(y) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 X_6 + \beta_7 X_7 + \beta_8 X_8 + \beta_9 X_9 + \beta_{10} X_{10} + \beta_{12} X_{12} + \beta_{13} X_{13} + \beta_{14} X_{14} + \beta_{15} X_{15} + \beta_{16} X_{16}$$

$$\text{probit}(y) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 X_6 + \beta_7 X_7 + \beta_8 X_8 + \beta_9 X_9 + \beta_{10} X_{10} + \beta_{12} X_{12} + \beta_{13} X_{13} + \beta_{14} X_{14} + \beta_{15} X_{15} + \beta_{16} X_{16}$$

Where,

x1: Less than four ANC visits by a skilled service provider	x9: Having unhygienic latrine
x2: Unskilled birth attendant/facility	x10: Soap was unavailable in hand washing place
x3: Mother involved in income-generating activities	x11: HH size ≥ 7
x4: Maternal BMI < 18.5	x12: HH dietary diversity score < 7
x5: Maternal education: no schooling	x13: Child's age > 18
x6: HH severe food insecurity	x14: Child's sex was male
x7: Monthly income < 15000 BDT	x15: Childhood illness in the last 15 days
x8: Did not involve with aquaculture	x16: Lacked access to mass media

and

$$\text{logit}(y) = \log[y/(1-y)]$$

Supplementary Table 1. *Suchana* inclusion criteria for registration of enrolling as vulnerable households

Vulnerable household verification questions	Inclusion criteria
Step 1	
<ul style="list-style-type: none"> Households currently participating/member of any livelihood, food security or asset transfer program 	If “NO” go ahead for next questions
Step 2	
<ul style="list-style-type: none"> Ability to afford three (3) full meals per day for all family members round the year Households monthly income BDT 7,500 or more Household productive asset value worth BDT 15,000 or more (excluding land, pond and homestead) Ownership of homestead land 10 decimals or more Ownership of cultivable land 50 decimals or more (excluding homestead or pond) 	If anyone is “NO” go ahead for next questions
Step 3	
<ul style="list-style-type: none"> Households have married women with in child bearing age (15 to 45 years) Households have pregnant women (including abandoned or widowed woman) Households have 0-23 months old children Households have adolescent girls (15-19 years) 	If anyone is ‘Yes’ go ahead for registration of enrolling as vulnerable Household
Sampling frame was prepared for collecting data from mother-child pair if the households had 0-23 months old children	

Supplementary Table 2a. Predictive ability of various indicators for the adjusted prevalence of stunting and adjusted prevalence difference (effect size) in the fitted multiple logistic regression model.

	Prediction of adjusted stunting [% (95% CI)]	Prediction of adjusted prevalence difference as effect size*	p-value
At least four ANC visits by a skilled service provider			
Yes	51.64 (50.05, 53.23)	Reference	
No	47.99 (45.46, 50.53)	3.65 (1.07, 6.22)	0.006
Birth attendant/facility			
Skilled	51.87 (50.23, 53.51)	Reference	
Unskilled	49.42 (47.48, 51.36)	2.45 (0.55, 4.35)	0.012
Mother involved in income-generating activities			
No	54.55 (50.90, 58.19)	Reference	
Yes	50.59 (49.08, 52.11)	3.95 (0.40, 7.51)	0.029
Maternal BMI			
BMI \geq 18.5	54.04 (52.01, 56.07)	Reference	
BMI <18.5	49.01 (47.21, 50.81)	5.03 (2.66, 7.41)	<0.001
Maternal education was primary completed			
Yes	54.66 (52.58, 56.74)	Reference	
No	48.21 (46.67, 49.75)	6.45 (4.49, 8.40)	<0.001
HH food insecurity			
Below severe	53.03 (50.91, 55.15)	Reference	
Severe	50.36 (48.63, 52.09)	2.66 (0.11, 5.22)	0.041
HH monthly income \geq15000 BDT			
Yes	51.31 (49.79, 52.84)	Reference	
No	48.58 (45.86, 51.30)	2.73 (0.17, 5.30)	0.037
Involved with aquaculture			
Yes	51.22 (49.72, 52.72)	Reference	
No	46.99 (43.30, 50.69)	4.23 (0.73, 7.73)	0.018
Hygienic latrine			
Yes	52.67 (50.94, 54.4)	Reference	
No	48.36 (46.5, 50.23)	4.31 (2.34, 6.28)	<0.001
Water and soap available in handwashing place			
Yes	52.64 (50.71, 54.58)	Reference	
No	48.54 (46.74, 50.33)	4.10 (1.83, 6.38)	<0.001
HH size			
Below seven	53.86 (51.98, 55.74)	Reference	
Seven or above	49.41 (47.70, 51.13)	4.44 (2.43, 6.46)	<0.001
HH dietary diversity			
HDDS \geq 7	53.92 (51.25, 56.60)	Reference	
HDDS <7	50.10 (48.70, 51.50)	3.83 (1.63, 6.02)	<0.001
Child's age			
Age \leq 18 months	56.72 (54.77, 58.67)	Reference	
Age >18 months	46.59 (44.82, 48.35)	10.1 (7.94, 12.32)	<0.001
Child's sex			
Female	53.25 (51.17, 55.34)	Reference	
Male	48.40 (46.78, 50.03)	4.85 (2.59, 7.10)	<0.001
Childhood illness in the last 15 days			
No	54.90 (52.04, 57.77)	Reference	
Yes	50.49 (48.94, 52.05)	4.41 (1.48, 7.34)	0.003
Access of mass media			
Yes	51.51 (49.88, 53.15)	Reference	
No	48.13 (45.39, 50.88)	3.38 (0.42, 6.34)	0.028

*Differences in the predicted values of stunting between the two groups were calculated using the Stata "adjrr" package

Supplementary Table 2b. Predictive ability of various indicators for the adjusted prevalence of stunting and adjusted prevalence difference (effect size) in the fitted multiple probit regression model.

	Prediction of adjusted stunting [% (95% CI)]	Prediction of adjusted prevalence difference as effect size*	p-value
At least four ANC visits by a skilled service provider			
Yes	51.64 (50.05, 53.23)	Reference	
No	47.99 (45.46, 50.53)	3.65 (1.08, 6.22)	0.007
Birth attendant/facility			
Skilled	51.87 (50.23, 53.51)	Reference	
Unskilled	49.42 (47.48, 51.36)	2.45 (0.54, 4.35)	0.011
Mother involved in income-generating activities			
No	54.55 (50.90, 58.16)	Reference	
Yes	50.59 (49.08, 52.11)	3.93 (0.39, 7.48)	0.024
Maternal BMI			
BMI ≥ 18.5	54.04 (52.01, 56.07)	Reference	
BMI < 18.5	49.01 (47.21, 50.81)	5.03 (2.66, 7.40)	< 0.001
Maternal education was primary completed			
Yes	54.66 (52.58, 56.74)	Reference	
No	48.21 (46.67, 49.75)	6.45 (4.49, 8.41)	< 0.001
HH food insecurity			
Below severe	53.01 (50.89, 55.12)	Reference	
Severe	50.37 (48.64, 52.10)	2.64 (0.09, 5.19)	0.042
HH monthly income ≥ 15000 BDT			
Yes	51.32 (49.79, 52.84)	Reference	
No	48.56 (45.84, 51.28)	2.75 (0.19, 5.32)	0.035
Involved with aquaculture			
Yes	51.22 (49.73, 52.71)	Reference	
No	46.99 (43.28, 50.69)	4.24 (0.73, 7.74)	0.018
Hygienic latrine			
Yes	52.67 (50.94, 54.4)	Reference	
No	48.36 (46.5, 50.23)	4.31 (2.34, 6.28)	< 0.001
Water and soap available in handwashing place			
Yes	52.64 (50.71, 54.58)	Reference	
No	48.53 (46.74, 50.33)	4.11 (1.83, 6.39)	< 0.001
HH size			
Below seven	53.86 (51.98, 55.73)	Reference	
Seven or above	49.41 (47.70, 51.13)	4.44 (2.43, 6.46)	< 0.001
HH dietary diversity			
HDDS ≥ 7	53.90 (51.23, 56.57)	Reference	
HDDS < 7	50.10 (48.71, 51.50)	3.79 (1.60, 5.98)	< 0.001
Child's age			
Age ≤ 18 months	56.72 (54.76, 58.67)	Reference	
Age > 18 months	46.59 (44.83, 48.35)	10.1 (7.93, 12.3)	< 0.001
Child's sex			
Female	53.25 (51.17, 55.33)	Reference	
Male	48.41 (46.78, 50.03)	4.85 (2.60, 7.10)	< 0.001
Childhood illness in the last 15 days			
No	54.90 (52.04, 57.75)	Reference	
Yes	50.50 (48.94, 52.05)	4.40 (1.47, 7.33)	0.003
Access of mass media			
Yes	51.51 (49.88, 53.15)	Reference	
No	48.13 (45.40, 50.86)	3.38 (0.42, 6.34)	0.028

*Differences in the predicted values of stunting between the two groups were calculated using the Stata "adjrr" package

STROBE Statement—Checklist of items that should be included in reports of *cross-sectional studies*

	Item No	Recommendation	Page No
Title and abstract	1	(a) Indicate the study's design with a commonly used term in the title or the abstract	1-2
		(b) Provide in the abstract an informative and balanced summary of what was done and what was found	1-2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	3-6
Objectives	3	State specific objectives, including any prespecified hypotheses	6
Methods			
Study design	4	Present key elements of study design early in the paper	6
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	6
Participants	6	(a) Give the eligibility criteria, and the sources and methods of selection of participants	6
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	6-7
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	6-7
Bias	9	Describe any efforts to address potential sources of bias	20
Study size	10	Explain how the study size was arrived at	7
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	7
Statistical methods	12	(a) Describe all statistical methods, including those used to control for confounding	8-9
		(b) Describe any methods used to examine subgroups and interactions	
		(c) Explain how missing data were addressed	
		(d) If applicable, describe analytical methods taking account of sampling strategy	8-9
		(e) Describe any sensitivity analyses	
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	11
		(b) Give reasons for non-participation at each stage	
		(c) Consider use of a flow diagram	
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	11
		(b) Indicate number of participants with missing data for each variable of interest	
Outcome data	15*	Report numbers of outcome events or summary measures	11
Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	11-14

		(b) Report category boundaries when continuous variables were categorized	
		(c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	11-15
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	
Discussion			
Key results	18	Summarise key results with reference to study objectives	17
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	20
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	17
Generalisability	21	Discuss the generalisability (external validity) of the study results	17-18
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	22

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at <http://www.plosmedicine.org/>, Annals of Internal Medicine at <http://www.annals.org/>, and Epidemiology at <http://www.epidem.com/>). Information on the STROBE Initiative is available at www.strobe-statement.org.

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A predictive modelling approach to illustrate factors correlating with stunting among children aged 12-23 months: a cluster randomized pre-post study

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1 A predictive modelling approach to illustrate factors correlating with stunting among 2 children aged 12-23 months: a cluster randomized pre-post study

3
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14
15 Word count: 4977

17 **Abstract**

18 **Objective** The aim of this study was to construct a predictive model in order to develop an
19 intervention study to reduce the prevalence of stunting among children aged 12-23 months.

20
21 **Design** The study followed a cluster randomized pre-post design and measured the impacts on
22 various indicators of livelihood, health, and nutrition. The study was based on a large dataset
23 collected from two cross-sectional studies (baseline and endline).

24
25 **Setting** The study was conducted in the north-eastern region of Bangladesh under the Sylhet
26 division, which is vulnerable to both natural disasters and poverty. The study specifically targeted
27 children between the ages of 12 and 23 months.

28
29 **Main outcome measures** Childhood stunting, defined as a length-for-age z-score (LAZ) <-2 , was
30 the outcome variable in this study. Logistic and probit regression models and a decision tree were
31 constructed to predict the factors associated with childhood stunting. The predictive performance

32 of the models was evaluated by computing the area under the receiver operating characteristic
33 (ROC) curve analysis.

34
35 **Results** The baseline survey showed a prevalence of 52.7% stunting, while 50.0% were stunted at
36 endline. Several factors were found to be associated with childhood stunting. The model's
37 sensitivity was 61% and specificity was 56%, with a correctly classified rate of 59% and an area
38 under the ROC curve of 0.615.

39
40 **Conclusion** The study found that childhood stunting in the study area was correlated with several
41 factors, including maternal nutrition and education, food insecurity, and hygiene practices. Despite
42 efforts to address these factors, they remain largely unchanged. The study suggests that a more
43 effective approach may be developed in future to target adolescent mothers, as maternal nutrition
44 and education are age-dependent variables. Policymakers and programme planners need to
45 consider incorporating both nutrition-sensitive and specific activities and enhancing collaboration
46 in their efforts to improve the health of vulnerable rural populations.

47
48 **Study registration:** RIDIE-STUDY-ID-5d5678361809b

49
50 **Keywords:** Childhood stunting, Chronic malnutrition, Global public health, Logistic regression,
51 Probit regression, Decision tree

52 53 **Strengths and limitations of this study**

- 54 • The study used a combination of parametric and non-parametric predictive models to
55 estimate the effect size of the independent variables and identify significant correlates of
56 childhood stunting
- 57 • The study was designed to mitigate the potential impact of seasonal factors by conducting
58 the baseline and endline surveys at the same time of the year
- 59 • A binary indicator of stunting based on a single LAZ cut-off point (<-2) may not provide
60 a complete evaluation of the severity of malnutrition among children as it does not
61 consider micronutrient deficiencies

- 62 • Use of recall data from the previous 24 hours for dietary diversity, household food
63 insecurity, domestic violence, and maternal healthcare may be subject to recall bias
- 64 • Biological data has not been collected such as enteropathogen and environmental enteric
65 dysfunction, which could have been related to childhood stunting

67 Introduction

68 Childhood stunting, which is defined as length-for-age z-score (LAZ) <-2 , is a major concern for
69 public health and has been widely used as an indicator of chronic malnutrition in children.^{1 2}
70 Although childhood stunting scenarios have much improved globally, the prevalence of childhood
71 stunting is still very high in low-resource settings, including countries such as Bangladesh.
72 According to the 2018 Global Nutrition Report, 150.8 million children (22.2%) under five years-
73 of-age are stunted globally, compared to 198.4 million (32.6%) and 165 million children in 2000
74 and 2011, respectively.^{3 4} Between 2000 and 2018, Asian countries have experienced a decrease
75 in the rate of stunting among children under five from 38.1% to 23.2%. However, South Asia still
76 has the highest prevalence of stunting in the region, with a rate of 38.9% in 2018.³ In Bangladesh,
77 about 5.5 million (36%) children under five were stunted in 2014,⁵ however by 2018, childhood
78 stunting has reduced to about 31%.² As the World Health Organization (WHO) considers a
79 childhood stunting rate of 15% to be an emergency situation, the current prevalence of childhood
80 stunting in Bangladesh reflects an alarming situation of chronic undernutrition.⁶

81
82 Literature suggests that children are at a higher prevalence of stunting if their mothers do not
83 receive adequate antenatal care, fail to rest sufficiently, do not consume additional food, and
84 neglect to take iron-folic acid (IFA) tablets during pregnancy.⁷⁻⁹ Additionally, maternal and child
85 health are correlated with mass media exposure, receiving a vitamin A capsule, having a skilled
86 birth attendant, and maternal education.^{6 8 10-12} Children in poor households in Bangladesh are more
87 likely to experience stunted growth if their mothers are employed, as there are inadequate day-care
88 centres available for the children, leading to insufficient breastfeeding.¹³ Moreover, evidence
89 suggests that a number of characteristics at the household level, which relate to both children and
90 mothers, can influence childhood stunting. The characteristics of the household head, household
91 food insecurity and lower dietary diversity, household lower-income, household involvement in
92 several earning activities, availability of sanitation facility at home, hand-washing status, family

1
2
3 93 size, religion, and receive several types of allowance from government are most often reported to
4 94 be associated with stunting in the literature.^{6 8 11 14-16}

5
6 95
7
8 96 Based on child characteristics, several indicators are associated with stunting. This status is
9 97 associated with two basic characteristics: a child's gender and age.⁸ Children are commonly
10 98 affected by the co-occurrence of illness in low- and middle-income countries, which is one of the
11 99 most common causes of stunting.¹⁷ Inadequate infant and young child feeding (IYCF) practices
12 100 also reduce child growth.^{8 15} However, these findings are mostly based on nationally representative
13 101 cross-sectional and cohort studies, or studies conducted in urban settings.^{18 19} Therefore, a
14 102 knowledge gap exists on whether similar results would be obtained when nationwide data are
15 103 compared with data for study populations from poor or very poor rural households in specific
16 104 vulnerable regions.

17 105
18 106 Sylhet is one such vulnerable region of north-east Bangladesh, comprising diverse terrains such as
19 107 plain land, hilly land, *Haor* (wetland), and flash flood-prone areas. This region is reported to
20 108 perform poorly for all important maternal healthcare indicators,²⁰ despite the fact that Bangladesh
21 109 has made substantial progress in improving the overall health of the population.²¹ Moreover, the
22 110 socio-economic profile of the inhabitants in Sylhet region includes both very rich and extremely
23 111 poor people. This scenario may worsen without the implementation of appropriate strategies in the
24 112 near future. Sylhet region is also performing poorly compared to the national averages for a number
25 113 of health and nutritional indicators. Critical indicators such as the infant mortality rate and
26 114 unemployment status of women are high.¹⁹ In comparison to the overall situation of Bangladesh,
27 115 where stunting among children under five has decreased, the Bangladesh Demographic and Health
28 116 Survey (BDHS) 2014 indicates the prevalence of childhood stunting in Sylhet is astonishingly
29 117 high, at 50%.¹⁹ This alarming figure provided the rationale for implementation of a comprehensive
30 118 intervention programme in this region. A large-scale nutrition programme, *Suchana: Ending the*
31 119 *Cycle of Undernutrition in Bangladesh; a multi-sectoral nutrition programme*, was undertaken
32 120 with the aim to prevent chronic malnutrition in Sylhet.

33 121
34 122 In general, *Suchana* nutrition interventions can be divided into two types: nutrition-sensitive and
35 123 nutrition-specific.²² The concept of nutrition-sensitive intervention refers to an intervention that

1
2
3 124 benefits the beneficiaries in terms of food and nutrition security, and also influences the underlying
4 125 determinants of nutrition. This type of intervention is largely delivered through the agricultural
5 126 sector (homestead vegetable and fruit production, pro-poor nutrition-sensitive aquaculture),
6 127 improved technology (mono-sex tilapia and carp-tilapia polyculture, subsistence fishing, fish
7 128 drying), demonstrations (village model farms and demo ponds, livestock, food security, promotion
8 129 of climate-smart technologies), and supported income-generating activities (skill development in
9 130 business management, engagement with the private sector and other sectors). As nutrition-specific
10 131 interventions were delivered through nutrition-sensitive interventions, their coverage,
11 132 effectiveness, and scale can be increased. It can meet the targets by lowering them and
12 133 implementing nutrition-specific interventions. A nutrition-specific intervention addresses the
13 134 immediate cause of malnutrition. Direct determinants of nutrition are the focus of this intervention.
14 135 There is a strong focus on nutrition-specific interventions in the health sector. Whether
15 136 implemented alone or jointly, nutrition-specific interventions improve health outcomes. Some
16 137 examples of nutrition-specific interventions are: counselling for mothers at the household level,
17 138 community-based nutrition education for spouses and in-laws, growth monitoring and promotion
18 139 sessions integrated with *Expanded Programme on Immunization* in communities, *Government of*
19 140 *Bangladesh* health facilities equipped with *severe acute malnutrition* service delivery, and support
20 141 for *National Nutrition Services* service delivery through community clinics, Union Health and
21 142 Family Welfare Centers, and Upazila health complexes.

22 143
23
24 144 The primary objective of the *Suchana* programme was to reduce the prevalence of childhood
25 145 stunting in the intervention areas. The secondary objectives were to assess the changes in *Suchana*
26 146 beneficiaries' households, in terms of an increase and diversification of household income, food
27 147 security status, optimal IYCF practices, haemoglobin status of children, the empowerment of
28 148 women, and adolescents' nutritional knowledge and practices.²²

29 149
30
31 150 The *Suchana* programme substantially improved nutritional behaviour, maternal healthcare
32 151 practices, women's empowerment, household income, and household food security in the
33 152 intervention area compared to the control area.²³ Contrary to predictions, however, *Suchana* did
34 153 not result in any significant reduction in the prevalence of childhood stunting. Therefore, although
35 154 most other factors related to childhood stunting improved, this raises the question of why the

155 prevalence of stunting did not reduce after the intervention. An important observation from the
156 *Suchana* survey was that the proportion of households in this study population using hygienic
157 latrines was quite low. This factor was associated with stunting in children,⁸ and did not
158 significantly improve by endline in the intervention areas compared to the control areas.

159
160 In this study, we aimed to construct a predictive model to attempt to explain whether any
161 improvements in associated factors may promote a significant reduction in stunting among
162 children aged 12-23 months from poor and extremely poor households in the Sylhet region.

165 **Methods**

166 **Study design and setting**

167 The *Suchana* programme was implemented in 157 *Unions* over 20 sub-districts in the Sylhet region
168 in the north-east of rural Bangladesh. The *Suchana* programme's protocol has been thoroughly
169 explained elsewhere.²² *Union*, the smallest local government and administrative entity in rural
170 Bangladesh, was considered as a cluster and divided into four phases at random. Phase-1 was
171 designated as the intervention group, while Phase-4 was the control group, and the other phases
172 were treated as learning phases.²² For implementation purposes, vulnerable villages were selected
173 within Phase-1 and Phase-4 areas. The staff of the programme chose vulnerable villages in each
174 *Union* based on their vulnerability (e.g., frequent floods or submerging, little or no intervention
175 from other development programmes, poverty or household living circumstances, remoteness and
176 accessibility issues, a high prevalence of superstitions and social taboos). After consultation with
177 the local government representatives, elected officials, and local elites as well as field visits, this
178 selection method was decided upon. The impacts of the intervention on livelihood, health, and
179 nutrition were measured using a pre-post design. A large dataset was collected from two cross-
180 sectional surveys (baseline and endline) under this study. The baseline survey was conducted in
181 November 2016 and February 2017, followed by the endline survey in the same months three years
182 later among the same population and different participants (Supplementary Figure 1).

184 **Outcome variable**

185 The outcome variable in this study was childhood stunting, which was defined as a length-for-age
186 z-score (LAZ) <-2 .²

188 **Independent variables**

189 Initially, a list of independent variables was finalized through results obtained from descriptive
190 and bi-variate analyses, as well as a comprehensive literature review (Table 1). These included at
191 least four antenatal care (ANC) visits by a skilled service provider, additional resting during
192 pregnancy, additional food consumption during pregnancy, consumption of at least 100 IFA tablets
193 during pregnancy, receiving vitamin A capsule after last delivery, birth attendant/facility, mother
194 involved in income-generating activities, maternal BMI, maternal education, household food
195 insecurity, household monthly income >15000 BDT, involved with aquaculture, hygienic latrine,
196 water and soap available in handwashing place, household size, household dietary diversity, sex
197 of household head, religion, received any grant/allowance/stipend from the government, access of
198 mass media, child's age, child's sex, childhood illness in the last 15 days, minimum dietary
199 diversity, early initiation of breastfeeding, and received colostrum. Household food insecurity
200 access scale was measured using the Food and Nutrition Technical Assistance's Guideline, which
201 categorizes household food insecurity into four levels: a) food secure, b) mildly food insecure, c)
202 moderately food insecure, and d) severely food insecure.²⁴ In the analysis herein, this indicator
203 was redefined as a binary indicator: severely food insecure or not severely food insecure.

205 **Sample size**

206 The sample size for this study was calculated with the STATA "*clustersampsi*" command module,
207 considering the number of clusters in the surveys and considering the expected prevalence of
208 childhood stunting in the control group (Supplemental Appendix 1). It was estimated that the
209 expected prevalence of stunting was 47%, which was hypothesized to be reduced to 41% after
210 three years of intervention. A sample size of 1520 per arm was calculated based on a 5% level of
211 significance, 80% power, 40 clusters per arm, and an intra-cluster correlation coefficient (ICC) of
212 0.01. After rounding, the estimated sample size per arm was 1620, and the total sample size was
213 3200 at baseline, with an equal number of participants in the control and intervention groups. For
214 evaluation purposes, the sample size at endline was doubled to ensure a stratified intervention

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3 215 component, resulting in a total sample size of 9600 mother-child pairs (baseline: 3200 and endline:
4 216 6400).²²

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8 218 **Sampling**

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10 219 The baseline and endline surveys were conducted in a total of eight and twelve villages
11 220 respectively, which were randomly selected from each *Union* using a list of vulnerable villages
12 221 provided by Save the Children. The most vulnerable households were identified and verified using
13 222 the inclusion criteria of the *Suchana* programme (Supplementary Table 1). These households were
14 223 then given an identification number to prepare the sampling frame and required households were
15 224 systematically selected for the surveys from the frame. The method of data collection is explained
16 225 in detail in the Supplemental Appendix 2.
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23 227 **Statistical analysis**

24 228 **General characteristics:** Stata-14 software (StataCorp LP, College Station, TX, USA) and R 4.2.2
25 229 (*rpart*)²⁵ were used to analyse the data. Bar diagram was used for data visualization. Descriptive
26 230 statistics, such as frequency and proportions for categorical variables and mean and standard
27 231 deviations for quantitative variables, were used to summarize the data at baseline and endline.
28 232 Cross-tabulation was used to present that outcome variable segregated by intervention and control
29 233 group at baseline survey as well as the endline survey. The *difference in difference* method was
30 234 used to estimate the contrast of an intervention by comparing the difference in the outcomes
31 235 between an intervention group and a control group before and after the intervention.²⁶
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41 237 **Predictive model:** Three statistical models were used as predictive models. Two parametric
42 238 models, such as Logistic and Probit regression models, and Decision Tree as a non-parametric
43 239 model. Logistic and Probit regression models were used as predictive models as well as classifier
44 240 models. The models were also used to investigate which factors were significantly associated with
45 241 childhood stunting, and estimate their effect size, in order to predict whether changes in
46 242 behavioural practices might potentially help to achieve targeted reductions in stunting. Using those
47 243 variables, a decision tree was applied, and the predictive performance was compared to other
48 244 models.
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246 For the parametric models, first, Chi-Square test was used to examine the bivariate associations
 247 between stunting and all possible explanatory variables. In the second step, variables with p -values
 248 <0.25 in the simple model were included in the multiple regression models.²⁷ In the final step, any
 249 independent variables thought to be likely predictors were added to the multiple regression model
 250 using the stepwise forward selection method. Some indicators, e.g., age, sex, and maternal
 251 nutritional status were added regardless of their p -value due to their scientific plausibility. The
 252 mathematical equation of logistic and probit regression models were given in the Supplemental
 253 Appendix 3. As a cluster variable, *Union* was used to adjust the standard errors. Furthermore, for
 254 the explanation of the regression model, a p -value <0.05 was considered as statistically significant,
 255 and the confidence interval (CI) of 95% was also reviewed. From the fitted model, the adjusted
 256 effect size (adjusted prevalence difference) against all predictors was estimated using the “*adjrr*”
 257 package in Stata. The list of independent variables with the value labels used in the model is given
 258 in Table 1.

259
 260 **Table 1. List of all independent variables**

Indicators	Code	Stunting Status*	Selection in the model
At least four ANC visits by a skilled service provider			
At least four ANC visits by a skilled service provider	0		Selected
Less than four ANC visits by a skilled service provider	1	Higher prevalence ⁸	
Additional resting during pregnancy			
Took more rest	0		Not selected
Did not take more rest	1	Higher prevalence ⁸	
Additional food consumption during pregnancy			
Consumed more food	0		Not selected
Did not consumed more food	1	Higher prevalence ^{7 8}	
Consumption of at least 100 IFA tablets during pregnancy			
Consumed at least 100 IFA tablets	0		Not selected
Did not consumed at least 100 IFA tablets	1	Higher prevalence ⁹	
Received vitamin A capsule after last delivery			
Received	0		Not selected
Did not receive	1	Higher prevalence ⁸	
Birth attendant/facility			
Skilled	0		Selected
Unskilled	1	Higher prevalence ¹⁰	
Mother involved in income-generating activities			
No	0		Selected
Yes	1	Higher prevalence ^{6 13}	
Maternal BMI			
BMI ≥ 18.5	0		Selected
BMI < 18.5	1	Higher prevalence ^{6 11}	
Maternal education			
			Selected

	At least one-year formal education	0		
	No schooling	1	Higher prevalence ^{6 11}	
	Access of mass media			
	Access	0		Selected
	No access	1	Higher prevalence ¹²	
	Household food insecurity			
	Below severe	0		Selected
	Severe	1	Higher prevalence ⁸	
	Household monthly income \geq15000 BDT			
	\geq 15000 BDT	0		Selected
	<15000 BDT	1	Higher prevalence ¹¹	
	Involved with aquaculture			
	Involved	0		Selected
	Did not involved	1	Higher prevalence ¹⁴	
	Hygienic latrine			
	Hygienic latrine	0		Selected
	Unhygienic latrine	1	Higher prevalence ^{6 11 15}	
	Water and soap available in handwashing place			
	Available	0		Selected
	Unavailable	1	Higher prevalence ¹⁵	
	Household size			
	Below seven	0		Selected
	Seven or above	1	Higher prevalence ¹¹	
	Household dietary diversity (HDDS)			
	HDDS \geq 7	0		Selected
	HDDS <7	1	Higher prevalence ⁸	
	Sex of household head			
	Female	0		Not selected
	Male	1	Higher prevalence ⁸	
	Household head education			
	At least one-year formal education	0		Not selected
	No schooling	1	Higher prevalence ⁶	
	Religion			
	Muslim	0		Not selected
	Non-Muslim	1	Lower prevalence ⁶	
	Received any grant/allowance/stipend from the government			
	Received	0		Not selected
	Did not receive	1	Higher prevalence ¹⁶	
	Child's age			
	Age \leq 18 months	0		Selected
	Age >18 months	1	Higher prevalence ⁸	
	Child's sex			
	Female	0		
	Male	1	Higher prevalence ⁸	
	Childhood illness in the last 15 days			
	No	0		Selected
	Yes	1	Higher prevalence ¹⁷	
	Minimum dietary diversity			
	Received	0		Not selected
	Did not receive	1	Higher prevalence ^{8 15}	
	Early initiation of breastfeeding			
	Received	0		Not selected
	Did not receive	1	Higher prevalence ⁸	

Received colostrum				Not selected
	Received	0		
	Did not receive	1	Higher prevalence ⁸	

¹Expected effects based on findings of the literature

Model evaluation: The predictive performance of the three statistical models was evaluated by computing model sensitivity and specificity, and calculating the area under the receiver operating curve (ROC) analysis. To ensure accurate results, the data was randomly split into a training set (75%) and a test set (25%) using a random-number seed 113843. The same training and test datasets were used for evaluating the performance of all algorithms to ensure consistency in the results. The sensitivity and specificity values, as well as the area under the ROC curve, were used to determine the overall accuracy of the algorithms in predicting childhood stunting.^{28 29}

Patient and public involvement

Patients and public were not actively involved in formulating the research question and or protocol development, including the outcome measures. To expedite the field implementation, however, local elites e.g. teachers, religious persons, and local government council members were informed about the study.

Results

General characteristics: Out of 9600 cases, 9501 cases were found to be available. The refusal rate was around 1%. With respect to the outcome indicator, stunting in children aged 12-23 months, 52.7% of children were stunted at the baseline survey (intervention group: 52.6%; control group: 52.8%), whereas the proportion of children exhibiting stunting at endline was 50.0% (intervention: 49.9%; control: 50.1%; Figure 1). At both the baseline and endline surveys, there was no significant difference in proportion between intervention and control areas. The *difference-in-difference* in outcomes over time was also insignificant.

Figure 2 describes several other indicators related to maternal and child health, including the status of consuming a minimum acceptable diet (intervention: 35.2%; control: 14.9%), minimum dietary diversity (intervention: 42.8%; control: 20.4%), maternal decision-making (intervention: 45.0%; control: 31.0%), at least four maternal ANC visits by a skilled service provider (intervention: 36.1%; control: 17.7%), minimum dietary diversity for women (intervention: 52.6%; control:

33.5%), a household dietary diversity score of at least seven (intervention: 88.9%; control: 78.3%), and household food security status (intervention: 26.6%; control: 20.2%). Results from the endline survey showed that these indicators were significantly improved in the intervention group compared to the control group. However, the availability of hygienic latrines did not increase in the intervention group (intervention: 44.0%; control: 44.0%). Table 2 shows the households' socio-demographic characteristics, women's general characteristics, and children's characteristics at baseline and endline.

Table 2. General characteristics of the *Suchana* beneficiaries

Indicators, <i>n</i> (%)	Baseline N=3200	Endline N=6301	Total N=9501
At least four ANC visits by a skilled service provider			
Yes	408 (12.8)	1530 (24.3)	1938 (20.4)
No	2792 (87.2)	4771 (75.7)	7563 (79.6)
Delivery at skilled birth attendant/facility			
Yes	1000 (31.2)	2769 (44.0)	3769 (39.7)
No	2200 (68.8)	3532 (56.0)	5732 (60.3)
Access of mass media			
Access	563 (17.59)	1169 (18.55)	1732 (18.23)
No access	2637 (82.41)	5132 (81.45)	7769 (81.77)
Mother involved in income-generating activities			
No	3102 (96.9)	5665 (89.9)	8767 (92.2)
Yes	98 (3.1)	639 (10.1)	737 (7.8)
Maternal BMI			
BMI \geq 18.5	1859 (58.1)	4073 (64.6)	5932 (62.4)
BMI <18.5	1341 (41.9)	2231 (35.4)	3572 (37.6)
Mother completed primary education			
Yes	1721 (53.8)	3808 (60.4)	5529 (58.2)
No	1479 (46.2)	2496 (39.6)	3975 (41.8)
Maternal age			
Age <30 years	2145 (67.0)	3559 (56.5)	5704 (60.0)
Age \geq 30 years	1055 (33.0)	2745 (43.5)	3800 (40.0)
Type of delivery			
Normal	2879 (90.0)	5529 (87.8)	8408 (88.5)
Caesarean	321 (10.0)	772 (12.3)	1093 (11.5)
PNC			
No	2152 (67.3)	4128 (65.5)	6280 (66.1)
Yes	1048 (32.8)	2173 (34.5)	3221 (33.9)
Household severely food insecure			
Yes	912 (28.5)	1016 (16.1)	1928 (20.3)
No	2288 (71.5)	5285 (83.9)	7573 (79.7)
Household monthly income \geq15000 BDT			
Yes	424 (13.2)	1015 (16.1)	1439 (15.1)
No	2776 (86.8)	5289 (83.9)	8065 (84.9)

Household involved with aquaculture				
	Yes	161 (5.0)	561 (8.9)	722 (7.6)
	No	3039 (95.0)	5740 (91.1)	8779 (92.4)
Hygienic latrine				
	Yes	1121 (35.0)	2782 (44.1)	3903 (41.1)
	No	2079 (65.0)	3519 (55.9)	5598 (58.9)
Water and soap available in handwashing place				
	Yes	862 (26.9)	3170 (50.3)	4032 (42.4)
	No	2338 (73.1)	3131 (49.7)	5469 (57.6)
Household savings				
	No	1080 (33.8)	2876 (45.6)	3956 (41.6)
	Yes	2120 (66.2)	3425 (54.4)	5545 (58.4)
Sex of household head				
	Female	110 (3.4)	501 (8.0)	611 (6.4)
	Male	3090 (96.6)	5799 (92.0)	8889 (93.6)
Source of drinking water				
	Tube well	2748 (85.9)	5713 (90.7)	8461 (89.0)
	Others	452 (14.1)	588 (9.3)	1040 (11.0)
Household dietary diversity score				
	HDDS \geq 7	2182 (68.2)	5322 (84.5)	7504 (79.0)
	HDDS $<$ 7	1018 (31.8)	979 (15.5)	1997 (21.0)
Household monthly income (Thousand BDT)¹				
Per capita income (Thousand)¹				
Household size¹				
Child's age in months²				
Length-for-age z-score²				
Weight-for-age z-score²				
Weight-for-length z-score²				
Child's age				
	Age $<$ 18 months	1745 (54.5)	3710 (58.9)	5455 (57.4)
	Age \geq 18 months	1455 (45.5)	2594 (41.1)	4049 (42.6)
Child's sex				
	Female	1567 (49.0)	3044 (48.3)	4611 (48.5)
	Male	1633 (51.0)	3257 (51.7)	4890 (51.5)
Childhood illness in the last 15 days				
	Yes	2867 (89.6)	5763 (91.5)	8630 (90.8)
	No	333 (10.4)	538 (8.5)	871 (9.2)

¹Median (IQR); ²Mean \pm SD

Correlated factors: The study used two parametric predictive models to determine the correlates of childhood stunting. The results, presented in Table 3, showed the adjusted odds ratios (aOR) computed from multiple logistic regression and the adjusted coefficients computed from multiple probit regression. These results provide important insights into the factors that increase the odds of stunting in childhood, and can inform public health interventions aimed at reducing stunting and improving child health. The aORs provide a quantitative measure of the relationship between

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3 308 different factors and childhood stunting, adjusting for *Union* as cluster variable. Understanding the
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5 309 correlates of childhood stunting is critical for addressing this important public health issue and
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7 310 improving the health and well-being of children globally. The results of this study show that a
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9 311 number of maternal, household and children factors were correlated with an increased prevalence
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11 312 of stunting in children. Children of mothers who did not receive at least four ANC visits from a
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13 313 skilled service provider had 1.16 times higher odds of stunting (95% CI: 1.05, 1.30; p-
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15 314 value=0.005). Children of mothers who gave birth with an unskilled birth attendant or facility had
16
17 315 1.11 times higher odds of stunting (95% CI: 1.02, 1.20; p-value=0.012). The odds of stunting were
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19 316 1.18 times higher in children whose mothers were involved in income-generating activities (95%
20
21 317 CI: 1.02, 1.37; p-value=0.030), 1.23 times higher in children of underweight mothers (95% CI:
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23 318 1.12, 1.36; p-value<0.001), and 1.31 times higher in children of low-educated mothers (95% CI:
24
25 319 1.20, 1.42; p-value<0.001). Furthermore, the lack of exposure to mass media was also found to be
26
27 320 associated with stunting, with odds of 1.15 (95% CI: 1.02, 1.30; p-value=0.025) times higher.
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29 321 Children from households with severe food insecurity, lower-income households, households not
30
31 322 involved in aquaculture, and households with low dietary diversity, were more likely to be stunted,
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33 323 with odds increasing by 1.12 (95% CI: 1.00, 1.24; p-value=0.041), 1.12 (95% CI: 1.01, 1.25; p-
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35 324 value=0.037), 1.19 (95% CI: 1.03, 1.38; p-value=0.018), and 1.17 (95% CI: 1.07, 1.29; p-
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37 325 value=0.001) times, respectively. The results also showed that the odds of stunting increased with
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39 326 increasing household size (95% CI: 1.11, 1.31; p-value<0.001), the absence of a hygienic latrine
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41 327 (95% CI: 1.10, 1.30; p-value<0.001), the absence of water and soap in the handwashing place
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43 328 (95% CI: 1.08, 1.30; p-value<0.001), increasing child age (95% CI: 1.39, 1.67; p-value<0.001),
44
45 329 and being male (95% CI: 1.11, 1.34; p-value<0.001). The odds of stunting were also 1.20 times
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47 330 higher in children with acute illness (95% CI: 1.06, 1.36; p-value=0.003). The logistic and probit
48
49 331 regression models were employed to predict stunting in a sample of 9501 individuals. Both models
50
51 332 were found to be significant, with log-likelihoods of -6387.94 and -6388.02, respectively, and
52
53 333 significant Wald chi-square statistics (p-value < 0.001). Predictive ability of various indicators for
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55 334 the adjusted prevalence of stunting and adjusted prevalence difference (effect size) are given in
56
57 335 Supplementary Table 2a and 2b. The Factors correlating with childhood stunting, as determined
58
59 336 by using a decision tree as a non-parametric predictive model, are also presented in Figure 3. The
60
337 decision tree result suggests that maternal education was the most important variable in predicting
338 childhood stunting, as it was the main root node. The other variables, such as maternal nutrition,

hand washing indicators, and hygienic latrine, were also important, as they were next root node variables. This tree model can be used to predict the childhood stunting status with relative ease.

Table 3. Factors correlating with stunting in children aged 12-23 months, computed using logistic and probit regression analyses

Indicators	Logistic		Probit	
	Adjusted OR (95% CI)	p-value	Adjusted Coef. (95% CI)	p-value
At least four ANC visits by a skilled service provider				
Yes	Reference		Reference	
No	1.16 (1.05, 1.30)	0.005	0.09 (0.03, 0.16)	0.005
Birth attendant/facility				
Skilled	Reference		Reference	
Unskilled	1.11 (1.02, 1.20)	0.012	0.06 (0.01, 0.11)	0.012
Mother involved in income-generating activities				
No	Reference		Reference	
Yes	1.18 (1.02, 1.37)	0.030	0.10 (0.01, 0.19)	0.030
Maternal BMI				
BMI ≥ 18.5	Reference		Reference	
BMI < 18.5	1.23 (1.12, 1.36)	0.000	0.13 (0.07, 0.19)	0.000
Maternal education was primary completed				
Yes	Reference		Reference	
No	1.31 (1.20, 1.42)	0.000	0.17 (0.12, 0.22)	0.000
Access of mass media				
Yes	Reference		Reference	
No	1.15 (1.02, 1.30)	0.025	0.09 (0.01, 0.16)	0.025
Household food insecurity				
Below severe	Reference		Reference	
Severe	1.12 (1.00, 1.24)	0.041	0.07 (0.00, 0.13)	0.042
Household monthly income ≥ 15000 BDT				
Yes	Reference		Reference	
No	1.12 (1.01, 1.25)	0.037	0.07 (0.00, 0.14)	0.035
Involved with aquaculture				
Yes	Reference		Reference	
No	1.19 (1.03, 1.38)	0.018	0.11 (0.02, 0.20)	0.018
Household size				
Below seven	Reference		Reference	
Seven or above	1.20 (1.11, 1.31)	0.000	0.12 (0.06, 0.17)	0.000
Hygienic latrine				
Yes	Reference		Reference	
No	1.20 (1.10, 1.30)	0.000	0.11 (0.06, 0.16)	0.000
Water and soap available in handwashing place				
Yes	Reference		Reference	
No	1.19 (1.08, 1.30)	0.000	0.11 (0.05, 0.16)	0.000
Household dietary diversity				
HDDS ≥ 7	Reference		Reference	
HDDS < 7	1.17 (1.07, 1.29)	0.001	0.10 (0.04, 0.16)	0.001
Child's age				
Age ≤ 18 months	Reference		Reference	
Age > 18 months	1.52 (1.39, 1.67)	0.000	0.26 (0.2, 0.32)	0.000

Child's sex					
	Female	Reference		Reference	
	Male	1.22 (1.11, 1.34)	0.000	0.13 (0.07, 0.18)	0.000
Childhood illness in the last 15 days					
	No	Reference		Reference	
	Yes	1.20 (1.06, 1.36)	0.003	0.11 (0.04, 0.19)	0.003
Sample size and regression diagnostic values for logistic and probit regression analyses		n = 9501 Log-likelihood = -6387.94 Wald chi2(17) = 427.79 p-value<0.001 Pseudo R ² = 0.0298		n = 9501 Log-likelihood = -6388.02 Wald chi2(17) = 441.18 p-value<0.001 Pseudo R ² = 0.0298	

Unions were adjusted as clusters. Baseline and endline were adjusted as time variables

Predictive performance: Table 4 describes the model validation based on sensitivity, specificity, and whether the model was correctly classified for the overall dataset, as well as the training and test datasets. The sensitivity and specificity of the model were around 60% and 55%, respectively for all models. The correctly classified rate was 59%, and the area under the ROC curve was around 61%. We found that these values were approximately equal among the three datasets (main, training, and test datasets); however, the predictive performance of the model was low.

Table 4. Predictive performance of the model for stunting based on classification, sensitivity, and specificity in the full, training and test datasets with area under the receiver operating characteristic curve analysis

	Logistic regression	Probit regression	Decision tree
Full dataset			
Overall accuracy	58.46	58.38	56.51
Sensitivity	61.21	61.25	61.15
Specificity	55.61	55.41	51.70
Area under the curve	61.54	61.54	56.72
Training Dataset			
Overall accuracy	58.83	58.62	57.66
Sensitivity	61.59	61.70	63.93
Specificity	55.36	55.42	51.61
Area under the curve	61.37	61.37	58.44
Test Dataset			
Overall accuracy	58.11	58.19	56.67
Sensitivity	60.23	60.23	61.58
Specificity	55.90	56.07	51.94
Area under the curve	61.76	61.77	58.01

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5 358 **Discussion**

6 359 In an effort to understand why the *Suchana* programme was not effective in reducing the
7 prevalence of childhood stunting, this study analyzed data from both the baseline and endline
8 360 surveys of the programme. The analysis aimed to identify the factors that were significantly
9 361 correlated with stunting and to evaluate the model's predictive performance. After controlling for
10 362 the *Union* as a cluster variable, the study found several indicators that were significantly related to
11 363 stunting. These included the number of ANC visits by a skilled service provider, household dietary
12 364 diversity, household food security, and household monthly income, all of which improved after
13 365 the intervention. However, it was noted that the household food security status did not reach the
14 366 target value of 50%, despite being an important factor associated with childhood stunting.^{8,30,31} On
15 367 the other hand, other outcome indicators of the *Suchana* programme, such as the dietary diversity
16 368 of children, maternal dietary diversity, and maternal empowerment, despite reaching their target
17 369 values, were not found to be associated with stunting in this study.
18 370

19 371
20 372 The study found that while the *Suchana* programme showed improvement in certain programme
21 373 indicators, it did not lead to a significant reduction in childhood stunting. Despite efforts to address
22 374 key factors such as maternal nutrition and education, household food security, and hygiene
23 375 practices, these factors remained largely unchanged. However, the study suggests that
24 376 interventions aimed at adolescent mothers may be more effective in improving maternal nutrition
25 377 and education, since these are age-dependent variables. Additionally, the results of the study were
26 378 also impacted by natural disasters in 2017, including heavy rains and flooding in the Sylhet region,
27 379 which resulted in widespread damage to agriculture, aquaculture, and homes in the study
28 380 population.^{32,33}
29 381

30 382 The study found a contradictory relationship between stunting and maternal involvement in
31 383 income-generating activities, with a higher prevalence of stunting observed among children whose
32 384 mothers were engaged in various earning activities. Although there was a slight increase in the
33 385 proportion of mothers involved in income-generating activities after the intervention, the lack of
34 386 childcare support for working mothers resulted in a marked rise in childhood stunting among low-
35 387 income households. It is important to address this issue by providing adequate childcare support

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3 388 measures for working mothers from poor families to ensure that the child's essential needs are not
4 389 impacted by the mother's employment status.¹³ Additionally, efforts should be made to increase
5 390 awareness among working mothers regarding the importance of child health and nutrition. This
6 391 can be achieved through targeted education and outreach programmes that provide information on
7 392 proper child feeding practices, hygiene, and health-seeking behaviours.
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12 394 The literature suggests that environmental enteropathy may contribute to poor growth among
13 395 children in rural Bangladesh and may represent an important factor affecting the study population
14 396 in the *Suchana* programme.³⁴ Although it was not specifically assessed in this study, indicators
15 397 such as unsanitary latrines, unimproved floors, a lack of handwashing practices, and low education
16 398 levels were available.^{18 35} Improving Water, Sanitation and Hygiene (WaSH) variables,
17 399 particularly latrine facilities and handwashing practices, may help reduce the burden of stunting in
18 400 young children. One of the components of the intervention was poultry, but our qualitative findings
19 401 revealed that many households shared living spaces with poultry, ducks, or other animals, which
20 402 could increase the risk of infections with *Campylobacter* species, a leading food-borne pathogen.¹⁸
21 403 ³⁶ Previous studies have shown a strong association between stunting and enteropathy among
22 404 children who do not respond to nutritional interventions, and findings from rural Bangladesh have
23 405 linked environmental conditions and stunting in children.³⁷⁻³⁹ While assessing environmental
24 406 enteropathy was beyond the scope of the *Suchana* evaluation, collecting data on indicators of
25 407 enteropathy in the intervention and control areas could help evaluate the impact of appropriate
26 408 interventions in the future. The failure to achieve the desired outcome may have been due to several
27 409 factors, including food insecurity and a lack of aquaculture involvement due to natural disasters,
28 410 poor WaSH status, a lack of focus on maternal education and nutrition, and a lack of focus on the
29 411 risk of enteropathogen burden.
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47 413 Another important finding based on the post-estimation findings as well as the value of the area
48 414 under the ROC curve was that the predictive performance of the model was low. Thus, we need to
49 415 identify other indicators from similar research contexts that correlated with childhood stunting but
50 416 were not included in our model. Future research in the field of childhood stunting should give
51 417 priority to the development of more suitable methods for monitoring and identifying effective
52 418 interventions. It is also essential to collect data that considers biological and environmental factors
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3 419 related to childhood stunting, following the literature. By considering these diverse factors, we can
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5 420 improve the accuracy and predictive performance of statistical models. This, in turn, can help draw
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7 421 more reliable conclusions about the effectiveness of interventions aimed at reducing childhood
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9 422 stunting in similar contexts. Additionally, evaluating the model on an independent dataset or
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11 423 conducting external validation could help to determine the generalizability of the model to new
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13 424 data.

14 425
15 426 This study will aid programme managers in prioritizing their focus and designing effective
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17 427 interventions to reduce childhood stunting. Sustainable solutions should be based on the needs of
18
19 428 the beneficiaries. Implementing short-term initiatives such as attendance at healthcare-led
20
21 429 workshops and campaigns can increase ANC visits, skilled birth attendance, and handwashing
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23 430 practices. Establishing women's healthcare services that focus on maternal and child health and
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25 431 nutrition will also help reduce the incidence of stunting.²³ Improved access to media can help
26
27 432 vulnerable communities benefit from government welfare programmes. Food security, income,
28
29 433 sanitation, aquaculture, and illness are all time-sensitive factors. Increasing food production
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31 434 through self-production or purchasing can improve household food security and nutrition.
32
33 435 However, household wealth and access to nearby markets can impact their ability to buy nutritious
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35 436 food. Climate change adaptation in agriculture is crucial to minimize current risks and prepare for
36
37 437 future uncertainties. Using organic fertilizers instead of chemicals in agriculture has environmental
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39 438 benefits, reducing the need for pesticides and protecting human health and biodiversity.
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41 439 Aquaculture can provide a source of protein and improve nutrition, but establishing these facilities
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43 440 takes time. Improving sanitation requires improving socioeconomic status, which is also a time-
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45 441 intensive process. It takes time to improve stunting, as shown by national surveys such as the
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47 442 BDHS and the Food Security and National Surveillance Project (FSNSP).^{2,40} Improving maternal
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49 443 nutrition and education is crucial for promoting the optimal growth and development of children.
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51 444 Adequate food, good environmental conditions, and access to schooling facilities during
52
53 445 adolescence are necessary for women to maintain their own health and to positively impact the
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55 446 health of their children. Emphasizing the education of female children can break the cycle of
56
57 447 poverty and stunting, as it can lead to improved knowledge and decision-making skills related to
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59 448 nutrition and health.^{6 11} To reduce childhood stunting in developing countries, comprehensive
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61 449 interventions that include nutritional support, food security, maternal education, income-

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3 450 generating activities for women with childcare support, and addressing domestic violence against
4 451 women should be implemented. These interventions should be tailored to the specific needs and
5 452 cultural context of the community in which they are implemented, and community participation
6 453 and engagement are essential for their success. By addressing the underlying factors contributing
7 454 to childhood stunting, we can make significant progress towards reducing its prevalence and
8 455 improving the health and well-being of children in developing countries. Furthermore, continued
9 456 monitoring and evaluation of these interventions is essential to ensure their effectiveness and to
10 457 identify areas for improvement.
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19 459 **Recommendation:** The *Suchana* model offers a holistic and integrated approach to addressing
20 460 food and nutrition security, recognizing undernutrition as a complex problem caused by multiple
21 461 factors. The endline survey of *Suchana* showed significant improvement in programme indicators.
22 462 The multi-sector approach of *Suchana* is a meaningful solution to addressing undernutrition.
23 463 However, policy makers should consider implementing additional nutrition-sensitive and specific
24 464 activities, such as promoting climate-resilient agriculture and increasing water and sanitation
25 465 coverage. It is also important to have a sustainable mechanism for improving food security and to
26 466 promote awareness of seasonal diseases associated with livestock and poultry. To further improve
27 467 the programme, indicators such as child sex, maternal education, and nutrition could be adjusted
28 468 during the design stage. The *Suchana* programme is one of the largest global nutrition
29 469 interventions, leading to positive changes in critical indicators, with long-term benefits expected
30 470 for the health and livelihoods of the beneficiaries.
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41 472 **Strength and limitation:** The study had several strengths, including a large sample size,
42 473 randomization, and appropriate sampling techniques. A dedicated quality control team was
43 474 involved in checking the data, and the use of precise anthropometry instruments and separate
44 475 training for the measurement team helped ensure accurate data collection. The study was also
45 476 designed to avoid seasonality by conducting the baseline and endline surveys at the same time of
46 477 the year. However, the study results may have been impacted by a lack of selection effect in the
47 478 implementation of the programme, as well as by the short time horizon of the study. The short
48 479 duration of the study may not have been enough to see a significant impact on stunting.
49 480 Additionally, changes in the study population between the baseline and endline surveys could also
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3 481 have contributed to the lack of differences observed in the results. Another limitation of this study
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5 482 is that we did not collect food intake data but only recall data from the previous 24 hours. These
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7 483 data may be subject to recall bias; thus, caution is necessary when drawing conclusions, especially
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9 484 for indicators such as dietary diversity, household food insecurity, domestic violence, and maternal
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11 485 healthcare. Finally, using a binary indicator of stunting based on a single LAZ cut-off point, which
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13 486 was defined as <-2 , may not provide a comprehensive assessment of the severity of malnutrition
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15 487 among children, as it fails to account for micronutrient deficiencies
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19 **Conclusion**

20 491 Our study revealed that childhood stunting was significantly correlated with a multitude of factors,
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22 492 and majority of the factors were found in poor status in our study area. Despite the implementation
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24 493 of an intervention programme, the situation remained unchanged due to factors such as food
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26 494 insecurity, lack of involvement in aquaculture, poor access to WaSH facilities, and a lack of focus
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28 495 on maternal education and nutrition. The study did not include important indicators such as
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30 496 enteropathogen and environmental enteric dysfunction, which might have contributed to the failure
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32 497 to achieve the desired outcome. The results suggest that policy makers and programme planners
33
34 498 should consider enhancing collaboration and coordination between nutrition-sensitive and specific
35
36 499 activities to address nutritional deficiencies and family health programmes in vulnerable rural
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38 500 populations.
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40 501
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42
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44
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46
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48
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16
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22 522
23 523 **Conflicts of Interest:** The authors declare no conflict of interest.
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26 524
27 525 **Author Contributions:** TA and NC originated the idea for the study and led the protocol design.
28 526 MAH conceptualized the manuscript. SMTA, SSR, MAH, NC, FDF, and TA contributed to the
29 527 survey design. MAH performed statistical analysis and drafted the manuscript. NC and ASGF
30 528 supervised the work, and critically reviewed and provided feedback for revising the manuscript.
31 529 MAH, NC, MA, FDF, FN, BZW, TJS, ASGF, TA, and SSR contributed to the revision of the final
32 530 draft for submission. All authors are responsible for the final content of the manuscript.
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36 531
37 532 **Ethics approval:** This study was approved by the Research Review Committee and Ethical
38 533 Review Committee, the two obligatory components of the Institutional Review Board (IRB) of
39 534 icddr,b. Ethics Committee's approval ID# 00001822. Informed written consent was obtained from
40 535 study participants.
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46 537 **Data availability statement:** The data that support the findings of this study are available on
47 538 request from the corresponding author. The data are not publicly available due to privacy and
48 539 ethical restrictions.
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For peer review only

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3 669 Figure 1. Prevalence of childhood stunting in the intervention and control areas at baseline
4 670 compared to endline. The p-value of the *difference-in-difference* was estimated using interaction
5 671 analysis in the multiple logistic regression model.
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10 673 Figure 2. Results framework and *Suchana* log frame indicators. ANC: antenatal care, HDDS:
11 674 household dietary diversity score, MDD-w: minimum dietary diversity for women.
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14 676 Figure 3. Factors correlating with stunting in children aged 12-23 months, computed using decision
15 677 tree analysis. (X₁: Less than four ANC visits by a skilled service provider, X₂: Unskilled birth
16 678 attendant/facility, X₃: Mother involved in income-generating activities, X₄: Maternal BMI <18.5,
17 679 X₅: Maternal education: no schooling, X₆: Household severe food insecurity, X₇: Monthly income
18 680 <15000 BDT, X₈: Did not involve with aquaculture, X₉: Having unhygienic latrine, X₁₀: Soap was
19 681 unavailable in hand washing place, X₁₁: HH size ≥7, X₁₂: HH dietary diversity score <7, X₁₃:
20 682 Child's age >18, X₁₄: Child's sex was male, X₁₅: Childhood illness in the last 15 days, and X₁₆:
21 683 Lacked access to mass media)
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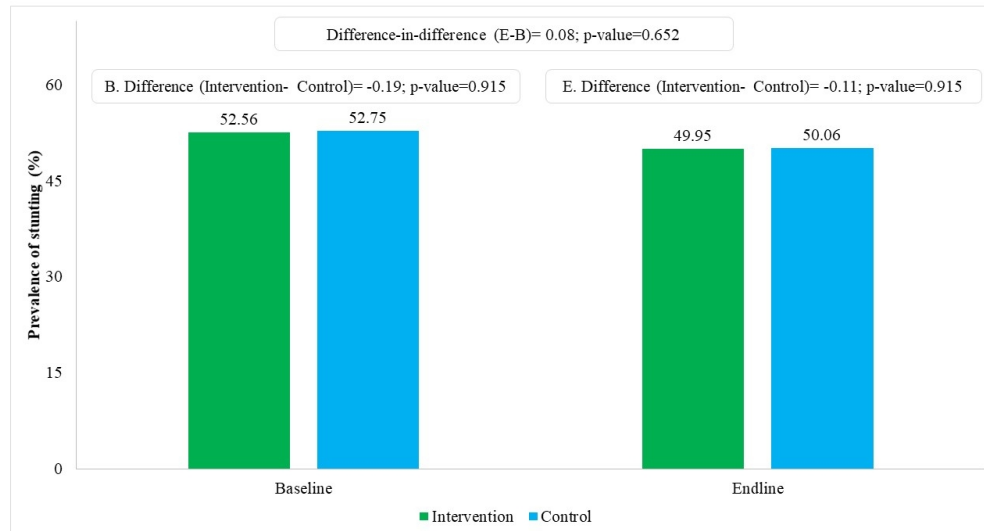


Figure 1. Prevalence of childhood stunting in the intervention and control areas at baseline compared to endline. The p-value of the difference-in-difference was estimated using interaction analysis in the multiple logistic regression model.

108x60mm (300 x 300 DPI)

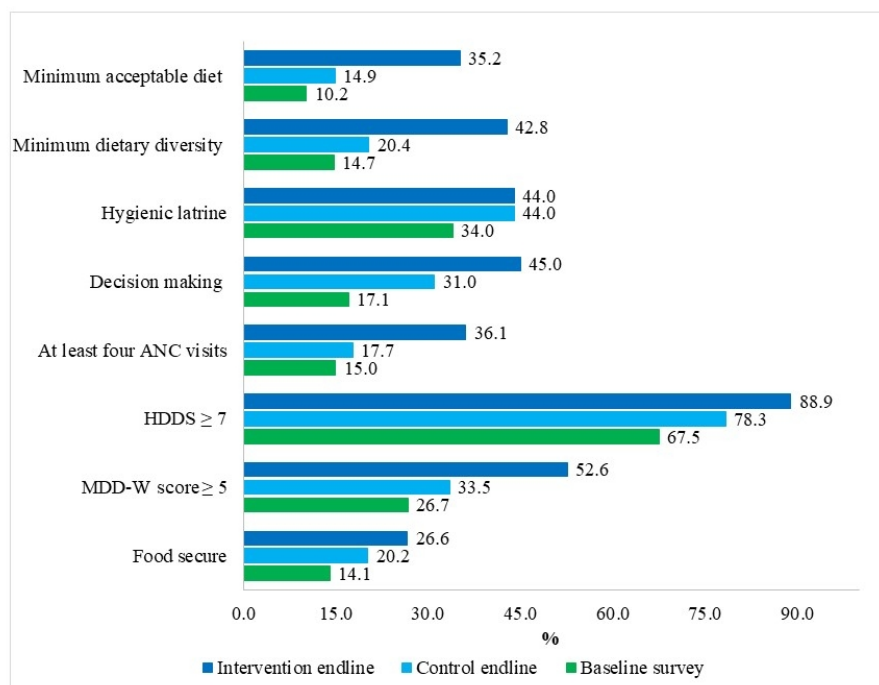


Figure 2. Results framework and Suchana log frame indicators. ANC: antenatal care, HDDS: household dietary diversity score, MDD-w: minimum dietary diversity for women.

254x190mm (96 x 96 DPI)

Appendix 1. Sample size calculation

```
clustersampsi, binomial samplesize p1(0.47) p2(0.41) k(40) rho(0.01)alpha(0.05) beta(0.8)
```

Output of the STATA command for sample size calculation

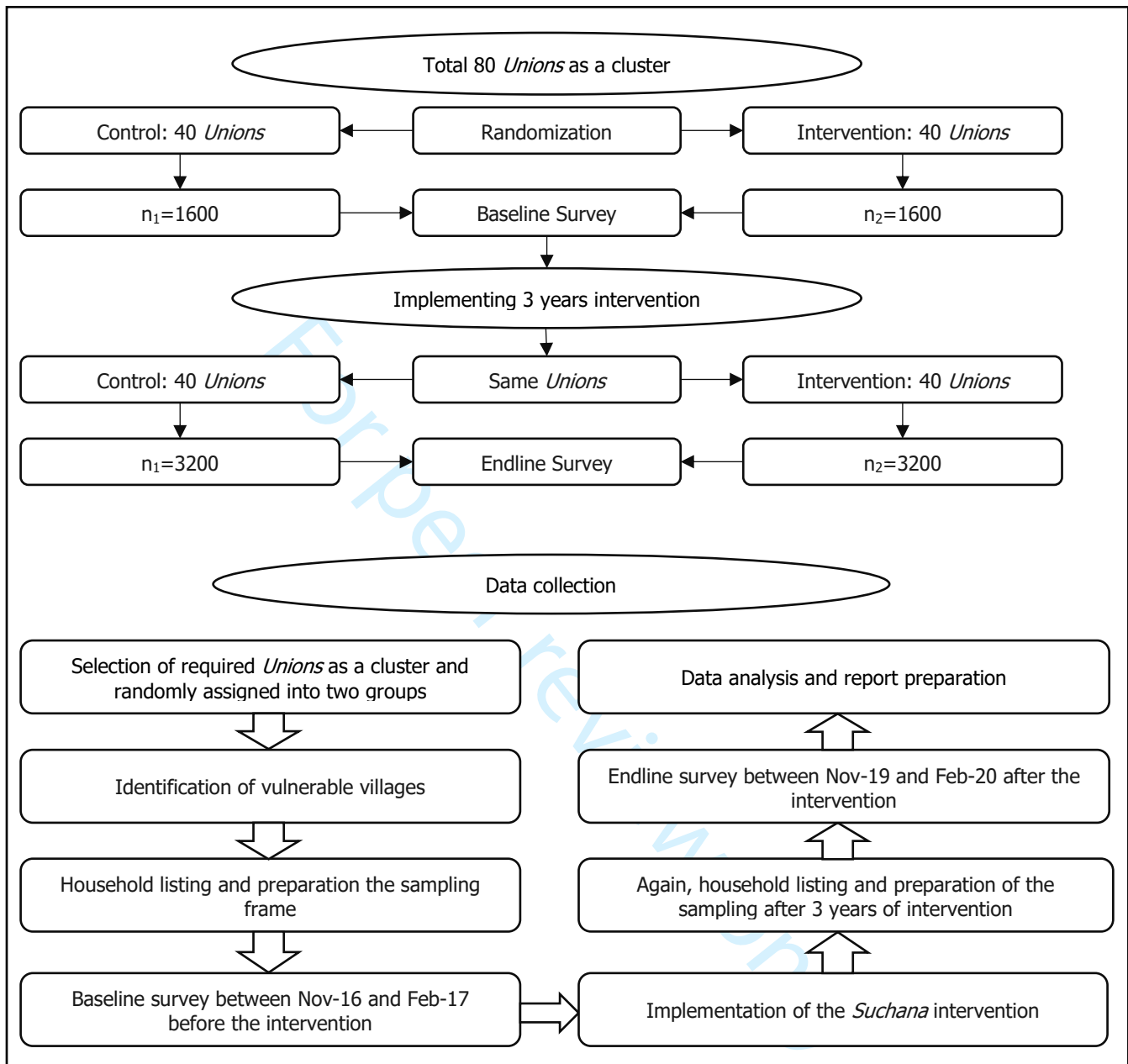
Sample size calculation to determine number of observations required per cluster, for a two-sample comparison of proportions (using normal approximations) without continuity correction.

For the user specified parameters:

```
p1: 0.4700
p2: 0.4100
significance level: 0.05
power: 0.80
number of clusters available: 40
intra cluster correlation (ICC): 0.0100
```

clustersampsi estimated parameters:

```
Firstly, assuming individual randomisation: sample size per arm: 1071
Then, allowing for cluster randomisation: average cluster size required: 38
sample size per arm: 1520
```



Supplementary Figure 1. The evaluation diagram of *Suchana* programme

Appendix 2. Data collection

The Suchana data collection software contained built-in validation rules. As the data were entered at the interviewer level and the records were uploaded to a server at the icddr,b using the built-in internet connectivity of the devices, maximum validation rules were set in the data system to prevent errors during data entry, which reduced the data entry burden. This allowed the data analysis team to review the

consistency of the data every day. Data were synchronized to the central server “Web Service” developed in Asp.Net based on the C# (C Sharp) code. Activities such as editing (after receiving any feedback from field staff members), updating, range checks, duplication checks, consistency checks, frequency checks and cross tabulation were regularly performed during the data entry period. In case of any unusual observations, the issues were discussed and resolved.

Appendix 3. Equation of logistic and probit regression

$$\text{logit}(y) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 X_6 + \beta_7 X_7 + \beta_8 X_8 + \beta_9 X_9 + \beta_{10} X_{10} + \beta_{12} X_{12} + \beta_{13} X_{13} + \beta_{14} X_{14} + \beta_{15} X_{15} + \beta_{16} X_{16}$$

$$\text{probit}(y) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 X_6 + \beta_7 X_7 + \beta_8 X_8 + \beta_9 X_9 + \beta_{10} X_{10} + \beta_{12} X_{12} + \beta_{13} X_{13} + \beta_{14} X_{14} + \beta_{15} X_{15} + \beta_{16} X_{16}$$

Where,

x1: Less than four ANC visits by a skilled service provider	x9: Having unhygienic latrine
x2: Unskilled birth attendant/facility	x10: Soap was unavailable in hand washing place
x3: Mother involved in income-generating activities	x11: HH size ≥ 7
x4: Maternal BMI < 18.5	x12: HH dietary diversity score < 7
x5: Maternal education: no schooling	x13: Child's age > 18
x6: HH severe food insecurity	x14: Child's sex was male
x7: Monthly income < 15000 BDT	x15: Childhood illness in the last 15 days
x8: Did not involve with aquaculture	x16: Lacked access to mass media

and

$$\text{logit}(y) = \log[y/(1-y)]$$

Supplementary Table 1. *Suchana* inclusion criteria for registration of enrolling as vulnerable households

Vulnerable household verification questions	Inclusion criteria
Step 1	
<ul style="list-style-type: none"> Households currently participating/member of any livelihood, food security or asset transfer program 	If “NO” go ahead for next questions
Step 2	
<ul style="list-style-type: none"> Ability to afford three (3) full meals per day for all family members round the year Households monthly income BDT 7,500 or more Household productive asset value worth BDT 15,000 or more (excluding land, pond and homestead) Ownership of homestead land 10 decimals or more Ownership of cultivable land 50 decimals or more (excluding homestead or pond) 	If anyone is “NO” go ahead for next questions
Step 3	
<ul style="list-style-type: none"> Households have married women with in child bearing age (15 to 45 years) Households have pregnant women (including abandoned or widowed woman) Households have 0-23 months old children Households have adolescent girls (15-19 years) 	If anyone is ‘Yes’ go ahead for registration of enrolling as vulnerable Household
Sampling frame was prepared for collecting data from mother-child pair if the households had 0-23 months old children	

Supplementary Table 2a. Predictive ability of various indicators for the adjusted prevalence of stunting and adjusted prevalence difference (effect size) in the fitted multiple logistic regression model.

	Prediction of adjusted stunting [% (95% CI)]	Prediction of adjusted prevalence difference as effect size*	p-value
At least four ANC visits by a skilled service provider			
Yes	51.64 (50.05, 53.23)	Reference	
No	47.99 (45.46, 50.53)	3.65 (1.07, 6.22)	0.006
Birth attendant/facility			
Skilled	51.87 (50.23, 53.51)	Reference	
Unskilled	49.42 (47.48, 51.36)	2.45 (0.55, 4.35)	0.012
Mother involved in income-generating activities			
No	54.55 (50.90, 58.19)	Reference	
Yes	50.59 (49.08, 52.11)	3.95 (0.40, 7.51)	0.029
Maternal BMI			
BMI \geq 18.5	54.04 (52.01, 56.07)	Reference	
BMI <18.5	49.01 (47.21, 50.81)	5.03 (2.66, 7.41)	<0.001
Maternal education was primary completed			
Yes	54.66 (52.58, 56.74)	Reference	
No	48.21 (46.67, 49.75)	6.45 (4.49, 8.40)	<0.001
HH food insecurity			
Below severe	53.03 (50.91, 55.15)	Reference	
Severe	50.36 (48.63, 52.09)	2.66 (0.11, 5.22)	0.041
HH monthly income \geq15000 BDT			
Yes	51.31 (49.79, 52.84)	Reference	
No	48.58 (45.86, 51.30)	2.73 (0.17, 5.30)	0.037
Involved with aquaculture			
Yes	51.22 (49.72, 52.72)	Reference	
No	46.99 (43.30, 50.69)	4.23 (0.73, 7.73)	0.018
Hygienic latrine			
Yes	52.67 (50.94, 54.4)	Reference	
No	48.36 (46.5, 50.23)	4.31 (2.34, 6.28)	<0.001
Water and soap available in handwashing place			
Yes	52.64 (50.71, 54.58)	Reference	
No	48.54 (46.74, 50.33)	4.10 (1.83, 6.38)	<0.001
HH size			
Below seven	53.86 (51.98, 55.74)	Reference	
Seven or above	49.41 (47.70, 51.13)	4.44 (2.43, 6.46)	<0.001
HH dietary diversity			
HDDS \geq 7	53.92 (51.25, 56.60)	Reference	
HDDS <7	50.10 (48.70, 51.50)	3.83 (1.63, 6.02)	<0.001
Child's age			
Age \leq 18 months	56.72 (54.77, 58.67)	Reference	
Age >18 months	46.59 (44.82, 48.35)	10.1 (7.94, 12.32)	<0.001
Child's sex			
Female	53.25 (51.17, 55.34)	Reference	
Male	48.40 (46.78, 50.03)	4.85 (2.59, 7.10)	<0.001
Childhood illness in the last 15 days			
No	54.90 (52.04, 57.77)	Reference	
Yes	50.49 (48.94, 52.05)	4.41 (1.48, 7.34)	0.003
Access of mass media			
Yes	51.51 (49.88, 53.15)	Reference	
No	48.13 (45.39, 50.88)	3.38 (0.42, 6.34)	0.028

*Differences in the predicted values of stunting between the two groups were calculated using the Stata "adjrr" package

Supplementary Table 2b. Predictive ability of various indicators for the adjusted prevalence of stunting and adjusted prevalence difference (effect size) in the fitted multiple probit regression model.

	Prediction of adjusted stunting [% (95% CI)]	Prediction of adjusted prevalence difference as effect size*	p-value
At least four ANC visits by a skilled service provider			
Yes	51.64 (50.05, 53.23)	Reference	
No	47.99 (45.46, 50.53)	3.65 (1.08, 6.22)	0.007
Birth attendant/facility			
Skilled	51.87 (50.23, 53.51)	Reference	
Unskilled	49.42 (47.48, 51.36)	2.45 (0.54, 4.35)	0.011
Mother involved in income-generating activities			
No	54.55 (50.90, 58.16)	Reference	
Yes	50.59 (49.08, 52.11)	3.93 (0.39, 7.48)	0.024
Maternal BMI			
BMI \geq 18.5	54.04 (52.01, 56.07)	Reference	
BMI <18.5	49.01 (47.21, 50.81)	5.03 (2.66, 7.40)	<0.001
Maternal education was primary completed			
Yes	54.66 (52.58, 56.74)	Reference	
No	48.21 (46.67, 49.75)	6.45 (4.49, 8.41)	<0.001
HH food insecurity			
Below severe	53.01 (50.89, 55.12)	Reference	
Severe	50.37 (48.64, 52.10)	2.64 (0.09, 5.19)	0.042
HH monthly income \geq15000 BDT			
Yes	51.32 (49.79, 52.84)	Reference	
No	48.56 (45.84, 51.28)	2.75 (0.19, 5.32)	0.035
Involved with aquaculture			
Yes	51.22 (49.73, 52.71)	Reference	
No	46.99 (43.28, 50.69)	4.24 (0.73, 7.74)	0.018
Hygienic latrine			
Yes	52.67 (50.94, 54.4)	Reference	
No	48.36 (46.5, 50.23)	4.31 (2.34, 6.28)	<0.001
Water and soap available in handwashing place			
Yes	52.64 (50.71, 54.58)	Reference	
No	48.53 (46.74, 50.33)	4.11 (1.83, 6.39)	<0.001
HH size			
Below seven	53.86 (51.98, 55.73)	Reference	
Seven or above	49.41 (47.70, 51.13)	4.44 (2.43, 6.46)	<0.001
HH dietary diversity			
HDDS \geq 7	53.90 (51.23, 56.57)	Reference	
HDDS <7	50.10 (48.71, 51.50)	3.79 (1.60, 5.98)	<0.001
Child's age			
Age \leq 18 months	56.72 (54.76, 58.67)	Reference	
Age >18 months	46.59 (44.83, 48.35)	10.1 (7.93, 12.3)	<0.001
Child's sex			
Female	53.25 (51.17, 55.33)	Reference	
Male	48.41 (46.78, 50.03)	4.85 (2.60, 7.10)	<0.001
Childhood illness in the last 15 days			
No	54.90 (52.04, 57.75)	Reference	
Yes	50.50 (48.94, 52.05)	4.40 (1.47, 7.33)	0.003
Access of mass media			
Yes	51.51 (49.88, 53.15)	Reference	
No	48.13 (45.40, 50.86)	3.38 (0.42, 6.34)	0.028

*Differences in the predicted values of stunting between the two groups were calculated using the Stata "adjrr" package

STROBE Statement—Checklist of items that should be included in reports of *cross-sectional studies*

	Item No	Recommendation	Page No
Title and abstract	1	(a) Indicate the study's design with a commonly used term in the title or the abstract	1-2
		(b) Provide in the abstract an informative and balanced summary of what was done and what was found	1-2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	3-6
Objectives	3	State specific objectives, including any prespecified hypotheses	6
Methods			
Study design	4	Present key elements of study design early in the paper	6
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	6
Participants	6	(a) Give the eligibility criteria, and the sources and methods of selection of participants	6
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	6-7
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	6-7
Bias	9	Describe any efforts to address potential sources of bias	20
Study size	10	Explain how the study size was arrived at	7
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	7
Statistical methods	12	(a) Describe all statistical methods, including those used to control for confounding	8-9
		(b) Describe any methods used to examine subgroups and interactions	
		(c) Explain how missing data were addressed	
		(d) If applicable, describe analytical methods taking account of sampling strategy	8-9
		(e) Describe any sensitivity analyses	
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	11
		(b) Give reasons for non-participation at each stage	
		(c) Consider use of a flow diagram	
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	11
		(b) Indicate number of participants with missing data for each variable of interest	
Outcome data	15*	Report numbers of outcome events or summary measures	11
Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	11-14

		(b) Report category boundaries when continuous variables were categorized	
		(c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	11-15
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	
Discussion			
Key results	18	Summarise key results with reference to study objectives	17
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	20
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	17
Generalisability	21	Discuss the generalisability (external validity) of the study results	17-18
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	22

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at <http://www.plosmedicine.org/>, Annals of Internal Medicine at <http://www.annals.org/>, and Epidemiology at <http://www.epidem.com/>). Information on the STROBE Initiative is available at www.strobe-statement.org.