Supplemental Materials for

Seasonality of Acute Malnutrition in African Drylands: Evidence from 15 Years of SMART Surveys

Introduction

This document provides additional details for the results presented in the article *Seasonality of Acute Malnutrition in African Drylands: Evidence from 15 Years of SMART Surveys*. Sections include a summary of dryland SMART surveys, and results from sensitivity analyses across aridity and livelihood zones. Multiple tests were performed to characterize the influence of environmental variables on estimated coefficients. Comparisons of results from logistic and beta regression models are also provided.

Summary of SMART Surveys

Country-level summaries of SMART surveys comprising this analysis are provided in Table A. 58.82% of included surveys comprise at least 30 clusters, and 75.76% of included surveys meet the minimum validity threshold of 25 clusters per survey (19). A minority of surveys (9.27%) meet the 'rule of thumb' survey design criteria of a minimum sample size of 900 from a minimum of 30 clusters. Although 24.24% of surveys included in this analysis do not meet SMART survey design criteria, no observations were dropped. This decision reflects the primary unit of analysis for the pooled study, which is the individual child. All logit regressions were implemented using a pooled sample of 412,370 children; therefore sampling errors and selection bias in the survey has limited influence on the child-level GAM outcome. Analysis of survey-level GAM prevalence is implemented later in this study as a comparison against seasonality estimates derived from individual data. Although GAM prevalence is affected by sampling errors and bias within the survey, this study pools GAM estimates from 561 SMART surveys to minimize the effect of individual outliers. Retention of all surveys provides sufficient sample size for weighted beta regressions across aridity and livelihood zone partitions, and allows for comparison of the seasonal pattern of GAM against the individual dataset.

Sensitivity for Pooled Dataset

Regression results for the pooled child-level logit regression from Eq 1 are presented in Table B. The magnitude of the first and second harmonic terms are stable with minor fluctuations across model specifications. Introduction of second harmonics diminishes the magnitude of the first harmonic sine term; however, the first harmonic cosine term remains consistently statistically significant. Linear trend is statistically significant in the most complex model, but odds ratios (OR) approximately one for quadratic and cubic trends indicate no evidence of nonlinearity in wasting prevalence over time. Statistical significance of the first harmonic cosine term (OR ≈ 0.78) and the second harmonic sine term (OR ≈ 0.85) and indicates the presence of two peaks of global acute malnutrition (GAM) in a periodic cycle.

Table A Summary of SMART Surveys

Country	Total Number of SMART Surveys	Number of Unique Months Surveyed	Average Number of Sampling Units Across SMART Surveys	Average Number of Children per SMART Survey	Average GAM Across SMART Surveys
Benin	4	1	41	813	9%
Burkina Faso	45	6	38	863	10%
Cameroon	3	2	58	892	8%
Central African Rep.	16	8	33	746	7%
Chad	87	12	32	626	15%
Cote d’Ivoire	9	4	22	562	8%
Eritrea	2	2	Unknown	811	10%
Ethiopia	13	5	37	600	12%
Gambia	4	1	27	934	11%
Guinea	5	2	29	731	4%
Guinea-Bissau	3	1	29	583	8%
Mali	13	4	40	826	12%
Mauritania	38	5	23	674	11%
Niger	25	9	33	825	12%
Nigeria	84	11	30	668	10%
Senegal	6	2	36	1349	11%
South Sudan	102	12	20	718	22%
Sudan	98	12	12	824	17%
Togo	4	3	36	625	10%

2 Table B Odds Ratios for Harmonic Logit of Wasting Prevalence for complete dataset

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
First Harmonic, sine	1.015**	1.021***	1.030***	1.016**	1.013**	0.995	1.003	1.012*	0.994	0.994
	(1.003, 1.027)	(1.009, 1.034)	(1.017, 1.042)	(1.003, 1.028)	(1.001, 1.026)	(0.982, 1.007)	(0.990, 1.015)	(1.000, 1.024)	(0.982, 1.006)	(0.982, 1.007)
First Harmonic, cosine	0.799***	0.798***	0.801***	0.799***	0.797***	0.784***	0.783***	0.785***	0.784***	0.784***
	(0.789, 0.810)	(0.788, 0.808)	(0.791, 0.811)	(0.789, 0.809)	(0.787, 0.808)	(0.774, 0.795)	(0.772, 0.793)	(0.774, 0.795)	(0.774, 0.795)	(0.774, 0.795)
Second Harmonic, sine						0.860***	0.867***	0.867***	0.860***	0.860***
						(0.849, 0.872)	(0.856, 0.878)	(0.856, 0.879)	(0.849, 0.871)	(0.848, 0.871)
Second Harmonic, cosine						1.003	0.99	0.981***	1.004	1.004
						(0.991, 1.015)	(0.978, 1.003)	(0.969, 0.992)	(0.992, 1.016)	(0.992, 1.017)
Linear Trend	0.994***			0.994***	0.998*	0.994***			0.993***	0.993***
	(0.993, 0.994)			(0.993, 0.995)	(0.995, 1.000)	(0.993, 0.994)			(0.992, 0.994)	(0.991, 0.996)
Quadratic Trend		1.000***		1	1.000***		1.000***		1	1
		(1.000, 1.000)		(1.000, 1.000)	(1.000, 1.000)		(1.000, 1.000)		(1.000, 1.000)	(1.000, 1.000)
Cubic Trend			1.000***		1.000***			1.000***		1
			(1.000, 1.000)		(1.000, 1.000)			(1.000, 1.000)		(1.000, 1.000)
Constant	0.346***	0.266***	0.240***	0.338***	0.313***	0.342***	0.263***	0.237***	0.348***	0.348***
	(0.339, 0.354)	(0.262, 0.271)	(0.236, 0.243)	(0.324, 0.351)	(0.293, 0.333)	(0.334, 0.349)	(0.259, 0.267)	(0.234, 0.240)	(0.333, 0.362)	(0.325, 0.371)
Observations	412,370	412,370	412,370	412,370	412,370	412,370	412,370	412,370	412,370	412,370
Log Likelihood	-168,160.30	-168,235.30	-168,404.40	-168,159.20	-168,154.90	-167,902.50	-168,003.10	-168,169.00	-167,902.00	-167,902.00
Akaike Inf. Crit.	336,328.70	336,478.70	336,816.80	336,328.50	336,321.80	335,817.00	336,018.10	336,349.90	335,818.10	335,820.10

Note: *p<0.1; **p<0.05; ***p<0.01

The stability of the estimated harmonic coefficients was tested through a set of increasingly complex logit regressions which incorporated environmental covariates during the month of survey for the pooled dataset (Eq 3). Here, t indexes the month of survey, T indexes the month of survey as a sequence of months in the study period, and λ represents an interaction between Temperature and Precipitation. Since NDVI can be understood as the lagged effect of temperature and precipitation, a sequence of increasingly complex models tested individual as well as joint effects.

$$logit(Wasting)_t = \beta_{0_t} + \beta_0 + \beta_1 sin(2\pi\omega T) + \beta_2 cos(2\pi\omega T) + \beta_3 sin(4\pi\omega T) + \beta_4 cos(4\pi\omega T) + \beta_5 T + \beta_6 Temperature_t + \beta_7 Precipitation_t + \beta_8 NDVI_t + \beta_9 \lambda_t \quad (3)$$

Regression results from Eq 3 are presented in Table C. All predictors except NDVI are observed to be individually and collectively statistically significant. The magnitude of the harmonic terms fluctuates marginally, but Models (4), (5), and (6) are stable in the magnitude and sign of effects. The interaction between temperature and precipitation is observed to be statistically significant at the 1% level in Models (5) and (6), but OR = 1 indicates that this linkage does not drastically affect GAM. ORs greater than one for temperature indicate a positive relationship between temperature and GAM, whereas ORs less than one for precipitation indicates an overall negative relationship between rainfall and GAM. NDVI has a negligible effect on other covariates and wasting.

3 Table C Sensitivity of Wasting to Environmental Covariates

	(1)	(2)	(3)	(4)	(5)	(6)
First Harmonic, sine	0.941***	0.942***	0.961***	0.937***	0.956***	0.955***
	(0.928, 0.954)	(0.928, 0.956)	(0.948, 0.975)	(0.923, 0.952)	(0.941, 0.970)	(0.940, 0.970)
First Harmonic, cosine	0.854***	0.742***	0.781***	0.845***	0.868***	0.873***
	(0.840, 0.868)	(0.730, 0.754)	(0.771, 0.792)	(0.825, 0.865)	(0.847, 0.890)	(0.851, 0.895)
Second Harmonic, sine	0.909***	0.886***	0.862***	0.910***	0.913***	0.909***
	(0.896, 0.922)	(0.873, 0.898)	(0.851, 0.874)	(0.897, 0.923)	(0.900, 0.926)	(0.896, 0.923)
Second Harmonic, cosine	1.032***	0.989*	0.99	1.029***	1.011	1.009
	(1.019, 1.045)	(0.977, 1.001)	(0.977, 1.002)	(1.015, 1.043)	(0.997, 1.025)	(0.995, 1.023)
Linear Trend	0.994***	0.994***	0.994***	0.994***	0.994***	0.994***
	(0.994, 0.994)	(0.994, 0.994)	(0.993, 0.994)	(0.994, 0.994)	(0.994, 0.994)	(0.993, 0.994)
Temperature in Survey Month	1.041***			1.039***	1.029***	1.029***
	(1.037, 1.046)			(1.034, 1.045)	(1.024, 1.035)	(1.023, 1.035)
Precipitation in Survey Month		0.999***		1	0.988***	0.988***
		(0.999, 0.999)		(1.000, 1.000)	(0.986, 0.990)	(0.986, 0.990)
NDVI in Survey Month			0.751***			0.94
			(0.709, 0.793)			(0.867, 1.013)
Interaction: Temperature and Precipitation					1.000***	1.000***
					(1.000, 1.001)	(1.000, 1.001)
Constant	0.107***	0.356***	0.380***	0.114***	0.144***	0.149***
	(0.094, 0.121)	(0.348, 0.365)	(0.368, 0.391)	(0.096, 0.132)	(0.121, 0.168)	(0.124, 0.173)
Observations	412,370	412,370	412,370	412,370	412,370	412,370
Log Likelihood	-167,731.30	-167,832.60	-167,852.20	-167,730.50	-167,640.70	-167,639.50
Akaike Inf. Crit.	335,476.50	335,679.20	335,718.50	335,477.00	335,299.50	335,299.10

Note: * p<0.1; ** p<0.05; *** p<0.01

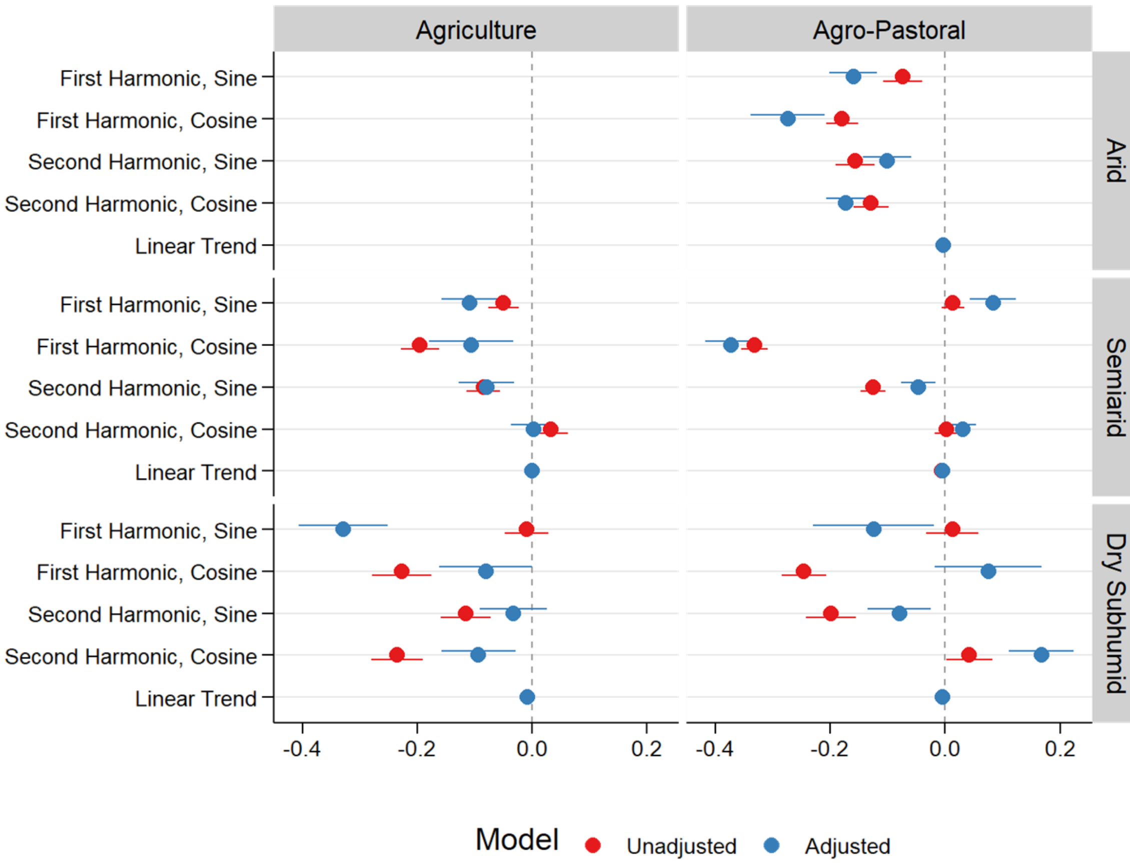
Sensitivity for Partitioned Dataset

Eq 2 was augmented with covariates including temperature, precipitation, and NDVI covariates to generate Eq 4, which was then used to study the stability of observed wasting response across livelihood and aridity zone partitions. Results from each partition are discussed in further sections.

$$logit(Wasting)_{A,L} = \beta_0 + \beta_1 sin(2\pi\omega T)_{A,L} + \beta_2 cos(2\pi\omega T)_{A,L} + \beta_3 sin(4\pi\omega T)_{A,L} + \beta_4 cos(4\pi\omega T)_{A,L} + \beta_5 T_{A,L} + \beta_6 Temperature_{A,L} + \beta_7 Precipitation_{A,L} + \beta_8 NDVI_{A,L} + \beta_9 \lambda_{A,L} \quad (4)$$

Figure A presents an overview of coefficients estimated for unadjusted (Eq 2, without environmental covariates) and adjusted (Eq 4, with environmental covariates) models. Overlapping confidence intervals and consistent signs generally indicate a high degree of alignment between adjusted and unadjusted models in Arid and Semiarid areas. This suggests that environmental factors influence, but do not completely explain, the seasonal pattern of GAM. Contrastingly, in Dry Subhumid regions, the inclusion of environmental covariates significantly alters unadjusted coefficient estimates. Wasting may therefore be more sensitive to environmental factors in Dry Subhumid regions compared to Arid and Semiarid regions.

Figure A Comparison of harmonic coefficient estimates for adjusted and unadjusted models across aridity zones and livelihood zones.



Sensitivity by Aridity Zones

Partitioning regressions by aridity zones allows for more nuanced analysis of seasonal wasting with respect to environmental covariates (Table D). Significant variability is observed in the regression coefficients for harmonic and environmental covariates in Arid, Semiarid, and Dry Subhumid areas. Most notably, a one unit increase in NDVI, which indicates greening, is associated with a 4.2 factor increase in the odds of wasting in Semiarid areas, all else being equal. This effect is unique to Semiarid areas, as greening is associated with lower odds of wasting in Arid and Dry Subhumid areas. This drastic increase points to highly variable environmental factors which may influence wasting within the drylands.

Table D Sensitivity of Wasting to Harmonic and Environmental Covariates by Aridity Zone

	Arid		Semiarid		Dry Subhumid	
	(1)	(2)	(3)	(4)	(5)	(6)
First Harmonic, sine	0.858*** (0.822, 0.893)	0.856*** (0.821, 0.891)	1.027** (1.000, 1.054)	1.143*** (1.111, 1.176)	0.752*** (0.715, 0.790)	0.728*** (0.688, 0.767)
First Harmonic, cosine	0.746*** (0.702, 0.790)	0.770*** (0.723, 0.818)	0.818*** (0.789, 0.847)	0.755*** (0.728, 0.783)	1.083*** (1.026, 1.139)	1.075*** (1.018, 1.131)
Second Harmonic, sine	0.915*** (0.878, 0.953)	0.904*** (0.867, 0.942)	0.888*** (0.867, 0.908)	0.964*** (0.941, 0.987)	0.959** (0.926, 0.993)	0.944*** (0.909, 0.979)
Second Harmonic, cosine	0.855*** (0.827, 0.884)	0.843*** (0.814, 0.872)	1.007 (0.988, 1.027)	1.043*** (1.022, 1.063)	1.237*** (1.197, 1.277)	1.211*** (1.169, 1.254)
Linear Trend	0.997*** (0.996, 0.997)	0.997*** (0.997, 0.998)	0.994*** (0.993, 0.994)	0.995*** (0.995, 0.996)	0.994*** (0.993, 0.994)	0.994*** (0.993, 0.994)
Temperature in Survey Month	0.987** (0.976, 0.998)	0.990* (0.979, 1.001)	1.020*** (1.011, 1.028)	1.027*** (1.019, 1.036)	1.209*** (1.189, 1.229)	1.190*** (1.167, 1.213)
Precipitation in Survey Month	0.993 (0.984, 1.003)	0.997 (0.987, 1.006)	0.998* (0.995, 1.000)	0.996*** (0.994, 0.999)	0.995*** (0.991, 0.998)	0.995*** (0.991, 0.998)
NDVI in Survey Month		0.407*** (0.185, 0.628)		4.237*** (3.651, 4.823)		0.638*** (0.459, 0.817)
Interaction: Temperature and Precipitation	1 (1.000, 1.000)	1 (1.000, 1.000)	1.000** (1.000, 1.000)	1.000** (1.000, 1.000)	1.000*** (1.000, 1.000)	1.000*** (1.000, 1.000)
Constant	0.413*** (0.284, 0.541)	0.420*** (0.290, 0.550)	0.193*** (0.146, 0.240)	0.085*** (0.063, 0.107)	0.001*** (0.001, 0.002)	0.003*** (0.001, 0.005)
Observations	79,377	79,377	230,890	230,890	102,103	102,103
Log Likelihood	-34,375.75	-34,370.45	-96,498.78	-96,288.74	-36,182.02	-36,177.06
Akaike Inf. Crit.	68,769.51	68,760.89	193,015.60	192,597.50	72,382.03	72,374.12

Note: *p<0.1; **p<0.05; ***p<0.01

9 Sensitivity by Livelihood Zone

Results from logit regressions partitioned by livelihood zones are presented in Table E. Variability is observed across livelihood zones, but results remain internally robust. The linkage between NDVI and wasting is once again notable. A one unit increase in NDVI in agricultural areas is associated with a approximately a 62% lower likelihood of wasting, whereas in agropastoral areas, the same increase in NDVI is associated with a 45% increase in likelihood of wasting. A marginally positive relationship of GAM with temperature and marginally negative relationship of GAM with precipitation is also affirmed. The contrasting effect of NDVI points to differences in livelihoods which may influence wasting through mediating factors such as socioeconomic status, access to resources, and environmental exposure.

Table E Sensitivity of Wasting to Harmonic and Environmental Covariates by Livelihood Zone

	Agriculture		Agro-Pastoral	
	(1)	(2)	(3)	(4)
First Harmonic, sine	0.872***	0.856***	1.032***	1.032***
	(0.846, 0.898)	(0.831, 0.882)	(1.012, 1.051)	(1.012, 1.051)
First Harmonic, cosine	1.021	1.029	0.837***	0.798***
	(0.973, 1.069)	(0.980, 1.078)	(0.813, 0.861)	(0.773, 0.823)
Second Harmonic, sine	1.064***	0.984	0.874***	0.889***
	(1.033, 1.095)	(0.953, 1.015)	(0.859, 0.889)	(0.873, 0.905)
Second Harmonic, cosine	0.98	0.930***	0.999	1.001
	(0.954, 1.006)	(0.905, 0.956)	(0.982, 1.016)	(0.984, 1.018)
Linear Trend	0.996***	0.995***	0.995***	0.995***
	(0.995, 0.996)	(0.995, 0.996)	(0.994, 0.995)	(0.995, 0.995)
Temperature in Survey Month	1.097***	1.067***	1.012***	1.011***
	(1.084, 1.110)	(1.054, 1.080)	(1.006, 1.019)	(1.005, 1.018)
Precipitation in Survey Month	0.995***	0.998	0.995***	0.994***
	(0.993, 0.998)	(0.995, 1.001)	(0.992, 0.998)	(0.991, 0.997)
NDVI in Survey Month		0.347***		1.455***
		(0.290, 0.403)		(1.319, 1.590)
Interaction: Temperature and Precipitation	1.000***	1.000***	1.000***	1.000***
	(1.000, 1.000)	(1.000, 1.000)	(1.000, 1.000)	(1.000, 1.000)
Constant	0.015***	0.045***	0.237***	0.219***
	(0.010, 0.020)	(0.028, 0.062)	(0.191, 0.282)	(0.177, 0.262)
Observations	169,850	169,850	242,520	242,520
Log Likelihood	-57,421.43	-57,340.41	-109,375.60	-109,344.30
Akaike Inf. Crit.	114,860.90	114,700.80	218,769.10	218,708.60

Note: *p<0.1; **p<0.05; ***p<0.01

Joint Robustness of Wasting

Combining aridity and livelihood partitions reveals critical variability within the drylands (Table F). Varying coefficients for harmonic terms indicates slightly different seasonal patterns of wasting across both livelihood and aridity zone partitions. Temperature is statistically significant in four of the six partitions, and the magnitude of the Temperature coefficient is greatest in Dry Subhumid regions. Precipitation is only statistically significant at the 1% level in the Dry Subhmid, Agriculture partition. The effect of NDVI is inconsistent across partitions, with a 3 factor increase in wasting in Semiarid, Agro-Pastoral areas and inverse effects everywhere else. This phenomenon may be driven by erroneous inclusion of surveys from Darfur and Equatoria regions, which were frequently surveyed during the high NDVI months of September – October.

13 **Table F Sensitivity of Wasting to Harmonic and Environmental Covariates by Aridity and Livelihood**

	Arid, Agriculture	**Arid, Agro-Pastoral**	**Semiarid, Agriculture**	**Semiarid, Agro-Pastoral**	**Dry Subhumid, Agriculture**	**Dry Subhumid, Agro-Pastoral**
First Harmonic, sine	1.016	0.852***	0.897***	1.087***	0.720***	0.883**
	(0.794, 1.238)	(0.817, 0.887)	(0.854, 0.940)	(1.043, 1.131)	(0.664, 0.776)	(0.790, 0.975)
First Harmonic, cosine	0.92	0.760***	0.899***	0.688***	0.923**	1.078
	(0.739, 1.101)	(0.711, 0.809)	(0.833, 0.965)	(0.658, 0.719)	(0.848, 0.997)	(0.978, 1.178)
Second Harmonic, sine		0.904***	0.924***	0.954***	0.968	0.923***
		(0.866, 0.942)	(0.879, 0.969)	(0.926, 0.983)	(0.912, 1.025)	(0.872, 0.974)
Second Harmonic, cosine		0.841***	1.003	1.031**	0.911***	1.182***
		(0.812, 0.870)	(0.963, 1.042)	(1.006, 1.056)	(0.852, 0.970)	(1.115, 1.249)
Linear Trend		0.997***	1.001	0.995***	0.992***	0.995***
		(0.997, 0.998)	(1.000, 1.001)	(0.995, 0.996)	(0.992, 0.993)	(0.994, 0.996)
Temperature in Survey Month		0.989**	1.013	1.025***	1.157***	1.116***
		(0.977, 1.000)	(0.996, 1.030)	(1.014, 1.037)	(1.106, 1.209)	(1.090, 1.143)
Precipitation in Survey Month		0.995	0.999	1.002	1.008***	0.995
		(0.985, 1.004)	(0.995, 1.003)	(0.998, 1.006)	(1.003, 1.013)	(0.985, 1.005)
NDVI in Survey Month		0.606	0.515***	3.022***	0.370***	0.765
		(0.230, 0.981)	(0.347, 0.683)	(2.466, 3.579)	(0.219, 0.521)	(0.377, 1.153)
Interaction: Temperature and Precipitation		1	1	1	1.000**	1
		(1.000, 1.000)	(1.000, 1.000)	(1.000, 1.000)	(1.000, 1.000)	(1.000, 1.001)
Constant	0.173***	0.414***	0.095***	0.115***	0.007***	0.015***
	(0.154, 0.193)	(0.283, 0.545)	(0.049, 0.141)	(0.075, 0.155)	(-0.003, 0.016)	(0.003, 0.027)
Observations	3,755	75,622	102,431	128,459	63,664	38,439
Log Likelihood	-1,587.48	-32,779.14	-36,491.03	-59,432.73	-19,027.29	-16,813.65
Akaike Inf. Crit.	3,180.96	65,578.29	73,002.07	118,885.50	38,074.57	33,647.30

Note: *p<0.1; **p<0.05; ***p<0.01

Comparison of Logistic and Beta Regression Estimates

Logistic regression was used to analyze individual child wasting outcomes, and beta regression was utilized for analysis of aggregate GAM prevalence data. Weights for beta regression were calculated as the sample size of children meeting inclusion criteria in each SMART survey divided by 100. Weighted regression was required to minimize sum of squared residuals and to account for differences in sample sizes across SMART surveys. This is particularly relevant for five SMART surveys in Burkina Faso and three SMART surveys in Senegal, all of which had sample sizes greater than 1500 children. We hypothesize that the original surveys were conducted in multiple communities within the same level one administrative region. However, this cannot be confirmed since no information about subnational locations of survey communities is included in the original dataset for the subset of eight high-sample SMART surveys. Regression weights were thus utilized for robust assessment of seasonal patterns from aggregate estimates of GAM across multiple communities.

Comparison of logistic and beta coefficient estimates reveals that seasonal signatures and peaks of GAM are preserved; however, confidence intervals of estimated harmonic coefficients from aggregate beta regression models are often wider than logistic regression estimates (Figure B). Estimates of linear trend do not change with aggregate data. The magnitude and statistical significance of harmonic coefficients changes with aggregation but the scaled seasonal pattern of GAM derived from a beta regression is very similar to that of a logistic regression (Figure C). Thus, the seasonal pattern of GAM is robust to aggregation and harmonic regression can be applied to aggregate GAM prevalence data with sufficient sample size.

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Figure B Comparison of Adjusted and Unadjusted Coefficients from Logistic and Beta Regression Models

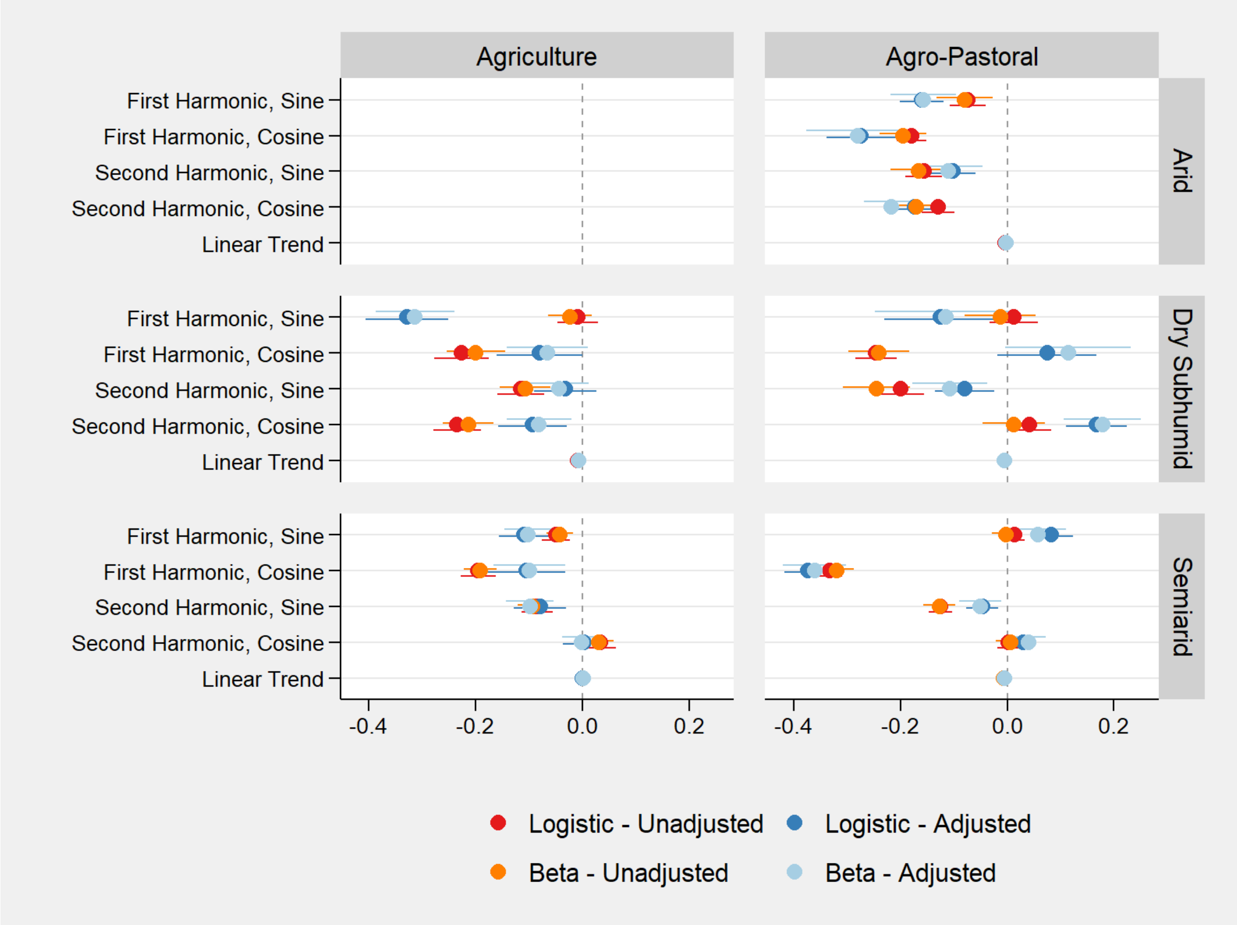

Figure C Seasonal Pattern of GAM from Harmonic Logistic Regression of Child-Level Wasting and Harmonic Beta Regression of Aggregate GAM Prevalence