

Supplementary Material

Household and Community Heterogeneity in Childhood Stunting in Ghana

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This supplementary file provides additional sample validation, household-structure summaries, sampler diagnostics, variance decomposition, sensitivity analyses, posterior predictive checks, PSIS-LOO results, and descriptive figures accompanying the preprint.

1 Analytic sample validation

The reconstructed analytic sample contained 4,928 children, including 927 who were stunted, across 3,545 households and 616 survey communities. The rescaled DHS sampling weights summed to 4,292.97, reproducing the official weighted height-for-age denominator of 4,293 after rounding. Survey-weighted stunting prevalence was 17.39%.

2 Household structure

Most households contributed a single eligible child: 2,398 of 3,545 households had one child in the analytic sample. A further 951 contributed two children, 165 contributed three, 26 contributed four, four contributed five, and one contributed nine. Overall, 1,147 households contained more than one eligible child, and about 51.3% of analysed children lived in these multi-child households.

3 Extended Model 3 diagnostics

The strengthened Model 3 diagnostic run used eight independent chains, each with 500 warmup and 500 retained draws, for 4,000 posterior draws.

Table S1: Sampler diagnostics for the strengthened Model 3 run

Chain	Divergences	BFMI	Max tree depth	Mean acceptance
1	0	0.519	6	0.946
2	0	0.655	6	0.943
3	0	0.530	6	0.935
4	0	0.660	6	0.935
5	0	0.514	6	0.937
6	0	0.562	6	0.937
7	0	0.534	6	0.941
8	0	0.651	6	0.929

No chain reached the configured maximum tree depth. Fixed effects had $\hat{R}$ values near 1.00 and large effective sample sizes. The community and household standard deviations remained slower-mixing, with $\hat{R}$ approximately 1.021 and 1.018 and bulk ESS approximately 544 and 524, respectively. Because the two

variance-component $\hat{R}$ values remain above the commonly used 1.01 guideline, their exact interval endpoints should be interpreted more cautiously than the fixed-effect intervals; the household-versus-community ordering remained stable across the model sequence and sensitivity analyses.

4 Variance decomposition

Table S2: Posterior variance summaries from the strengthened Model 3 run

Quantity	Median	2.5th percentile	97.5th percentile
Community SD	0.389	0.067	0.610
Household SD	1.234	0.940	1.535
Community ICC	0.030	0.001	0.073
Household VPC	0.307	0.203	0.406
Same-household correlation	0.339	0.236	0.436
Community MOR	1.45	1.07	1.79
Household MOR	3.24	2.45	4.32

5 Prior sensitivity

The main fixed-effect estimates changed little under tighter and wider weakly regularizing priors. The posterior median OR for unimproved water was about 1.48 under both alternatives, compared with 1.50 in the primary model. For higher maternal education, the corresponding ORs were about 0.44 under the tighter prior, 0.37 in the strengthened primary run, and 0.35 under the wider prior.

Table S3: Prior-sensitivity summaries for selected fixed effects

Prior	Comparison	Median OR	2.5th percentile	97.5th percentile
Tighter	Male vs female	1.45	1.21	1.76
Tighter	Unimproved water	1.48	1.14	1.88
Tighter	Unimproved sanitation	1.15	0.91	1.47
Tighter	Higher maternal education	0.44	0.26	0.70
Wider	Male vs female	1.52	1.25	1.85
Wider	Unimproved water	1.48	1.12	2.06
Wider	Unimproved sanitation	1.10	0.84	1.43
Wider	Higher maternal education	0.35	0.18	0.66

6 Survey-weight sensitivity

For the survey-weight sensitivity analysis, DHS household-member weights were rescaled to have mean one and then used to weight the Bernoulli log-likelihood contributions. The water estimate became less precise (OR 1.38, 95% posterior interval 0.90–2.07), although the posterior probability that its coefficient was positive remained about 0.94. The directions of the sex, age, richest-versus-poorest wealth, and higher maternal-education estimates were unchanged.

7 Missing maternal-education sensitivity

A full-sample sensitivity model retained all 4,928 children by treating missing maternal education as a separate category. The main pattern was similar: unimproved water OR 1.35 (1.01–1.74), higher maternal

Table S4: Survey-weight pseudo-posterior sensitivity

Comparison	Median OR	2.5th percentile	97.5th percentile
Male vs female	1.53	1.22	1.97
Age 24–35 vs 0–5 months	3.45	2.20	5.38
Richest vs poorest	0.30	0.16	0.61
Unimproved water	1.38	0.90	2.07
Unimproved sanitation	1.14	0.82	1.65
Higher maternal education	0.31	0.15	0.61

education OR 0.38 (0.22–0.63), and a much less precise estimate for the missing-education category, OR 1.11 (0.80–1.53).

Table S5: Full-sample missing-maternal-education sensitivity

Comparison	Median OR	2.5th percentile	97.5th percentile
Male vs female	1.44	1.21	1.70
Age 24–35 vs 0–5 months	2.90	2.11	4.10
Richest vs poorest	0.39	0.24	0.66
Unimproved water	1.35	1.01	1.74
Unimproved sanitation	1.15	0.90	1.48
Missing maternal education vs none	1.11	0.80	1.53
Higher maternal education vs none	0.38	0.22	0.63

8 Age functional-form sensitivity

Replacing the six age categories with a cubic B-spline had little effect on the main estimates:

Table S6: Selected age-spline sensitivity results

Comparison	Median OR	2.5th percentile	97.5th percentile
Male vs female	1.53	1.27	1.86
Richest vs poorest	0.35	0.19	0.61
Unimproved water	1.49	1.12	2.00
Unimproved sanitation	1.11	0.86	1.44
Higher maternal education	0.37	0.20	0.67

9 Detailed WASH sensitivity

10 Independent GEE robustness checks

As an independent check, we fitted logistic generalized estimating equation (GEE) models with exchangeable working correlation at the household and community levels. The estimated working correlation was 0.154 for household clustering and 0.024 for community clustering. These values are not Bayesian ICCs; they are used only to check whether the stronger within-household dependence appears under a different modelling framework.

The GEE fixed-effect estimates were similar to the Bayesian sensitivity results. In the binary-WASH specification, unimproved water had OR 1.40 (1.12–1.74). Replacing categorical age with a cubic spline

Table S7: Selected detailed-WASH sensitivity results

Comparison	Median OR	2.5th percentile	97.5th percentile
Surface water vs improved	1.52	1.10	2.08
Unprotected groundwater vs improved	1.41	0.90	2.21
Open defecation vs improved sanitation	1.23	0.92	1.64
Other unimproved vs improved sanitation	0.93	0.68	1.31
Higher maternal education vs none	0.38	0.20	0.67

gave OR 1.39 (1.12–1.74). With detailed WASH coding, surface water had OR 1.43 (1.12–1.83), while the estimate for unprotected groundwater was less precise at OR 1.34 (0.93–1.94).

Table S8: Selected independent GEE robustness checks

Specification / comparison	OR	Lower 95% CI	Upper 95% CI
Binary WASH: unimproved water	1.40	1.12	1.74
Spline age: unimproved water	1.39	1.12	1.74
Detailed WASH: surface water	1.43	1.12	1.83
Detailed WASH: unprotected groundwater	1.34	0.93	1.94

11 Predictive checks and PSIS-LOO

Posterior predictive checks reproduced the unweighted overall and age-specific prevalence in the 4,503-child complete-case Model 3 sample. These observed values are distinct from the survey-weighted descriptive prevalence reported for the 4,928-child core sample. For the strengthened Model 3 run, PSIS-LOO produced ELPD -2011.47 , with maximum Pareto $k = 0.69$ and no observations above 0.70 . Harmonized Model 2 had five observations above Pareto $k = 0.70$ and none above one. The ELPD difference favouring Model 3 was only 0.92 with SE 3.38 , indicating effectively equivalent predictive performance.

Table S9: Final observation-level PSIS-LOO comparison

Quantity	Model 2	Model 3
ELPD-LOO	-2012.39	-2011.47
Observations with Pareto $k > 0.70$	5	0
Observations with Pareto $k > 1.00$	0	0

Model 3 minus Model 2 ELPD difference = 0.92 (SE 3.38). The comparison is conditional observation-level prediction within the observed hierarchy.

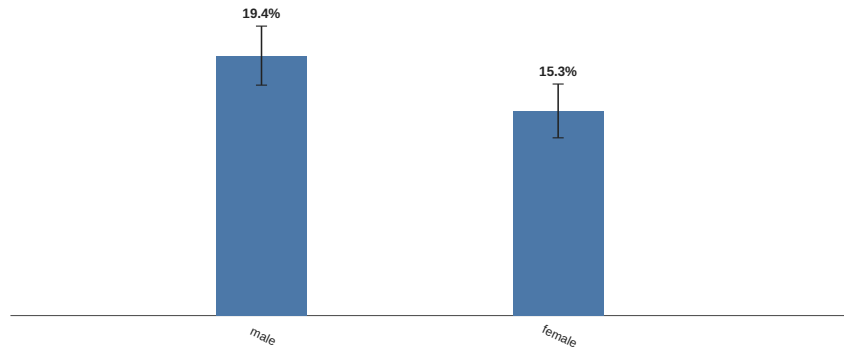
12 Additional descriptive figures

13 Additional hierarchical-model figures

14 Model-sequence variance summary

15 Selected final-model parameter diagnostics

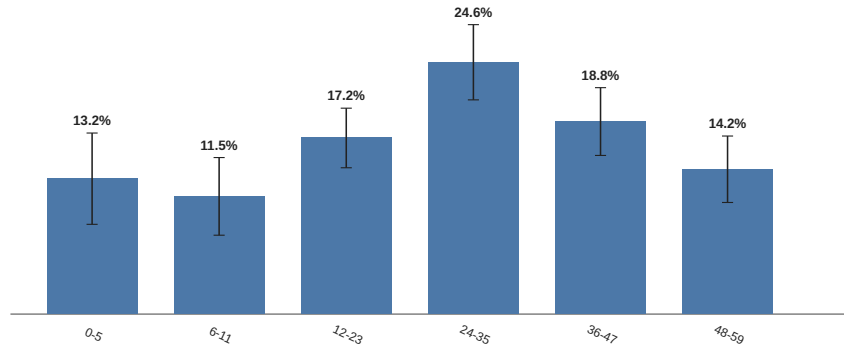
Weighted stunting prevalence by sex



Bars show weighted prevalence; whiskers show 95% design-based confidence intervals.

Figure S1: Survey-weighted stunting prevalence by child sex.

Weighted stunting prevalence by child age



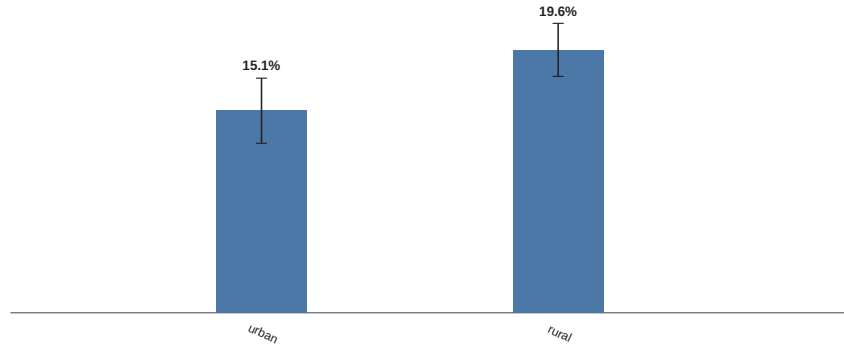
Bars show weighted prevalence; whiskers show 95% design-based confidence intervals.

Figure S2: Survey-weighted stunting prevalence by child age group.

Table S10: Selected variance quantities across Models 1–3

Model	Community SD	Household SD	Community ICC	Household VPC	Community MOR	Household MOR
Model 1	0.416	1.066	0.038	0.246	1.49	2.76
Model 2 full sample	0.390	1.100	0.033	0.260	1.45	2.86
Model 2 harmonized (same 4,503-child sample as Model 3)	0.391	1.222	0.031	0.301	1.45	3.21
Model 3, locked eight-chain	0.389	1.234	0.030	0.307	1.45	3.24

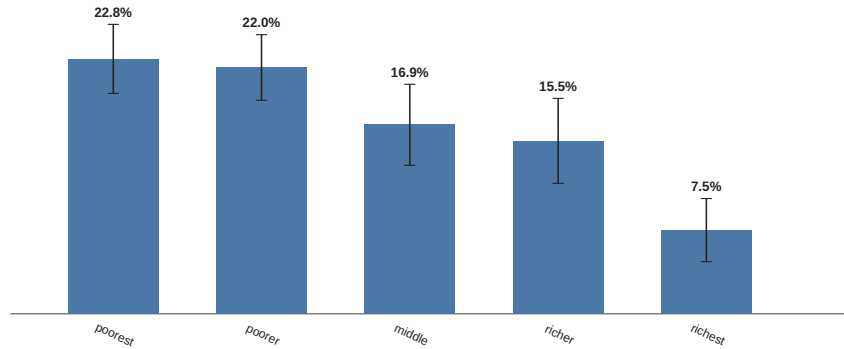
Weighted stunting prevalence by residence



Bars show weighted prevalence; whiskers show 95% design-based confidence intervals.

Figure S3: Survey-weighted stunting prevalence by place of residence.

Weighted stunting prevalence by household wealth



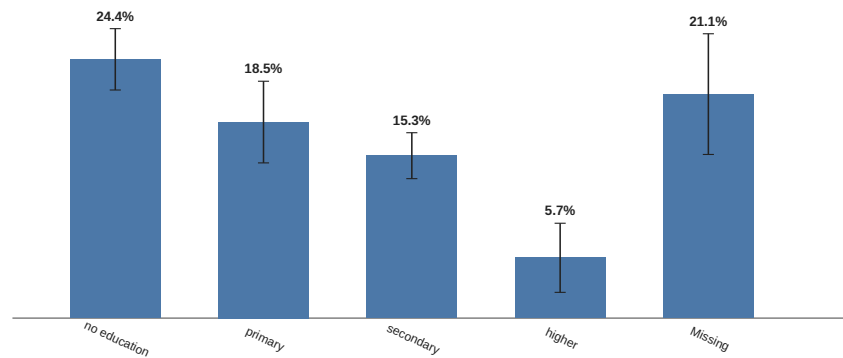
Bars show weighted prevalence; whiskers show 95% design-based confidence intervals.

Figure S4: Survey-weighted stunting prevalence by household wealth quintile.

Table S11: Selected parameter diagnostics from the locked eight-chain Model 3

Parameter	Median	2.5th percentile	97.5th percentile	$\hat{R}$	Bulk ESS
Intercept	-2.598	-3.276	-1.955	1.003	1,830
Community SD	0.389	0.067	0.610	1.021	544
Household SD	1.234	0.940	1.535	1.018	524
Male coefficient	0.409	0.218	0.599	1.001	6,871
Age 24–35 coefficient	1.070	0.721	1.437	1.001	3,302
Richest wealth coefficient	-1.020	-1.622	-0.449	1.000	3,670
Unimproved-water coefficient	0.404	0.138	0.687	1.001	5,444
Unimproved-sanitation coefficient	0.112	-0.155	0.377	1.002	6,098
Higher maternal education coefficient	-1.003	-1.624	-0.433	1.002	6,030

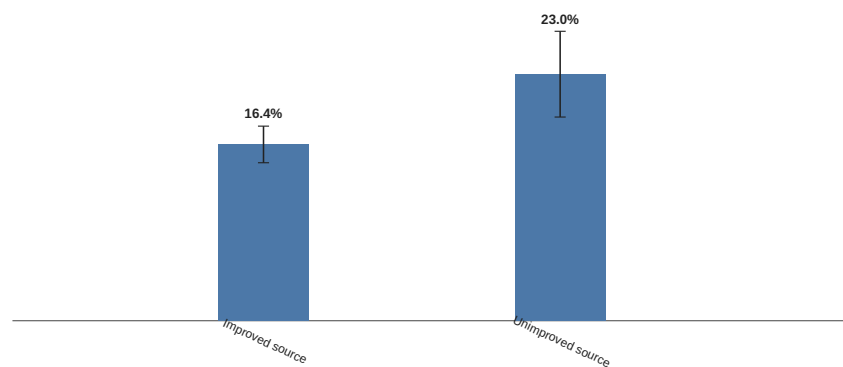
Weighted stunting prevalence by maternal education



Bars show weighted prevalence; whiskers show 95% design-based confidence intervals.

Figure S5: Survey-weighted stunting prevalence by maternal education.

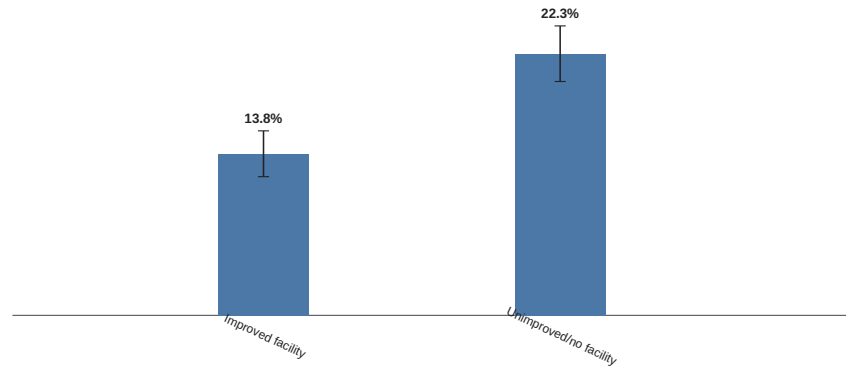
Weighted stunting prevalence by drinking-water source



Bars show weighted prevalence; whiskers show 95% design-based confidence intervals.

Figure S6: Survey-weighted stunting prevalence by drinking-water source.

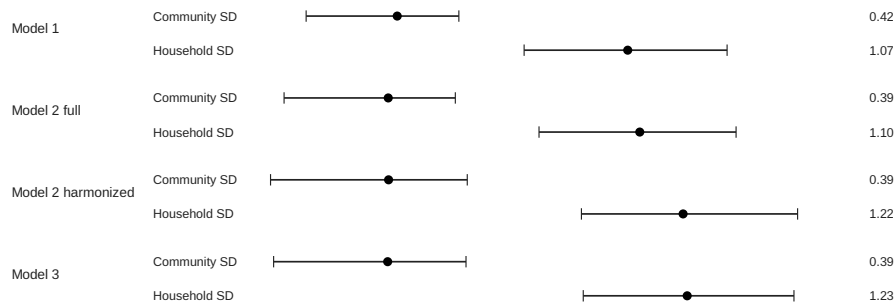
Weighted stunting prevalence by sanitation



Bars show weighted prevalence; whiskers show 95% design-based confidence intervals.

Figure S7: Survey-weighted stunting prevalence by sanitation category.

Household and community heterogeneity across models



Latent-scale random-effect standard deviation; lines show 95% posterior intervals.

Figure S8: Household and community variance components across the principal model sequence.

Model 3 posterior predictive check

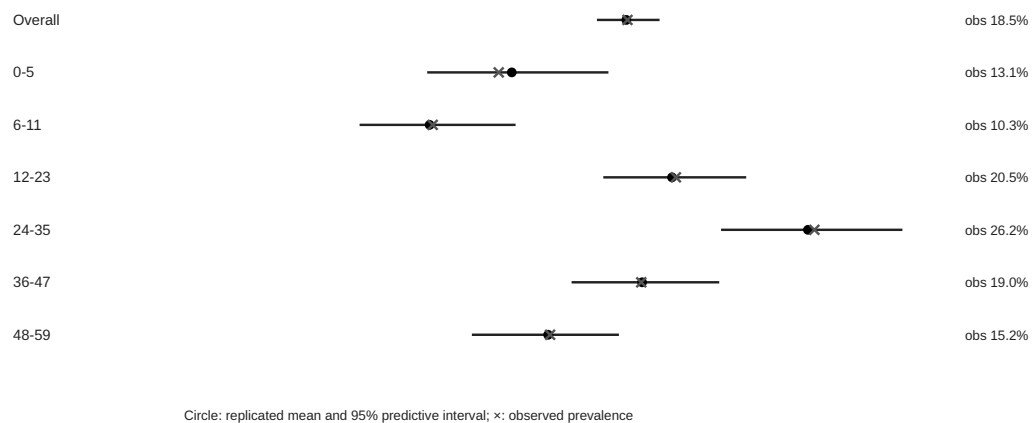


Figure S9: Posterior predictive check for unweighted prevalence in the 4,503-child complete-case Model 3 sample. These observed values differ from the survey-weighted descriptive prevalence reported for the 4,928-child core sample.