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Nutritional disadvantage and early childhood development: stunting, the Early Childhood Development Index 2030 and wealth-related inequality in 20 low- and middle-income countries

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Abstract

Purpose.

Stunting and delayed early childhood development share determinants but are usually studied separately. We quantified the association between stunting and the Early Childhood Development Index 2030 (ECDI2030), and compared the wealth-related inequality of the two outcomes across 20 countries.

Methods.

Cross-sectional analysis of 20 rounds of the Multiple Indicator Cluster Survey (MICS6/MICS7, 2021–2025) including 71,210 children aged 24–59 months with valid ECDI2030 and height-for-age z-score (HAZ). Stunting was defined as HAZ < -2. The association was estimated with quasi-Poisson models adjusted for age, sex, maternal education, wealth, country, books, stimulation and early childhood education. Inequality was measured with concentration indices, decomposed with the Wagstaff method, and examined across countries by random-effects meta-regression.

Results.

Stunting prevalence was 27.3% and 59.5% of children were on track. Off-track development was more common among stunted children (adjusted prevalence ratio 1.18; 95% confidence interval (CI) 1.15–1.21); within-country differences ranged from − 4.0 to 22.8 percentage points (median 10.9). Each 1-standard-deviation higher HAZ was associated with 0.46 additional ECDI2030 points. Wealth-related inequality favoured the rich for ECDI2030 in all 20 countries (Erreygers 0.067; 95% CI 0.057 to 0.077), with confidence intervals excluding zero in 18 countries; stunting was concentrated among the poor (-0.091; -0.139 to -0.043). Home learning factors contributed most to ECDI2030 inequality; maternal education and urban residence to stunting.

Conclusion.

Stunting is associated with lower developmental attainment, but the two inequalities have different structures. These are associations, not causal effects; nutrition-specific programmes may not close the developmental gap alone; integrated approaches warrant evaluation.

Introduction

Nutrition in the first 1,000 days and through early childhood shapes both physical growth and brain development. Stunting, defined as a height-for-age z-score below − 2 SD of the WHO Child Growth Standards [1], is the most widely used population marker of chronic undernutrition and repeated infection, and remains the indicator for Sustainable Development Goal (SDG) 2.2.1. Stunting reflects a

history of inadequate dietary quality and quantity, enteric and systemic infection, and suboptimal care, and it is associated with impaired cognitive, language and socio-emotional development [2,3,4]. The Early Childhood Development Index 2030 (ECDI2030) was introduced to monitor SDG indicator 4.2.1; it comprises 20 caregiver-reported items covering health, learning and psychosocial well-being in children aged 24–59 months [5,6,7].

The nutritional pathway to development is biologically plausible. Chronic undernutrition limits the availability of iron, iodine, zinc, choline and long-chain polyunsaturated fatty acids that are required for myelination and synaptic development; repeated diarrhoea and environmental enteric dysfunction produce systemic inflammation that further constrains brain growth; and undernourished children may receive less responsive care and fewer learning opportunities because caregiver time and household resources are stretched [2,4]. Observational evidence is consistent with this pathway: a pooled analysis of 15 low- and middle-income countries reported lower developmental scores among stunted children [3]. Stunting should nevertheless be read as a marker of nutritional disadvantage rather than as a direct cause of poor development [4], which is why we quantify association rather than effect.

Both outcomes also follow a socioeconomic gradient, but the two strands of evidence have developed separately. Wealth-related inequality in malnutrition has been quantified in dozens of countries using concentration indices [8,9], while inequality in early childhood development has been described using earlier ECDI instruments [10,11]. Many cross-country analyses have focused on ranking countries by the level of inequality; fewer have tested whether that level is associated with national characteristics, and fewer still have compared the structure of inequality between a nutritional and a developmental outcome in the same children, with the same ranking variable, the same index family and the same decomposition. This separation has three consequences: it is unclear whether the two inequalities share a common structure; policy recommendations are split between nutrition and early childhood development sectors; and it is difficult to distinguish inequality that is driven by the population burden of a condition from inequality that reflects the distribution of opportunity.

We therefore analysed 20 MICS6 and MICS7 surveys conducted between 2021 and 2025, including 71,210 children aged 24–59 months with valid ECDI2030 and anthropometry. We asked three questions. First, what is the magnitude and direction of wealth-related inequality in stunting, in ECDI2030 and in co-occurring stunting and off-track development? Second, which factors contribute to each inequality, and do the structures differ? Third, which country characteristics are associated with between-country differences in inequality? Before addressing these questions we quantified the association between stunting and ECDI2030, because the policy relevance of developmental inequality depends on whether nutritional disadvantage and developmental disadvantage affect the same children.

The study contributes a common inequality framework for a nutritional and a developmental outcome, a country-level test of the determinants of inequality, and a harmonisation approach for ECDI2030 across two questionnaire generations. It does not estimate causal effects, does not test measurement

invariance of ECDI2030 across countries, and does not compare absolute living standards, because the asset index is ranked within each survey.

Materials and methods

Study design and data sources

This was a cross-sectional, secondary analysis of 24 micro-datasets from rounds 6 and 7 of the Multiple Indicator Cluster Survey (MICS) downloaded from the UNICEF MICS archive (mics.unicef.org; accessed 1 November 2026). Surveys were conducted between 2021 and 2025 (Supplementary Table S1). MICS are nationally representative household surveys based on stratified multistage probability samples; each dataset includes household, under-five and women files with sampling weights, primary sampling units (PSUs) and strata. Only the under-five file was used. Reporting follows STROBE [12].

Study sample

Four of the 24 datasets were excluded because both outcomes could not be computed. Jamaica, Nigeria and Trinidad and Tobago do not include anthropometry in the under-five file. Uzbekistan has 3,091 children with valid HAZ and 1,237 with ECDI2030, but the intersection is empty. Nigeria had 16,830 children aged 24–59 months with ECDI2030 but no HAZ, the largest sample loss. The final sample comprised 20 countries.

Eligibility criteria were: age 24–59 months; completed interview (UF17 = 1); ECDI2030 administered; and valid HAZ, defined as HAZFLAG not equal to 1 and |HAZ| of 6 SD or less. The selection flow was 85,559 children aged 24–59 months in the 20 countries, 81,129 with valid HAZ (4,430 excluded, 5.2%), 75,359 with ECDI2030, and 71,210 with both.

ECDI2030 scoring

ECDI2030 contains 20 caregiver-reported items covering health (4 items), learning (11 items) and psychosocial well-being (5 items). Scoring followed the UNICEF technical manual [5] and the MICS7 TC.10.1 syntax: items 1–18 score 1 for a yes response; item 19 scores 1 for any frequency other than daily; item 20 scores 1 for any response other than more or a lot more; items not administered score 0. Children were classified as on track using age-specific cut-offs of 7, 9, 11, 13 and 15 points for the 24–29, 30–35, 36–41, 42–47 and 48–59 month groups.

Because MICS6 and MICS7 use different variable numbering for the same 20 items, mapping was performed by item position: EC6-EC25 in MICS7, EC21-EC40 in MICS6 and ECD1-ECD20 in Benin, where ECD0 is a screening item and is not scored. Only one item is conditional (item 7, asked when item 6 is yes); it scores 0 when not administered. Caregiver-reported items are subject to documented measurement error, which we did not correct at the item level [13].

Anthropometry

HAZ was taken from the derived variable HAZ2, based on the WHO 2006 standards [1]. Stunting was defined as HAZ < -2 and severe stunting as HAZ < -3. Observations flagged by HAZFLAG or with |HAZ| above 6 were excluded.

Outcomes

The primary outcomes were the ECDI2030 score (continuous, age-adjusted) and stunting (binary). HAZ was used as a secondary continuous outcome, with the generalised concentration index as the main measure because the standard concentration index is undefined when mean HAZ is close to zero. The ECDI2030 score was age-adjusted by subtracting the mean of the 6-month age band of the child within each country and adding back the national mean; this removes age-related differences without setting the mean to zero, which would make the concentration index undefined. The co-occurring outcome was defined as stunting with off-track development; because it is uncommon, it was analysed only in the nine countries with at least 100 cases.

Stunting and ECDI2030

The association between stunting and off-track development was estimated with survey-weighted quasi-Poisson regression with a log link, reporting prevalence ratios. Models included age, sex, maternal education and wealth quintile, and country fixed effects to account for between-country differences in prevalence; a second model additionally included children books, early stimulation activities and early childhood education attendance, the factors that contributed most to ECDI2030 inequality. Within-country differences in the prevalence of off-track development between stunted and non-stunted children were also described, because pooled differences mix between-country variation in both stunting and developmental delay.

Ranking variable and covariates

The ranking variable was the household wealth index (wscore), a principal-component asset index [14]. It is not income, is ranked within each survey, and therefore captures relative position only. It was used as a continuous variable to preserve ranking information and to avoid unstable decompositions with a five-level categorical variable.

Covariates were child age and sex, maternal education, ethnicity, region, urban residence, drinking-water source, sanitation, number of books, number of early stimulation activities and attendance at early childhood education. Maternal education used at least six different coding schemes across the 24 datasets and was harmonised into three levels based on variable labels: primary or less; lower or upper secondary, including vocational; and tertiary. Water and sanitation were classified from labels rather than codes, because identical codes have different meanings across countries. Early stimulation was

measured as six activities; MICS7 stores six binary items (EC5A-EC5F) while MICS6 stores multiple-response items with string values, from which any adult involvement was derived before counting. Books were dichotomised as three or more, and early childhood education attendance was taken from UB8, with children younger than 36 months assigned 0 following the MICS7 syntax (a structural zero). Region was collapsed to the four largest regions plus other; ethnicity was included only where at least two groups had 40 or more children (eight countries).

Inequality measures

Five indices were used. The standard concentration index is C = 2 times the weighted covariance of y and R divided by the mean, where R is the weighted fractional rank in the wealth distribution [15]. The generalised concentration index (GCI) omits the mean and is defined when the mean is close to zero. The Erreygers index is E = [4 times the mean divided by (b - a)] times C for bounded variables [16]; for a binary outcome the index is bounded by 4 times the mean times (1 - mean). The slope index of inequality (SII) is the predicted difference between the richest and poorest ranks from a weighted linear regression on rank [17]; the relative index of inequality (RII) is the ratio of predicted prevalence at the poorest versus the richest rank from a weighted logistic regression [15,17]. RII is not hard-bounded by 4 times the mean times (1 - mean), although it remains mean-dependent.

For HAZ, the GCI was the primary measure and the standard concentration index is reported for reference (Supplementary Table S4). For stunting, the Erreygers index was primary, with SII and RII as complementary absolute and relative measures. For the ECDI2030 score, the concentration index on the age-adjusted score was primary and the Erreygers index on the raw 0–20 score served as a bounded reference. For co-occurring stunting and off-track development, the Erreygers index was used.

Post hoc changes. The original protocol specified the standard concentration index for HAZ and the Erreygers index for the ECDI2030 score. The GCI, the Erreygers index for stunting, and the SII and RII were added after inspecting the data, when the standard concentration index of HAZ proved undefined in nine countries and the Erreygers index was found to be bounded by the prevalence. These are therefore post hoc analytical choices, not pre-specified ones, and are declared here and in the reporting checklist.

Decomposition

Contributions were decomposed using the Wagstaff method [18]. Categorical variables were entered as dummy sets and contributions were summed within each factor. Results are reported as percentage contributions with interquartile ranges (IQR) and the number of countries with positive contributions. When the total index is close to zero, percentage contributions become unstable; therefore only medians across countries are interpreted. The decomposition describes the arithmetic contribution of covariates to inequality; it does not identify causal pathways or mediation.

Country-level determinants

Between-country differences were examined by random-effects meta-regression with inverse-variance weights [19,20], estimated by REML with the Hartung-Knapp adjustment for small numbers of units (k = 20) [21], with DerSimonian-Laird estimates for comparison [19]. Multiple testing was controlled by the Benjamini-Hochberg procedure within each outcome family [22]. Six outcomes were modelled: E(stunting), E(ECDI2030), GCI(HAZ), E(co-occurrence), SII(stunting) and RII(stunting). Country characteristics were stunting prevalence and on-track prevalence (computed from the analysis data), log gross domestic product per capita at purchasing power parity (PPP), Human Development Index, Gini coefficient, rural population share, public education spending and survey year. GDP, rural population and education spending were obtained from the World Bank; HDI and Gini from OWID/UNDP. Each characteristic was entered in a separate univariable model; multivariable models were limited to three variables. Gini was available for 15 countries, HDI for 19, education spending for 18 and the co-occurring outcome for nine. Because RII is a ratio, models for RII used log(RII) with standard errors obtained from the confidence limits.

Statistical inference

All estimates accounted for the full survey design, with PSUs nested within strata and survey.lonely.psu set to adjust. Strata containing a single PSU (53% of strata in Lao PDR, 75% in Vanuatu and 9% in Thailand) were pooled by region before resampling, because otherwise between-cluster variance would be zero. Confidence intervals were obtained by cluster bootstrap in which PSUs were resampled with replacement within strata and all children in selected PSUs were retained (B = 2,000 for indices and 1,000 for decompositions; percentile intervals). Design effects were substantial: median design effect for stunting was 1.62 and median effective sample size was 61.8% of the nominal sample. Analyses used all available observations for each estimate. The decomposition used complete cases on the model covariates, which excluded Benin from the book and stimulation terms and Nauru from the urban-residence term; no imputation was performed.

Sensitivity analyses

Eight sensitivity scenarios were run: exclusion of Comoros and Eswatini; restriction to 36–59 months; a stunting threshold of HAZ < -1; ECDI2030 cut-offs shifted by -1 and + 1 point; separate analyses of MICS6 and MICS7; exclusion of the conditional item; and unweighted analyses. Agreement was assessed both by Spearman rank correlation and by the change in pooled estimates. Additional robustness checks included leave-one-country-out meta-regression, decomposition without water and sanitation, comparison of age-adjustment approaches, internal consistency (alpha) and external validation against published 0–59 month stunting estimates.

Software and ethics

Analyses were performed in R 4.6.1 with the survey, haven and data.table packages. MICS data are publicly available and anonymised; the original surveys were approved by national authorities under the MICS protocol, and no additional ethical approval was required. Analysis code is available from the corresponding author.

Results

Sample characteristics and burden of malnutrition and developmental delay

The sample comprised 71,210 children aged 24–59 months in 20 countries (mean age 42.8 months; 51.8% boys). Stunting prevalence was 27.3% (95% CI 26.7–27.8), severe stunting 10.3%, on-track ECDI2030 59.5% (59.0-60.1), and co-occurring stunting with off-track development 15.4% (15.0-15.9). Stunting ranged from 1.7% in Tonga to 50.7% in Afghanistan and on-track development from 30.7% in Afghanistan to 88.7% in Kosovo (Table 1).

Table 1
Sample size and prevalence of stunting, on-track ECDI2030 and co-occurring stunting with off-track development

Country	n	Co-occurring (%)	On track ECDI2030 (%)	Stunting (%)
All 20 countries	71,210	15.4	59.5	27.3
Afghanistan	13,720	37.9	30.7	50.7
Azerbaijan	1,551	3.0	72.6	6.6
Bangladesh	13,433	8.8	71.2	25.1
Benin	7,775	25.8	40.8	39.3
Comoros	1,757	10.8	36.3	14.1
Eswatini	1,337	12.9	47.7	21.2
Fiji	1,202	2.1	82.8	8.1
Kazakhstan	3,874	1.8	75.4	7.0
Kosovo	717	1.1	88.7	4.6
Kyrgyzstan	1,904	4.8	71.3	15.4
Lao PDR	5,231	18.0	59.0	36.2
Montenegro	776	2.2	82.0	6.8
Nauru	172	4.1	76.2	19.8
Nepal	3,881	14.4	63.6	30.5
Thailand	6,806	2.5	80.0	9.6
Tonga	644	0.8	74.2	1.7
Tunisia	1,175	4.1	77.4	12.1
Turkmenistan	1,999	2.5	86.6	9.4
Ukraine	2,101	2.2	72.0	7.3
Vanuatu	1,155	10.2	70.1	29.9

Weighted estimates with design-based 95% confidence intervals (not shown).

Stunting and ECDI2030

Off-track development was reported for 56.6% of stunted children and 34.4% of non-stunted children. The adjusted prevalence ratio was 1.18 (95% CI 1.15–1.21) after adjustment for age, sex, maternal education, wealth and country, and 1.18 (1.15–1.21) after further adjustment for books, early stimulation

and early childhood education. Each 1-standard-deviation higher HAZ was associated with 0.46 additional ECDI2030 points (95% CI 0.41–0.50).

Within countries, the difference in the prevalence of off-track development ranged from − 4.0 to 22.8 percentage points (median 10.9; sample-weighted mean 10.0), and exceeded 20 percentage points only in Tonga (22.8). The pooled difference in Table 2 is larger than the within-country median because it also reflects between-country differences in both outcomes. The gap was 15 percentage points or more in Tonga, Azerbaijan, Montenegro and Nepal, was smallest in Kazakhstan, Ukraine and Kyrgyzstan, and was reversed in Nauru.

Table 2
Prevalence of off-track ECDI2030 by stunting status

Country	n	Not stunted (%)	Stunted (%)	Difference (pp)
All 20 countries	71,210	34.4	56.6	22.2
Tonga	644	25.4	48.3	22.8
Azerbaijan	1,551	26.0	46.2	20.2
Montenegro	776	16.9	32.7	15.8
Nepal	3,881	31.6	47.3	15.7
Turkmenistan	1,999	11.9	26.9	14.9
Comoros	1,757	61.6	76.2	14.6
Lao PDR	5,231	36.1	49.6	13.5
Kosovo	717	10.7	23.8	13.0
Tunisia	1,175	21.1	33.7	12.6
Afghanistan	13,720	63.7	74.8	11.2
Benin	7,775	55.0	65.7	10.7
Eswatini	1,337	50.1	60.6	10.5
Fiji	1,202	16.4	26.5	10.2
Bangladesh	13,433	26.7	35.2	8.5
Thailand	6,806	19.4	25.7	6.2
Vanuatu	1,155	28.2	34.1	5.9
Kyrgyzstan	1,904	28.2	31.2	3.0
Ukraine	2,101	27.8	30.4	2.6
Kazakhstan	3,874	24.5	26.3	1.8
Nauru	172	24.6	20.6	-4.0

Wealth-related inequality in stunting and in ECDI2030

Wealth-related inequality in ECDI2030 was positive in all 20 countries (Erreygers 0.067; 95% CI 0.057 to 0.077), indicating that developmental attainment was concentrated among wealthier children, although confidence intervals excluded zero in 18 countries and between-country heterogeneity was substantial (I2 = 77.5%). Stunting was concentrated among poorer children (Erreygers − 0.091; -0.139 to -0.043; I2 = 97.0%), with the strongest gradients in Lao PDR, Nepal, Benin and Afghanistan. The relative index of

inequality for stunting was 2.05 (1.49 to 2.61). Co-occurring stunting and off-track development was concentrated among the poor in all nine analysable countries (-0.139; -0.187 to -0.090).

Table 3
Wealth-related inequality in stunting, ECDI2030 and HAZ

Country	n	E stunting	E ECDI	GCI HAZ	RII stunting	E co-occurrence
Afghanistan	13,720	-0.212 (-0.242; -0.179)	0.078 (0.067; 0.088)	0.169 (0.145; 0.192)	1.90 (1.71; 2.10)	-0.213 (-0.238; -0.183)
Azerbaijan	1,551	-0.022 (-0.061; 0.021)	0.048 (0.025; 0.073)	0.078 (0.023; 0.135)	1.68 (0.65; 5.04)	–
Benin	7,775	-0.230 (-0.263; -0.198)	0.099 (0.085; 0.113)	0.175 (0.149; 0.200)	2.46 (2.16; 2.83)	-0.204 (-0.232; -0.175)
Bangladesh	13,433	-0.138 (-0.157; -0.119)	0.059 (0.051; 0.066)	0.132 (0.118; 0.145)	2.32 (2.05; 2.61)	-0.076 (-0.090; -0.062)
Comoros	1,757	-0.141 (-0.198; -0.088)	0.102 (0.070; 0.136)	0.137 (0.089; 0.187)	4.82 (2.75; 8.88)	-0.124 (-0.175; -0.074)
Fiji	1,202	-0.054 (-0.097; -0.011)	0.034 (0.009; 0.059)	0.165 (0.111; 0.217)	2.78 (1.24; 6.56)	–
Kazakhstan	3,874	0.005 (-0.017; 0.029)	0.072 (0.054; 0.091)	0.059 (0.031; 0.089)	0.91 (0.56; 1.45)	–
Kyrgyzstan	1,904	-0.080 (-0.129; -0.032)	0.037 (0.012; 0.061)	0.116 (0.077; 0.157)	2.20 (1.39; 3.57)	–
Lao PDR	5,231	-0.348 (-0.390; -0.307)	0.098 (0.079; 0.115)	0.274 (0.244; 0.302)	4.70 (3.87; 5.76)	-0.244 (-0.280; -0.208)
Montenegro	776	0.017 (-0.033; 0.078)	0.043 (-0.051; 0.119)	-0.025 (-0.191; 0.099)	0.69 (0.19; 2.17)	–
Nepal	3,881	-0.249 (-0.292; -0.201)	0.104 (0.086; 0.123)	0.226 (0.194; 0.258)	3.60 (2.74; 4.70)	-0.160 (-0.194; -0.125)
Nauru	172	0.028 (-0.131; 0.175)	0.040 (-0.050; 0.123)	0.002 (-0.102; 0.102)	0.81 (0.24; 2.89)	–
Eswatini	1,337	-0.165 (-0.221; -0.112)	0.066 (0.042; 0.090)	0.171 (0.134; 0.210)	3.34 (2.24; 5.10)	-0.123 (-0.172; -0.072)

Country	n	E stunting	E ECDI	GCI HAZ	RII stunting	E co-occurrence
Thailand	6,806	-0.029 (-0.052; -0.005)	0.061 (0.037; 0.082)	0.081 (0.045; 0.117)	1.57 (1.08; 2.26)	-0.012 (-0.024; -0.001)
Turkmenistan	1,999	-0.059 (-0.097; -0.024)	0.048 (0.028; 0.067)	0.054 (0.015; 0.093)	2.60 (1.50; 4.66)	–
Tunisia	1,175	0.071 (0.013; 0.125)	0.050 (0.022; 0.080)	-0.048 (-0.110; 0.013)	0.41 (0.21; 0.85)	–
Ukraine	2,101	-0.080 (-0.133; -0.031)	0.068 (0.029; 0.106)	0.029 (-0.029; 0.091)	5.73 (1.99; 16.71)	–
Vanuatu	1,155	-0.106 (-0.174; -0.032)	0.043 (0.012; 0.076)	0.036 (-0.039; 0.105)	1.71 (1.17; 2.46)	-0.096 (-0.147; -0.049)
Kosovo	717	0.001 (-0.038; 0.042)	0.086 (0.054; 0.121)	0.059 (-0.011; 0.128)	0.98 (0.28; 4.31)	–
Tonga	644	0.009 (-0.009; 0.029)	0.050 (0.001; 0.100)	0.103 (0.044; 0.159)	0.47 (0.09; 2.94)	–

What drives the two inequalities

For ECDI2030, the largest contributions came from the home learning environment: books (median 16.5%), early stimulation activities (12.7%), maternal education (10.8%), early childhood education attendance (5.5%) and urban residence (5.5%). Water and sanitation contributed only 1–2%. For stunting, the largest contributions were maternal education (10.5%), urban residence (9.2%), improved sanitation (4.6%), books (3.8%), region (3.0%) and improved water (2.8%). The interquartile ranges for sanitation and water included zero. Medians are not additive and should not be summed. By developmental domain, inequality was largest for the learning domain, although that domain contains 11 of the 20 items (Supplementary Table S3).

Table 4
Percentage contribution of factors to wealth-related inequality

Factor	ECDI2030: median (IQR)	ECDI: countries > 0	Stunting: median (IQR)	Stunting: countries > 0
≥ 3 children's books	16.5 (7.9 to 26.3)	19/19	3.8 (0.6 to 16.0)	15/19
≥ 4 stimulation activities	12.7 (4.8 to 21.6)	18/19	1.0 (-4.1 to 5.7)	10/19
Maternal education	10.8 (2.3 to 24.1)	17/20	10.5 (2.1 to 19.1)	16/20
Early childhood education	5.5 (0.4 to 17.4)	15/20	1.4 (-1.1 to 4.7)	12/20
Urban residence	5.5 (2.1 to 17.1)	16/19	9.2 (0.8 to 24.1)	14/19
Ethnicity	1.8 (0.8 to 2.7)	6/8	1.1 (-6.7 to 28.6)	4/8
Improved sanitation	1.7 (0.3 to 12.7)	15/20	4.6 (-2.7 to 13.6)	15/20
Improved water	1.2 (-0.9 to 3.9)	12/20	2.8 (-2.2 to 8.0)	15/20
Region	0.3 (-9.2 to 10.1)	10/20	3.0 (0.3 to 13.2)	15/20
Child age	0.1 (-0.0 to 0.8)	14/20	0.1 (-0.6 to 0.6)	11/20
Male	-0.4 (-1.0 to 0.2)	7/20	0.1 (-0.2 to 1.8)	12/20

Number of countries with positive contributions is below 20 where a factor is unavailable: books and stimulation activities in Benin, and urban residence in Nauru. IQR, interquartile range.

Country characteristics associated with inequality

On the absolute scale, stunting inequality was strongly associated with the national burden of stunting (beta = -0.006 per percentage point; p < 0.001; R2 = 70.4%), with HDI (p < 0.001; R2 = 63.7%) and with log GDP (p 0.003). ECDI2030 inequality was moderately associated with on-track prevalence (R2 = 37.6; p 0.007) and HDI (R2 = 37.9). On the logarithmic scale, however, RII was not associated with stunting prevalence (beta = 0.015; p 0.068; R2 = 0.0%) or HDI (p 0.022; R2 = 0.0%), and no association remained significant after false-discovery-rate control for any outcome. Gini and rural population share were not associated with any outcome (Table 5).

Table 5
Univariable random-effects meta-regression of inequality indices on country characteristics

Country characteristic	E ECDI2030	E co-occurrence	E stunting	GCI HAZ	RII stunting	SII stunting
Stunting prevalence (%)	0.001 (0.022)	-0.005 (0.006)	-0.006 (< 0.001)	0.003 (0.006)	0.040 (0.048)	-0.010 (< 0.001)
On-track ECDI2030 (%)	-0.001 (0.007)	0.003 (0.051)	0.004 (< 0.001)	-0.003 (0.011)	-0.034 (0.048)	0.007 (< 0.001)
log gross domestic product per capita at purchasing power parity (PPP)	-0.011 (0.10)	0.063 (0.082)	0.087 (0.003)	-0.054 (0.020)	-0.567 (0.11)	0.131 (0.003)
HDI	-0.128 (0.009)	0.681 (0.005)	0.821 (< 0.001)	-0.501 (0.004)	-5.761 (0.028)	1.231 (< 0.001)
Gini ×100	0.000 (0.64)	-0.000 (0.97)	-0.004 (0.38)	0.003 (0.42)	0.059 (0.34)	-0.006 (0.38)
Rural population (%)	0.000 (0.98)	-0.001 (0.77)	-0.002 (0.086)	0.002 (0.067)	0.019 (0.17)	-0.003 (0.086)
Public education spending (% GDP)	-0.008 (0.011)	0.006 (0.71)	0.034 (0.020)	-0.028 (0.009)	-0.371 (0.016)	0.051 (0.020)
Survey year	-0.001 (0.83)	0.010 (0.65)	0.025 (0.18)	-0.023 (0.097)	-0.256 (0.28)	0.037 (0.18)

REML with Hartung-Knapp adjustment; p values in parentheses; dash indicates insufficient data. RII was modelled on the logarithmic scale.

Sensitivity analyses

Spearman rank correlations with the main specification were at least 0.78 across all scenarios (Supplementary Table S2), but rank correlation is insensitive to changes in the pooled level, so Table S2 also reports the change in pooled estimates. The largest change followed redefining stunting as HAZ < -1 (pooled E(stunting) from to -0.132). Excluding Comoros and Eswatini changed the pooled estimate of E(stunting) by 0.007, omitting weights by 0.004 and restricting to 36–59 months by 0.003. Estimates did not differ detectably between MICS6 and MICS7 for stunting inequality (-0.107 vs -0.062; p = 0.35), but the comparison is based on 12 and 8 countries and has limited power. After exclusion of water and sanitation from the decomposition, contributions were essentially unchanged (books 16.8%; stimulation 14.4%; maternal education 11.4%), although the ranking variable still included these items. The concentration index of the raw and age-adjusted ECDI2030 score was correlated at r = 0.98. Median alpha was 0.84, and the mean Spearman correlation of item-difficulty profiles across countries was 0.88. Compared with published 0–59 month stunting estimates for 15 countries, our 24–59 month estimates correlated at r = 0.98 (mean difference plus 1.9 percentage points).

Discussion

Principal findings

In 71,210 children from 20 low- and middle-income countries, stunting was associated with a higher prevalence of off-track development (adjusted prevalence ratio 1.18), and each 1-SD higher HAZ with 0.46 additional ECDI2030 points. The within-country difference varied widely (median 10.9 percentage points), so the pooled figure should not be read as a universal gap. Wealth-related inequality in ECDI2030 was positive in every country, although confidence intervals excluded zero in 18, whereas inequality in stunting varied widely and was concentrated among the poor mainly where stunting was common. The two inequalities were generated by different factors: the home learning environment for development, and maternal education and urban residence for stunting, with smaller contributions from sanitation and water.

Nutritional determinants of early childhood development

Our results are consistent with the literature linking undernutrition to developmental delay [5,3,4]. Nutrient availability, infection and inflammation, and caregiving are plausible mechanisms [5,2]. We did not test mediation, and the decomposition of ECDI2030 inequality cannot identify whether caregiving mediates the stunting-development association; the contribution of stimulation and books to inequality is compatible with, but does not demonstrate, that pathway.

The size of the association should be read on the ratio scale rather than on the pooled absolute difference. After adjustment for age, sex, maternal education, wealth and country, and further adjustment for books, stimulation and early childhood education, the prevalence ratio remained 1.18. This indicates that the association is not explained by the socioeconomic and home-learning covariates we measured, but it does not establish an independent causal effect, because unmeasured confounding remains possible and the design is cross-sectional.

Why developmental inequality is consistent in direction while stunting inequality is not

The contrast between the two outcomes is the central finding. ECDI2030 inequality was positive in all 20 countries, with a pooled Erreygers index of 0.067 and high between-country heterogeneity ($I^2 = 77.5\%$); confidence intervals excluded zero in 18 countries. Stunting inequality was also mostly pro-poor but varied far more ($I^2 = 97.0\%$) and was close to zero in countries where stunting had become uncommon. A plausible explanation is that the home learning environment is a consumption good that scales with household resources in every economy, rich or poor, whereas stunting depends on the local epidemiology of infection, water and sanitation, and health-system coverage, which differ substantially across countries and can be modified by public policy.

A methodological caveat applies to the stunting results. The Erreygers index for a binary outcome is bounded by 4 times the mean times (1 - mean), so its maximum possible magnitude is smaller where stunting is rare. The strong association between E(stunting) and national stunting prevalence (R2 = 70.4%) is therefore partly a property of the scale. When we modelled log(RII), which is not hard-bounded in this way, no association with stunting prevalence remained (p 0.068). The appropriate conclusion is not that inequality and burden are unrelated, but that the absolute gradient is larger than the relative gradient; policy statements should specify which scale they refer to.

Implications for public nutrition policy

Three implications follow, all of which are tentative given the cross-sectional design. First, stunting identifies children at higher probability of being off track, and this association persisted after adjustment for measured socioeconomic and home-learning factors. Stunting may therefore be useful for targeting, but the results do not show that reducing stunting would reduce developmental delay; the literature indicates that stunting is a marker of disadvantage rather than a direct cause of poor development [4].

Second, the factors that contributed most to ECDI2030 inequality were books, stimulation, early childhood education and maternal education, none of which is addressed by typical nutrition programmes. The Nurturing Care Framework integrates nutrition with responsive caregiving and early learning [23]; our results are consistent with that integration but do not test it. Integrated programmes that combine nutrition support with parenting and access to books should be evaluated for equity effects rather than assumed to be superior.

Third, sanitation and water contributed modestly to stunting inequality, with interquartile ranges that included zero. They are recognised nutrition-sensitive sectors [24,25], but trial evidence on linear growth has been inconsistent, and our decomposition cannot establish that improving them would change the distribution of stunting. The overlap between these covariates and the wealth index also means that their contributions may be partly structural, and removing them from the decomposition does not remove them from the ranking variable.

Comparison with previous work

Our stunting results agree with multi-country analyses showing that undernutrition is concentrated among poorer households in most settings [8,9], and with evidence that the association between stunting and mean burden depends on the inequality measure used [8]. The developmental results extend earlier descriptions of socioeconomic gradients in ECDI [10,11] by showing that the gradient persists in the ECDI2030 era. The co-occurrence findings are consistent with Jeong et al. [26], who reported higher co-occurrence of stunting and off-track development in poorer households. Unlike analyses that focus on prevalence [14] or on individual-level associations [3], we compare the structure of inequality between the two outcomes using a common framework. Emerson and Llewellyn [27] used ECDI2030 to identify cognitive delay at the individual level, which complements our population-level focus on inequality.

Strengths and limitations

Strengths include a large, harmonised sample from 20 countries; design-based inference with cluster bootstrap; concurrent measurement of anthropometry and ECDI2030 in the same children; a common wealth ranking; and extensive sensitivity and robustness analyses.

Several limitations must be acknowledged. The design is cross-sectional, so all associations are concurrent and cannot be interpreted causally. ECDI2030 is caregiver-reported and subject to floor and ceiling effects, cultural expectations about developmental milestones, and the Angoff-derived cut-offs; measurement invariance across 20 languages and contexts was not formally tested, and internal consistency and item-difficulty correlations are only indirect checks. The asset index is relative within countries, so cross-country comparisons concern inequality, not living standards. Four countries were excluded, including Nigeria with 16,830 children with ECDI2030 but no anthropometry; if their inequality differs systematically, pooled estimates would be biased. Surveys span 2021 to 2025, so between-country differences are partly temporal. Effective sample sizes were low (median 61.8% of nominal for stunting), widening confidence intervals in small countries. Assigning 0 for early childhood education attendance to children younger than 36 months is a structural zero and may bias that contribution. Decomposition assumes linear relationships, percentage contributions are unstable when the total index is near zero (which is why the HAZ decomposition is reported only in Supplementary Table S5), and the decomposition cannot identify mediation. The analytical framework includes several post hoc choices, described above. Finally, many models were fitted across 20 countries; false-discovery-rate control was applied, but residual false positives cannot be excluded.

Conclusion

In 20 low- and middle-income countries, stunting was associated with a higher prevalence of off-track early childhood development, and wealth-related inequality in ECDI2030 was positive in every country, although confidence intervals excluded zero in 18. The factors that contributed most to developmental inequality were those of the home learning environment, whereas stunting inequality was driven mainly by maternal education and urban residence, with smaller contributions from sanitation and water. These are associations from a cross-sectional design and do not establish causal effects. Nutrition-specific programmes remain essential for growth, but closing the developmental gap may require integrating nutrition with early learning and responsive caregiving; this hypothesis should be tested rather than assumed. Surveillance that measures nutrition and development in the same children, and that reports both absolute and relative inequality, would make these trade-offs visible to policy-makers.

Declarations

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Competing interests. The authors have no relevant financial or non-financial interests to disclose.

Ethics approval. This study used publicly available, anonymised secondary data from the UNICEF MICS programme. Each original survey was approved by the relevant national ethics committee under the MICS protocol. No additional approval was required for this secondary analysis.

Consent to participate. Informed consent was obtained by the original survey teams from all participants or their guardians. No identifiable information was accessed.

Consent for publication. Not applicable.

Data availability. The datasets analysed are publicly available from the UNICEF MICS archive (https://mics.unicef.org). Analysis code is available from the corresponding author on reasonable request.

Author contributions. L.N.K.L. and T.N.N. conceived the study. L.N.K.L. designed the analytical framework, curated and harmonised the datasets, performed the statistical analyses, produced the tables and figures, and wrote the first draft of the manuscript. T.N.N. contributed to data curation and validation, interpretation of the results, and critical revision of the manuscript. Both authors read and approved the final version and agree to be accountable for all aspects of the work. Full names and CRediT roles are listed on the title page.

Use of artificial intelligence. Artificial intelligence tools were used solely to assist with literature searching, and with checking the semantics and English grammar of the manuscript. They were not used to generate data, results or substantive scientific content, and the authors take full responsibility for the final text.

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Figures

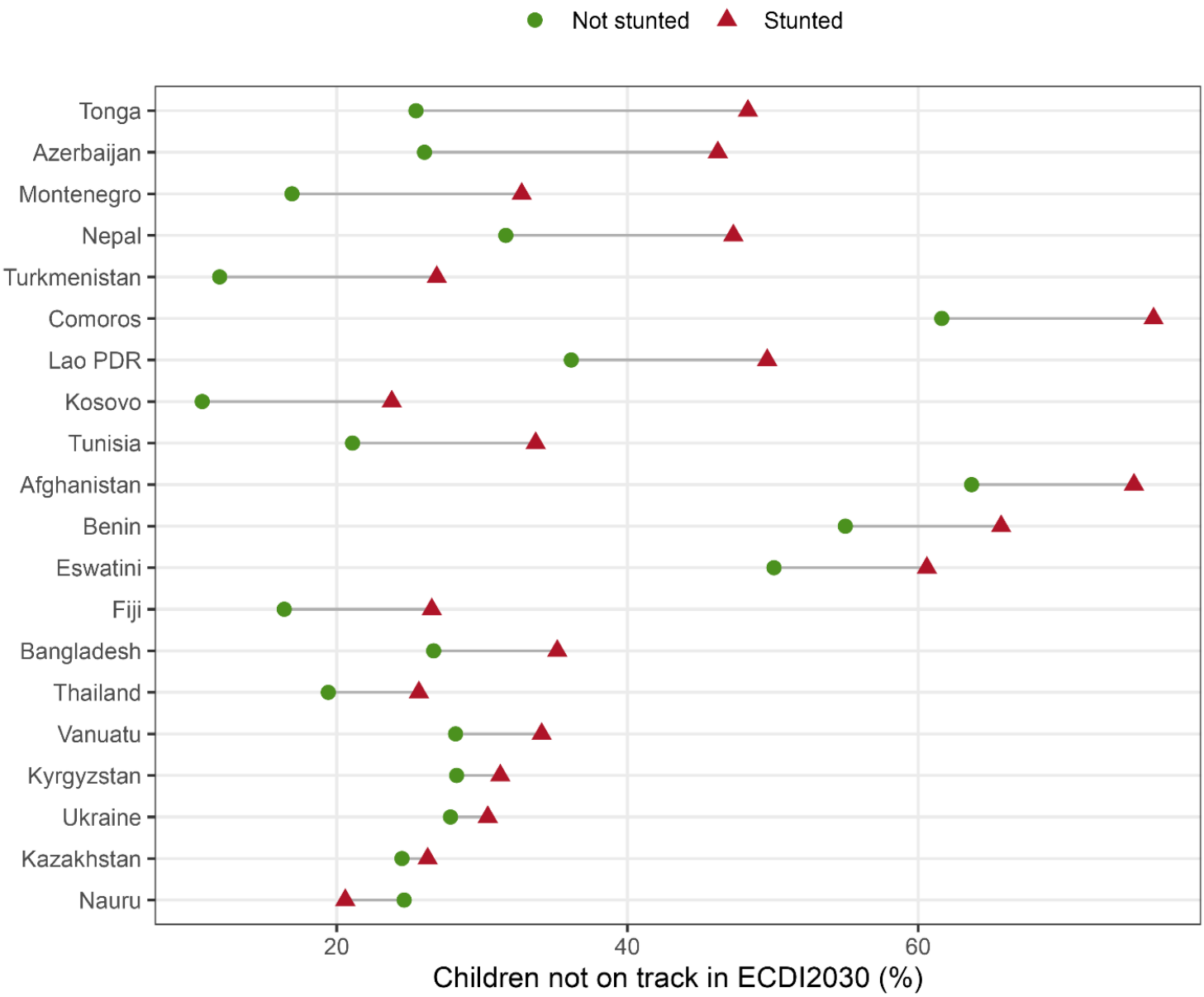

Figure 1

Prevalence of off-track ECDI2030 among stunted and non-stunted children, by country. Countries are ordered by the absolute difference.

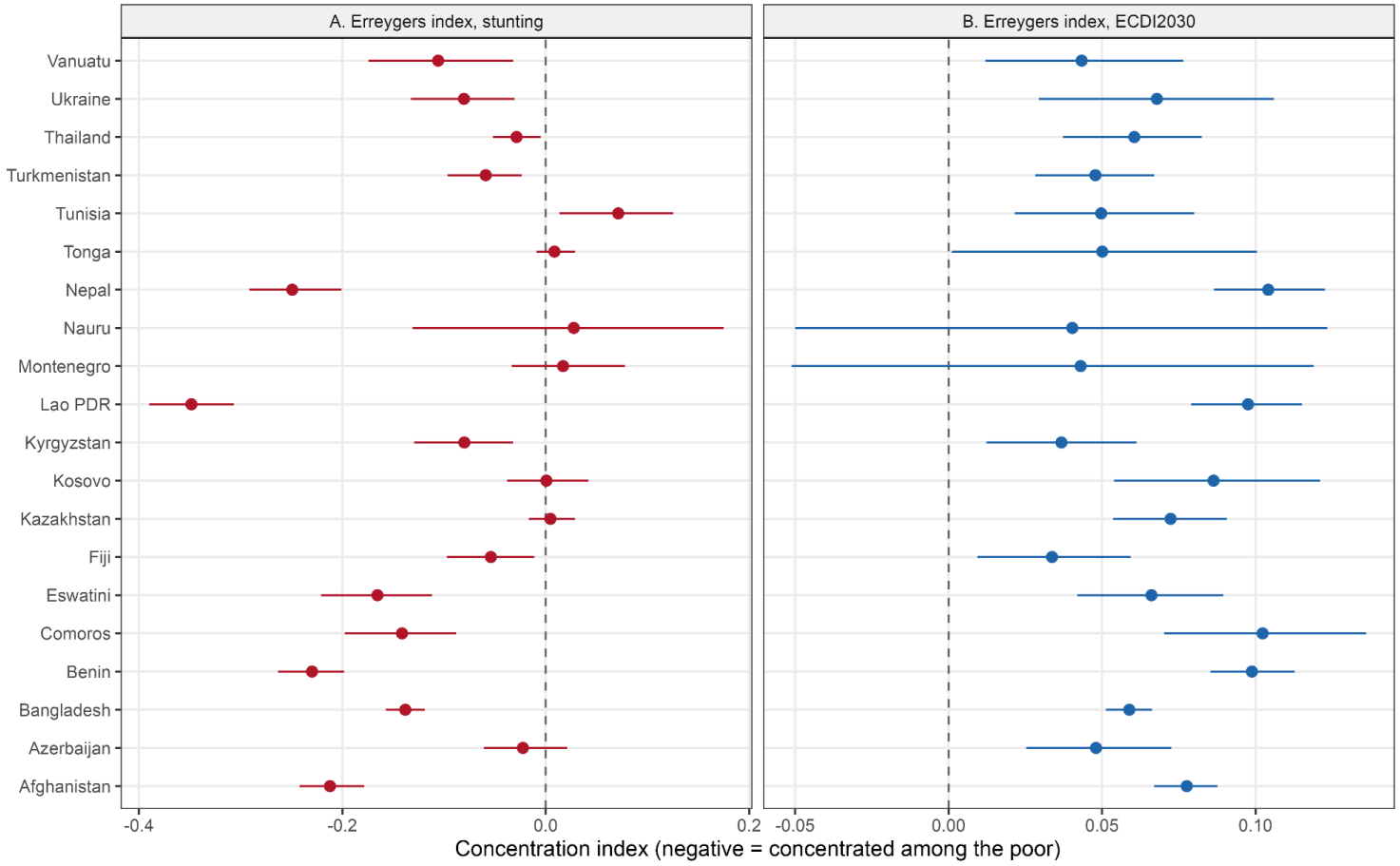

Figure 2

Erreygers indices for stunting (A) and ECDI2030 (B) by country, with cluster-bootstrap 95% confidence intervals.

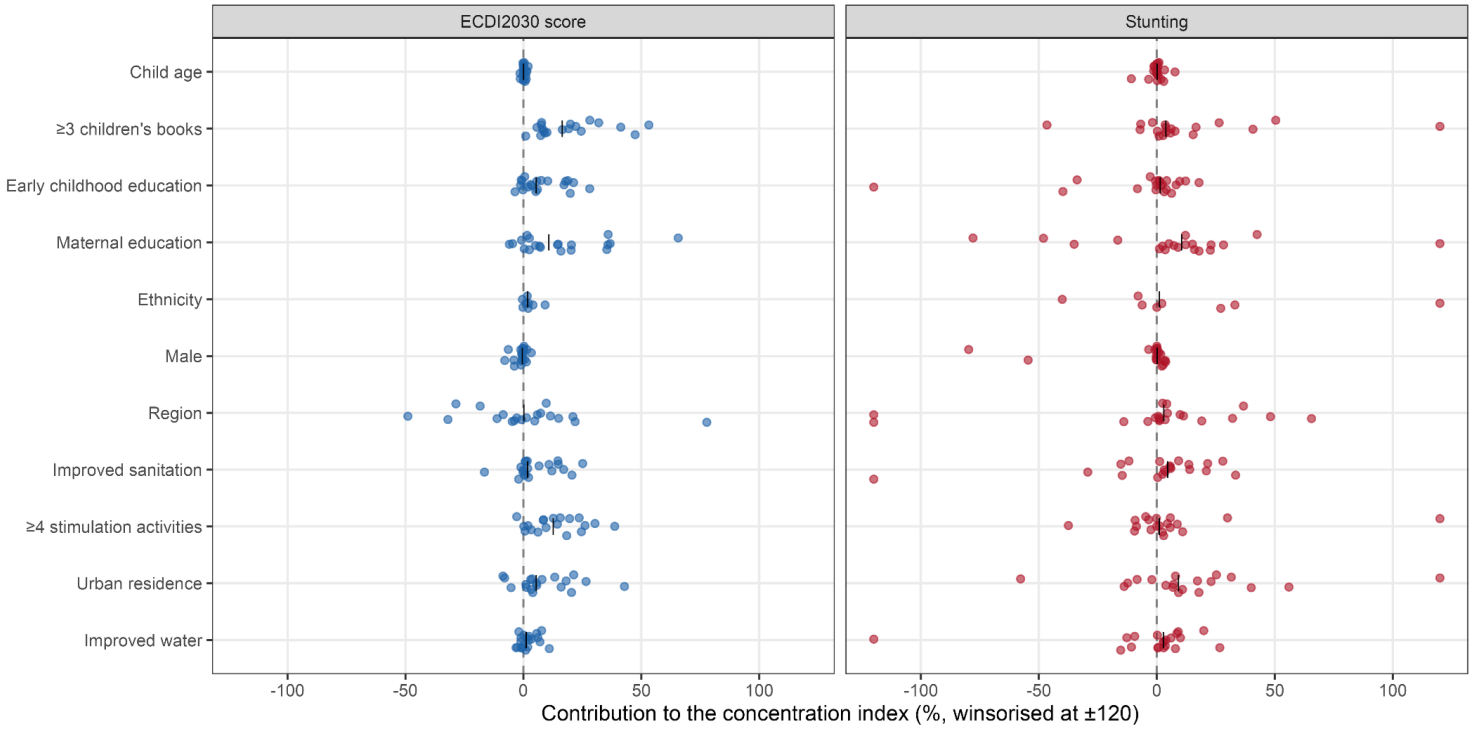

Figure 3

Distribution of percentage contributions across the 20 countries (each point is a country; horizontal bar is the median; winsorised at plus or minus 120%).

Supplementary Files

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- NutrireSupplementary.docx