Climate, climate shocks and child nutrition in Africa's diverse farming systems

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Abstract:

Notwithstanding improvements over the last several decades, food and nutrition insecurity is still widespread and progresses made have been uneven. In Africa, the central and western parts scored the lowest and highest reduction in malnutrition, respectively. This regional heterogeneity is expected given the spatial variation in (inclusive) economic growth, agro-ecology, market access, the prevalence of diseases and infections, as well as institutional and policy environments (e.g., social protection systems) that affect the various dimensions of food and nutrition security. At the same time, climatic and weather changes are expected to worsen in the coming decades with potentially devastating effects in the region, given its heavily relies on rain-fed agriculture and the market and institutional failures that limit the set of coping and adaptation strategies. This study examines the linkages between climatic shocks and child undernutrition in the diverse farming systems of Africa. We examine effects of climatic changes not only through yields (agricultural mechanism) but also through vector-borne and gastrointestinal diseases (health mechanism). Preliminary results suggest significant heterogeneity in the incidence of child undernutrition and the effects of climatic shocks by agro-ecology and farming systems, meriting further investigation we are currently undertaking to disentangle the role of each mechanism.

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1. Introduction

Notwithstanding improvements over the last several decades, food and nutrition insecurity is still widespread and progresses made have been uneven. For example, between 2000 and 2016, the number of stunted children has declined from 198 to 155 million (28%) globally, with the rate of decline for Africa (from 38% to 31%) less than half that for Asia (38% to 24%) and Latin America and the Caribbean (18% to 11%) (UNICEF, WHO, and WB, 2017). Within Africa, the central and western parts scored the lowest and highest reduction in malnutrition, respectively. This regional heterogeneity is expected given the spatial variation in the rate of (inclusive) economic growth, agro-ecology, market access, the prevalence of diseases and infections, as well as institutional and policy environments (e.g., social protection systems) that affect the various dimensions of food and nutrition security – the availability, accessibility, utilization, and stability of food.

Climate-related agricultural shocks are perceived important determinants of nutrition outcomes in rural Africa. Nonetheless, there is surprisingly little empirical evidence on the linkage between the two. There is growing literature that attempts to link climate shocks to nutrition outcomes, often motivated by agricultural mechanisms, but without enough attention given to how climate change and weather variability affect crop yields, which in turn heavily determine livestock productivity via feed. Moreover, it is implausible that climatic shocks will have homogenous effects across different farming systems. For example, Schlenkera and Roberts (2009) document a positive association between temperature and yields up to 29° Celsius for corn, 30° Celsius for soybeans, and 32° C for cotton beyond which effects are quite very harmful based on data from the US. In an Africa setting, crop modelling shows that rice has quite different temperature-yield profile to maize and wheat, being much more robust to heat. Cassava is also likely to be more robust to heat, and is continuously cropped and therefore often thought of as a "food security crop". In sumt, farming systems matter a lot and should be carefully examined when assessing the climate-nutrition relationships.

Further challenge is the fact that many nutrition studies do not consider the dynamics of growth faltering, documented in Victora et al. (2009). Population level growth faltering is a phenomenon that occurs entirely in the first 1000 days after conception, so children in the 0-23-month range are still falling behind and therefore not fully exposed to shocks. Hence, as Alderman and Headey (2017) argue, mixing together 0-23 month and 24-59 month samples is a bad idea. Authors note that HAZ researchers should focus on the 24-59 months old children when the effects of early childhood shocks have presumably fully played out.

Thanks to several collaborative efforts by governments, multilateral donors, academic and research institutions, the collection of (and access to) spatially-explicit, quantitative socio-economic data in the developing world has significantly improved over the years (Azzarri et al., 2016). This, coupled with improvements in the availability of rasterized biophysical data, has created new opportunities for a systematic analysis of complex and multi-dimensional development challenges, including child malnutrition. Child malnutrition not only has short-term adverse effects (e.g., through ill health and mortality) but also long-term effects through impaired cognitive development, educational achievement and overall economic productivity (Grantham-McGregor et al., 2007).

While the link between weather shocks and agricultural productivity is relatively clearer, the linkage between weather shocks and nutrition is more complex and operates through multiple channels. Establishing causal links between weather variability, agricultural production, and nutrition is challenging due to the uncertainty in the responsiveness of crop to weather shocks and the role of socioeconomic factors that mitigate or amplify the effects of weather variability (World Food Program 2011). In addition to their effects through agricultural production, weather shocks can impact nutrition by shifting diets towards energy-dense processed foods (Bloem et al 2010), by increasing floods and proliferation of diseases that affect the body's absorptive capacity (Ramin and McMichael 2009), and by impacting air quality (Bernstein and Myers 2011).

While a warming trend will help extend the growing seasons of high- and mid-latitude areas, potentially enabling more productive agricultural seasons, with the opposite effect expected in already warm low-latitude areas (Porter 2005). Nonetheless, there is a broad consensus on the fact that the negative effects of weather variability will most likely outweigh any positives, especially in already vulnerable areas with high concentration of poverty and food and nutrition insecurity (Gilles 2005; Knox et al 2012; McMichael 2001). Some work has been done to tie climate data with agricultural productivity and child nutrition data, finding that environmental stresses lead to both depressions in agricultural productivity and increases in child malnutrition. Studies often test the link between environmental stresses and nutrition directly, either explicitly or implicitly identifying a theoretical causal pathway. In Kenya, for example, Grace et al (2012) examine the relationship between weather condition (precipitation and surface temperatures) and prevalence of stunting and underweight among children. They document that weather shocks not only slow down child growth but have long term impacts on children's likelihood of completing secondary education. Other studies confirm the long-term impacts of weather shocks, identifying reduced schooling and economic productivity stemming from child malnutrition (Alderman 2010).

This study examines the linkages between climate change (long-term) and weather variability on the one hand and child nutritional outcomes on the other in rural Africa south of the Sahara (SSA). We introduce three innovations to the existing literature. *First*, we consider specific weather shocks that could affect nutrition not only through agricultural mechanism (per crop model prediction) but also through health-related causal mechanisms (e.g., infectious gastrointestinal and vector-borne diseases such as malaria). Second, and considering the heterogeneity in weather-yield responses, the analysis will be disaggregated by the main farming systems in the region. Third, we pay close attention to dynamics of growth faltering and examine effects of lagged weather shocks on standardized height-for-age z-score (HAZ) for kids 24-59 months old.

Preliminary results show several (policy) variables are positively correlated with children's height-for-age z-scores (stunting) and weight-for-height z-scores (wasting), including mother's education, improved water, sanitation and hygiene (WASH) and dwelling condition. Both expose to below-average (dry spell) and above-average (wet spell) precipitation during the planting and growing (PG hereon after) season of the pervious cropping season are positively correlated with wasting of older (25-59 months) children. Expose to sustained incidence of dry spell is also positively correlated with stunting of older children. Significant heterogeneity in the effects of climatic shocks by farming systems.

2. Data

The analysis uses data from Advancing Research on Nutrition and Agriculture (AReNA) project. Nutrition and health data from all the available Demographic and Health Surveys (DHS) have been harmonized and merged with spatially-explicit land-scape level bio-physical, economic and environmental data using the Global Positioning System (GPS) coordinates of DHS clusters.[1] Our analysis uses data from the most recent DHS wave for 24 countries in Africa south of the Sahara

[1] The coordinates of the DHS clusters have been moved randomly (within a 10km range) for the sake of confidentiality. Since the resolution of the spatial data layers are mostly 5 minutes (10km) or 30 seconds (1km), we use a 10km square spatial unit to extract/average the value of the biophysical variables.

covering the period 1990 – 2010 (Appendix Table A1). [2] The analysis is restricted to 0-59 months old children living in rural areas and for whom anthropometric data are available. When examining the effects of weather shocks, we also excluded DHS clusters with missing GPS coordinates and hence spatially-explicit biophysical data.

The sources of landscape-level biophysical and economic data processed as part of AReNA are as follows. A time series of monthly average precipitation (in millimeters) and surface temperature (degree Celsius) data come from the Climate ResearchTime Series Grid Version 3.23 at the University of East Anglia. Weather data covers 1980 – 2010 and has a 0.5-degree spatial resolution (Harris e al., 2014). Data on agro-ecological zones (AEZ) and length of growing period (days) come from IIASA/FAO and HarvestChoice (2015). Information about travel time to the nearest city with a population of at least 20, 000 (Euclidian distance, in minutes) is obtained from HarvestChoice (2015) Data on the share of land equipped for irrigation (2005) come from Siebert et al. (2015)? Rural population density data (number per square kilometer) come from the Center for International Earth Science Information Network (CIESIN) at Columbia University.[3] Cluster-level 2005 data on livestock wealth come from ILRI/FAO. In addition, we use data on per capita gross domestic product based on purchasing power parity (PPP) (current international $).[4]

To construct shock indicators, we focus on the planting and growing season (hereon after PG season) season of the respective country. Previous studies that examine the impact of weather shocks focused on a variety of time periods, ranging shortest to longest from the duration of the wet season (Bezabih et al 2014) to the entire year (Dell et al 2012; Ndamani and Watanabe 2015). Most studies that examine effects on agricultural productivity and other outcomes have considered weather shocks during the growing and planting season (Bertelli 2015; Kubik and Maurel 2016; Hagos et al 2014; Porter 2005), rather than the whole cropping season of growing, planting, and harvest (Arslan et al 2015).

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[2] The 24 countries included in the study are the following: Burundi, Burkina Faso, Cameron, Cote d'Ivoire, Congo Democratic Republic, Congo, Ethiopia, Ghana, Kenya, Lesotho, Madagascar, Mali, Mozambique, Malawi, Namibia, Niger, Nigeria, Rwanda, Senegal, Swaziland, Tanzania, Uganda, Zambia, and Zimbabwe. We restrict the analysis to1998 - 2010 since temperature and rainfall data in AReNA data files are for 1993 to 2010 and we consider up to the effects of shocks that occurred up to five years before the DHS-survey year.

[3] http://sedac.ciesin.columbia.edu/data/collection/gpw-v3/

[4] http://data.worldbank.org/indicator/NY.GDP.PCAP.PP.CD

In our case, the PG season is defined based on maize cropping calendar from the United Nations Food and Agricultural Organization.[5] Whenever maize cropping dates are available sub-nationally, the PG season is defined by sub-region. Indicators are constructed to measure weather shocks occurring up to five PG seasons (lag periods $L1$ to $L5$) prior to DHS-survey implementation year t. For households surveyed in t and month m^s and where m^s falls after the first month of the harvest season (m^h), $L1$ measures the PG season at $t-1$ while $L2$ to $L5$ measure the PG season in $t-2$ to $t-5$, respectively. If m^s falls before m^h, $L1$ measures the PG season in $t-2$ while $L2$ to $L5$ measure the PG season in $t-3$ to $t-6$, respectively. Defining lags this way is deemed necessary since the nutritional effects of a weather shock (through the agricultural production channel) occurring in the PG season in t may not be fully captured using anthropometric data collected in the same year and month m^s if m^s precedes m^h. That is, possible effects would not have been reflected on nutritional outcomes since drought-impacted households would not have started harvesting their produce in m^s.

For each lag period and DHS survey year t, four weather shock indicators are constructed – the number of months of the PG season where monthly precipitation is more than one standard deviation above the long-term average (LTA) precipitation constructed based on a monthly time series data from 1980 to t (hereafter months of wet spell); the number of months of the PG season where precipitation is less than one standard deviation below LTA (hereafter months of dry spell); the number of months of the PG season with monthly temperature more than one standard deviation above LTA (hereafter months of heat wave); and the number of PG months with monthly temperature less than one standard deviation below LTA (hereafter months of cold wave). The analysis herein focuses on the effects of L1 and cumulative (L1 to L5) shocks.

As summarized in Table 1, different cohorts of children would have been exposed to L1 shocks at different stages of their growth. Specifically, younger cohort (0-24 months) would have been exposed to shocks during their early formative years, either directly (through reduced intake of complementary feeds of adequate nutritive value as well as weather-borne diseases) or indirectly (through reduced intake of nutritious food by the mother during the first six (exclusive breast-feeding) months. Given that 0-24 months is the age period where stunting sets in, early exposure to weather shocks could have lasting developmental effects (Tesfu, 2016; Victora, 2010). When

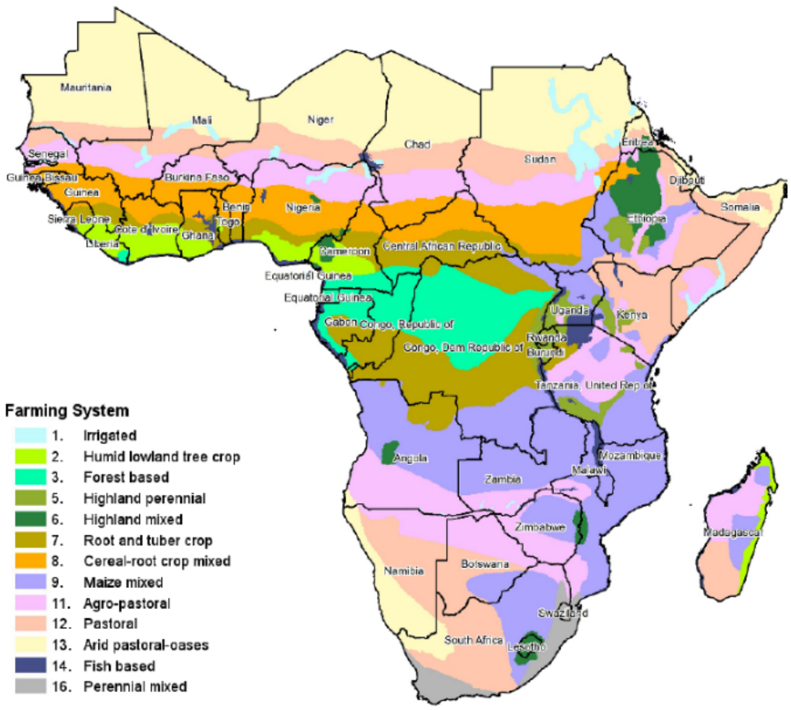
[5] http://www.fao.org/agriculture/seed/cropcalendar/welcome.do

examining cumulative shocks, the younger cohort would have been exposed to shocks between two to three years, (including in utero) while older cohorts would have been exposed to three to five years of shocks. The farming systems of interest are summarized below.

Table 1 Years of exposure to weather shocks (by child age and lag period)

	Lag period	
Child's age (months)	L1	Cumulative (L1 to L5)
0-12	1 year (since birth)	2 years : in utero and 1st year
13-24	1 year (since 1st birthday)	3 years : in utero and first two years
25-36	1 year (since 2nd birthday)	4 years : in utero and first three years
37-48	1 year (since 3rd birthday)	5 years : in utero and first four years
49-59	1 year (since 4th birthday)	5 years (entire life)

Africa’s farming systems



Farming Systems	Land Area (% of region)	Agric. Popn. (% of region)	Principal Livelihoods
Irrigated	1	2	Rice, cotton, vegetables, rainfed crops, cattle, poultry
Tree Crop	3	6	Cocoa, coffee, oil palm, rubber, yams, maize, off-farm work
Forest Based	11	7	Cassava, maize, beans, cocoyams
Rice-Tree Crop	1	2	Rice, banana, coffee, maize, cassava, legumes, livestock, off-farm work
Highland Perennial	1	8	Banana, plantain, enset, coffee, cassava, sweet potato, beans, cereals, livestock, poultry, off-farm work
Highland Temperate Mixed	2	7	Wheat barley, tef, peas, lentils, broadbeans, rape, potatoes, sheep, goats, livestock, poultry, off-farm work
Root Crop	11	11	Yams, cassava, legumes, off-farm work
Cereal-Root Crop Mixed	13	15	Maize, sorghum, millet, cassava, yams, legumes, cattle
Maize Mixed	10	15	Maize, tobacco, cotton, cattle, goats, poultry, off-farm work
Large Commercial and Smallholder	5	4	Maize, pulses, sunflower, cattle, sheep, goats, remittances
Agro-Pastoral Millet/Sorghum	8	8	Sorghum, pearl millet, pulses. sesame, cattle, sheep, goats, poultry, off-farm work
Pastoral	14	7	Cattle, camels, sheep, goats, remittances
Sparse (Arid)	17	1	Irrigated maize, vegetables, date palms, cattle, off-farm work
Coastal Artisanal Fishing	2	3	Marine fish, coconuts, cashew, banana, yams, fruit, goats, poultry, off-farm work
Urban Based	<1	3	Fruit, vegetables, dairy, cattle, goats, poultry, off-farm work

Sources: Auricht et al., 2014.; Dixon et al. 2001.

Child nutritional outcomes are constructed using DHS anthropometric data. The new World Health Organization (WHO) Child Growth Standards (WHO 2006) are used to construct standardized age- and sex-specific z-scores for child height-for-age (HAZ) and weight- for-height (WHZ).[6] HAZ reflects linear growth and can measure long-term growth faltering or stunting, as a chronic problem. WHZ reflects proper body proportion and is particularly sensitive to acute weight loss due to a recent hunger and/or disease resulting in wasting (World Bank 2008).

Following the approach by the WHO Global Database on Child Growth and Malnutrition, we consider children with HAZ below minus 2 standard deviations (SD) but above minus 3 SD from the reference population as moderately stunted while those with WHZ below minus 2 SD but above minus 3 SD as moderately wasted. The (unconditional) density distributions of HAZ and WHZ for children in different AEZ are summarized in Figures 1 and 2, respectively, against the standard normal density. The HAZ density is far to the left of the standard normal, suggesting a relatively high incidence of stunting in the region. Children in arid areas have higher HAZ then their counterparts in humid/sub-humid areas (Figure 1) while they are more likely to be wasted (Figure 2). Nonetheless, and as is shown later, children living in arid areas account for only about 2% of the sample.

[6] Children with extreme z-scores per WHO's recommended cut-off points are excluded.

Figure 1 Unconditional distribution of height-for-age z-scores by agro-ecology

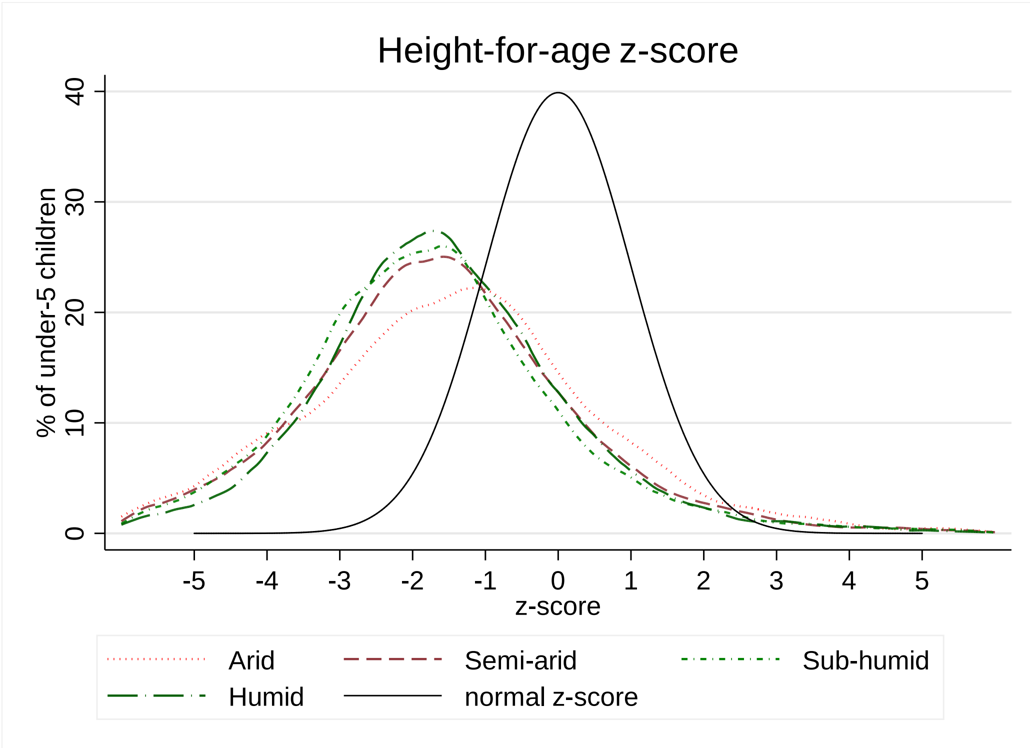


Figure 2 Unconditional distribution of weight-for-height z-scores by agro-ecology

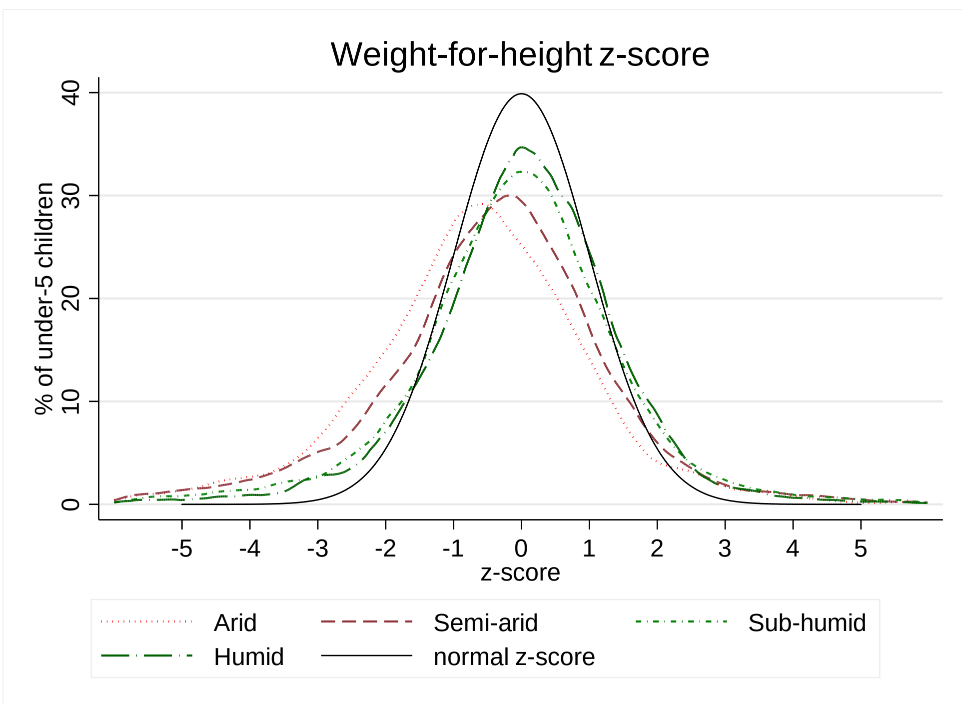


Figure 3 shows heterogeneity in the incidence of moderate stunting and wasting by farming systems, where perennial mixed systems is associated with the lowest incidence of undernutrition while the opposite is true for irrigated systems, especially for wasting.

Figure 3 Moderate (rural) undernutrition by farming systems

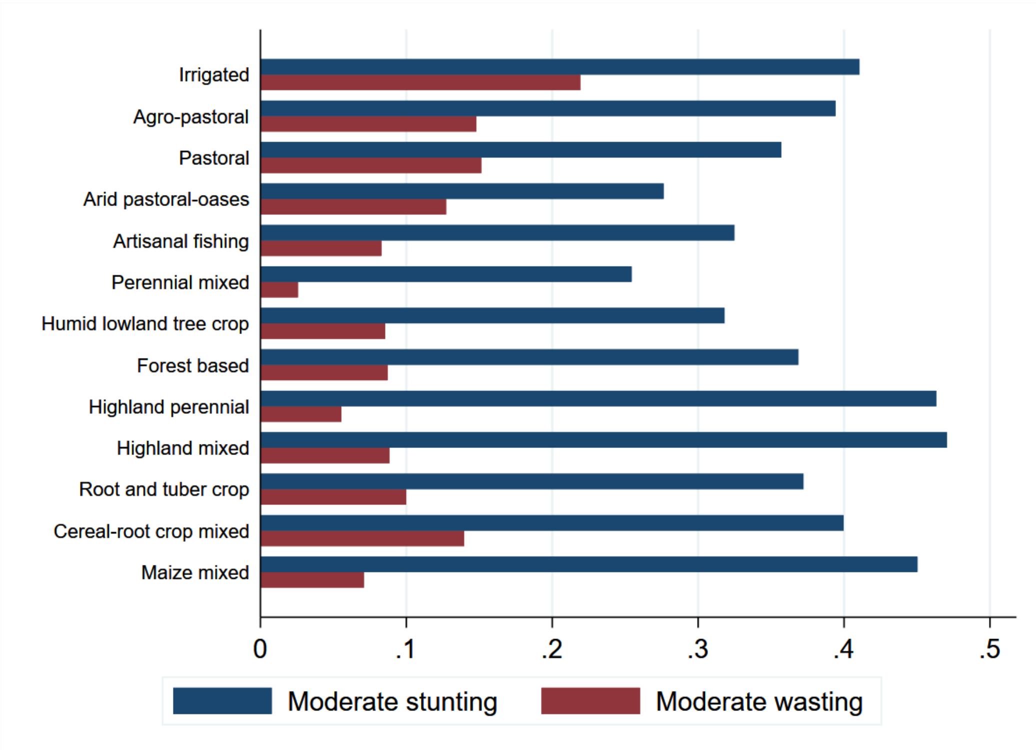
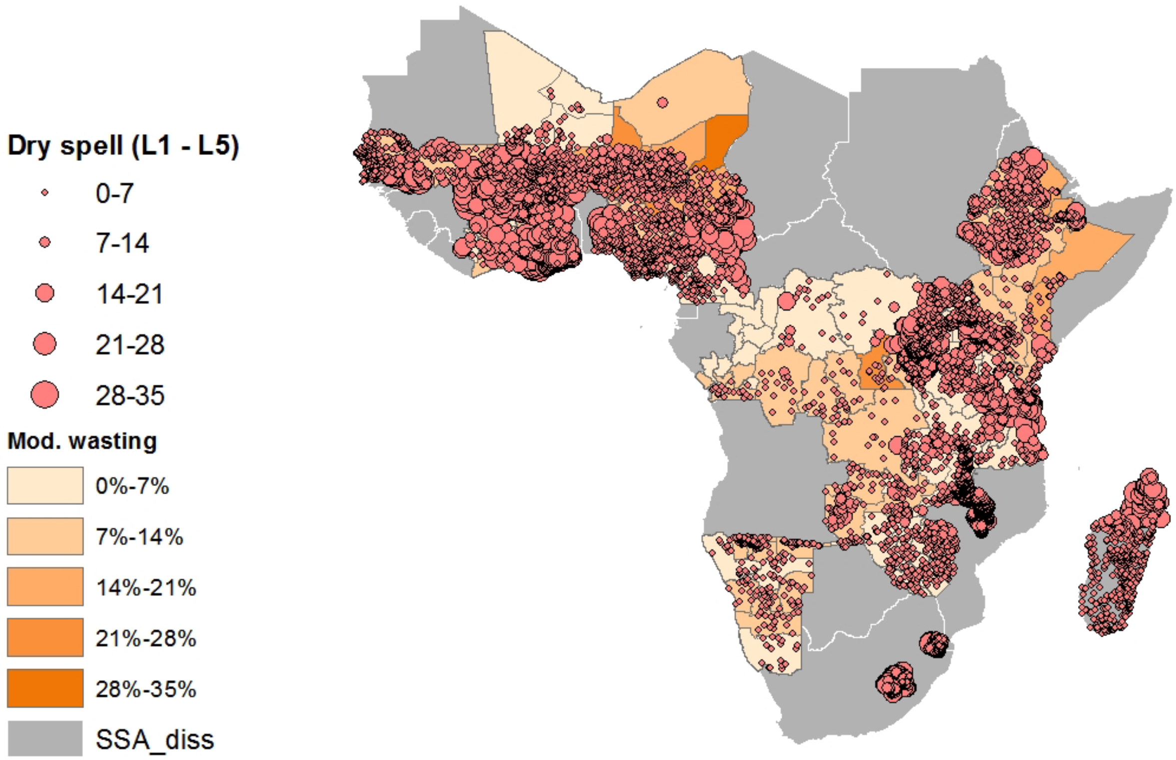


Figure 4 shows heterogeneity in the spatial distribution of moderate wasting and cumulative dry spells, with positive association observed in some parts of the continent (e.g., western Africa).

Figure 4 Spatial distribution of moderate wasting and cumulative dry spells



Child malnutrition could result from several factors including mother's heath and nutritional status before and during pregnancy, maternal and child nutrition and health during the formative years of the child's life and beyond. Guided by the available theoretical and empirical literature, our regression analysis controls for several child-, mother-, household-, and landscape-level variables summarized Table 2. Factor analysis (principal-component factor method) is used to construct indices of household wealth (durable assets and livestock), dwelling condition, the quality/source of drinking water and toilet condition (WASH index) in the spirit of Filmer and Pritchett (2001).

Table 2 Descriptive summary

Male child (%)	0.50	(0.50)
Child had diarrhea (past two weeks) (%)	0.16	(0.37)
Child had cough (past two weeks) (%)	0.22	(0.41)
Under-five children per household	5.36	(4.45)
Height for age z-score (HAZ)	-1.69	(1.77)
Weight for height z-score (WHZ)	-0.21	(1.56)
Household characteristics		
Woman's education in single years	3.23	(3.79)
Child's mother at birth (years)	26.7	(6.93)
Total number of children ever born	4.28	(2.55)
Female household head (%)	0.17	(0.38)
Good dwelling condition (index)	6.2e-09	(0.87)
Durable-assets based wealth (index)	6.6e-10	(0.98)
Livestock wealth (index)	-4.9e-09	(0.91)
Good WASH condition (index)	-9.2e-10	(0.56)
Landscape-level characteristics		
Share of irrigated crop land	2.91	(13.17)
Rural population density (#/sq km)	120.8	(149.07)
Length of growing period (days)	192.7	(65.53)
Headcount of cluster-level livestock wealth (TLU)	3550.0	(4594.19)
Travel time to cities with 20K people (minutes)	214.6	(205.86)
Months of planting and growing season	4.85	(1.55)
Arid agro-ecology (AEZ)	0.022	(0.15)
Semi-arid (AEZ)	0.49	(0.50)
Sub-humid (AEZ)	0.31	(0.46)
Humid (AEZ)	0.17	(0.38)
Observations	85288	

Note: Weighted summaries from rural 0-59 months old children from the most recent DHS waves

3. Statistical model

To examine the correlates of child malnutrition, Equation 1 is estimated using weighted least squares on data pooled across the most recent DHS waves.

$$Z_{it} = \alpha_0 + \beta_1 Dry_{it} + \beta_2 Wet_{it} + \beta_3 Heat_{it} + \beta_4 Cold_{it} + \gamma_1 Pre_{it}^{LTA} + \gamma_2 Pre_{it}^{LTA}\text{^}2 + \delta_1 Temp_{it}^{LTA} + \delta_2 Temp_{it}^{LTA}\text{^}2 + \lambda Child024_{it} + \pi_1 DryXChild024_{it} + \pi_2 WetXChild024_{it} + \pi_3 HeatXChild024_{it} + \pi_4 ColdXChild02_{it}4 + \boldsymbol{\Phi}'\boldsymbol{X}_{it} + \boldsymbol{\Omega}'\boldsymbol{Z}_{it} + \boldsymbol{f} + \varepsilon_{it} \quad 1$$

where i and t are indices for child and survey year; Z is either HAZ or WHZ; Dry, Wet, $Heat$, and $Cold$ measure the number of PG months experiencing dry spell, wet spell, heat wave, and cold wave, as discussed in Section 2, respectively; Pre^{LTA}, Pre^{LTA} ^2, $Temp^{LTA}$, and $Temp^{LTA}$ ^2 measure historical average precipitation and temperature and their squared terms for capturing possible non-linearity; $Child024$ is an indicator that equals one if child is between 0-24 months old; interaction terms between each type of weather shock – W– and $Child024$ is given by WX$Child024$ ($\forall\, W \in Dry, Wet, Heat, Cold$); $\boldsymbol{X}$ contains child-, mother-, and household-level covariates. Land-scape level variables that could affect agricultural potential and nutritional outcomes are included in $\boldsymbol{Z}$; $\boldsymbol{f}$ includes fixed effects for country, AEZ, and interview month; ε_{it} is the model error.

Parameter estimates $\widehat{\beta_k}$ $(k = 1, 2, 3, 4)$ measure the effects of a month increase in each type of shock on the respective z-sore for children 25-59 months old (in percent) while the effects of shocks on the z-scores on children 0-24 months old are captures by $(\widehat{\beta_k} + \widehat{\pi_k})$ $(k = 1, 2, 3, 4)$. Two versions of Equation 1 are estimated, first controlling for L1 shocks, and then controlling for cumulative (L1 to L5) shocks. All summary statistics and regressions are weighted to account for disproportionate sampling and non-response per the guideline provided by DHS. To examine possible differential effects of shocks by farming systems, we re-estimate Equation 1 on a subsample of children who reside in the five most dominant farming systems: mixed maize system, agro-pastoral, highlight mixed, roots, and cereal and roots as summarized in XXX

4. Preliminary results and discussion

Table 3 summarizes the correlates of HAZ and WHZ from Equation 1 from controlling for L1 weather shocks. Regarding child characteristics, younger (0-24 months old) children and boys are more likely to be both stunted and wasted than older children and girls, on average. Younger children are more stunted than older children by about a factor of 0.45 standard deviations (SD) while boys are more stunted than girls by about 0.17 SD. Children with diarrhea in the two weeks preceding the interview date are also more likely to be both stunted (0.18 SD) and wasted (.20) than those who were not. The larger the number of siblings, the more likely children will be stunted suggesting possible crowding out by other siblings.

Household-level characteristics that are positively correlated with both HAZ and WHZ include the education of the mother, good water, sanitation, and hygiene (WASH) condition, improved dwelling condition, and ownership of durable assets. Positive effect of mother's education on child nutritional status and health has previously been documented in Kenya (Abuya et al., 2012); Cameroon (Gwatkin et al., 2000); and Tanzania, Malawi, and Zimbabwe (Makoka, 2013). Conceptually, better educated women may not only earn higher, but may have better health knowledge (e.g., breastfeeding) and intra-household decision power, including over fertility, nutrition and health choices.

Poor WASH condition could spread bacteria and soil-transmitted helminths that cause diarrhea and subsequently limit the body's ability to absorb crucial micro- and macro-nutrients. Poor WASH condition proxied by open defecation has been linked to child malnutrition in Ethiopia (Headey, 2014) and Nepal (Headey and Hoddinott, 2014) while a systematic review of studies on the effects of various WASH interventions has documented marginal improvement in the linear growth of under-five children (Dangour et al., 2013).

Children of households in top tercile of livestock wealth have lower WHZ (wasted). While livestock ownership can positively affect child nutrition through increased consumption of animal-source foods, it could negatively impact child nutritional outcomes through animal-borne diarrheal diseases, substitution of breast milk, and reduced time for household and child caring (Azzarri, et al. 2015; Griffin and Abrams, 2001; Hetherington et al., 2017; Leroy and Frongillo, 2007). A recent cross-country study document a positive association between the presence of animal feces in the residential compound and stunting in Ethiopia and Bangladesh (Headey et al., 2017) while a meta-analysis of 29 studies document a positive association between domestic animal exposure and diarrheal illness in more than two-third of the studies (Zambrano et al., 2014). None of the bio-physical variables we controlled for (share of irrigation coverage, population density, market access, cluster-level livestock wealth) are significantly correlated with stunting (Table 3, column 4) or wasting (Table 3, column 8) except the length of growing period, although the magnitude is quite small.

Table 3 Pooled OLS estimates of the correlates of HAZ and WHZ (T-1 weather shocks)

	Height-for-age z-score (HAZ)				Weight-for-height z-score (WHZ)			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Child's age (months)	-0.124***	-0.121***	-0.122***	-0.123***	-0.018***	-0.017***	-0.016***	-0.015***
	(0.002)	(0.002)	(0.003)	(0.003)	(0.002)	(0.002)	(0.002)	(0.003)
Child's age^square	0.002***	0.002***	0.002***	0.002***	0.000***	0.000***	0.000***	0.000***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Male child (%)	-0.173***	-0.174***	-0.175***	-0.171***	-0.045***	-0.046***	-0.043***	-0.041***
	(0.013)	(0.014)	(0.014)	(0.015)	(0.012)	(0.013)	(0.013)	(0.014)
Child had diarrhea (past two weeks) (%)	-0.180***	-0.180***	-0.188***	-0.179***	-0.203***	-0.220***	-0.210***	-0.204***
	(0.020)	(0.021)	(0.022)	(0.022)	(0.019)	(0.020)	(0.021)	(0.021)
Child had cough (past two weeks) (%)	-0.026	0.016	0.003	-0.000	0.020	-0.047***	-0.059***	-0.064***
	(0.017)	(0.018)	(0.019)	(0.019)	(0.016)	(0.016)	(0.017)	(0.018)
Child is 0-24 months old (Child024)	-0.472***	-0.468***	-0.475***	-0.468***	-0.425***	-0.466***	-0.496***	-0.480***
	(0.030)	(0.042)	(0.044)	(0.046)	(0.026)	(0.038)	(0.039)	(0.041)
Woman's education in single years	0.032***	0.038***	0.036***	0.034***	0.055***	0.042***	0.029***	0.027***
	(0.002)	(0.003)	(0.003)	(0.003)	(0.002)	(0.002)	(0.003)	(0.003)
Age of child's mother at birth (years)	0.018**	0.018**	0.012	0.012	-0.002	-0.007	0.004	0.003
	(0.008)	(0.009)	(0.009)	(0.009)	(0.007)	(0.008)	(0.008)	(0.008)
Age of the mother (years)^2	-0.000	-0.000	0.000	0.000	0.000	0.000	-0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Total number of children ever born	-0.026***	-0.027***	-0.026***	-0.028***	-0.000	0.009*	0.005	0.007
	(0.005)	(0.006)	(0.006)	(0.006)	(0.005)	(0.005)	(0.005)	(0.005)
Female household head (%)	0.007	0.021	-0.020	-0.023	0.019	0.009	-0.007	-0.005
	(0.020)	(0.021)	(0.022)	(0.023)	(0.017)	(0.018)	(0.018)	(0.019)
Top tercile of WASH condition (index)	0.053***	0.035*	0.014	0.011	0.075***	0.087***	0.044**	0.041*
	(0.019)	(0.020)	(0.022)	(0.022)	(0.018)	(0.018)	(0.021)	(0.021)
Top tercile of good dwelling condition (index)	0.113***	0.099***	0.112***	0.101***	0.125***	0.073***	0.038*	0.048**
	(0.018)	(0.019)	(0.022)	(0.023)	(0.017)	(0.018)	(0.020)	(0.021)
Top tercile of durable assets (index)	0.131***	0.078***	0.095***	0.090***	0.028*	0.051***	0.046***	0.045***
	(0.017)	(0.017)	(0.018)	(0.019)	(0.016)	(0.016)	(0.017)	(0.017)
Top tercile of livestock ownership (index)	0.064***	0.019	0.027	0.043*	-0.082***	-0.051***	-0.085***	-0.076***
	(0.019)	(0.019)	(0.022)	(0.023)	(0.019)	(0.018)	(0.019)	(0.020)

Table 3 Pooled OLS estimates of the correlates of HAZ and WHZ (T-1 weather shocks) (‘Cond)

	Height-for-age z-score (HAZ)				Weight-for-height z-score (WHZ)			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Months of dry spell (Dryspell)		0.042**	-0.038	-0.029		-0.094***	-0.060***	-0.069***
		(0.018)	(0.024)	(0.025)		(0.018)	(0.023)	(0.024)
Months of wet spell (Wetspell)		0.050***	0.010	0.009		-0.064***	-0.064***	-0.053***
		(0.014)	(0.016)	(0.017)		(0.012)	(0.014)	(0.015)
Months of cold wave (Coldwave)		0.025	0.025	0.061		0.029	-0.032	0.008
		(0.024)	(0.034)	(0.039)		(0.021)	(0.027)	(0.032)
Months of heat wave (Heatwave)		-0.022***	-0.034**	-0.039**		0.038***	0.015	0.019
		(0.008)	(0.015)	(0.016)		(0.008)	(0.014)	(0.015)
DryspellXChild024		0.047**	0.046*	0.045*		-0.014	-0.012	0.013
		(0.023)	(0.023)	(0.024)		(0.025)	(0.026)	(0.026)
WetspellXChild024		-0.003	-0.005	-0.000		0.040**	0.057***	0.037*
		(0.018)	(0.019)	(0.020)		(0.018)	(0.019)	(0.021)
ColdwaveXChild024		0.040	0.035	0.030		0.012	0.006	-0.032
		(0.029)	(0.031)	(0.035)		(0.029)	(0.030)	(0.034)
HeatwaveXChild024		0.010	0.007	0.006		0.002	0.004	0.004
		(0.010)	(0.010)	(0.010)		(0.010)	(0.010)	(0.010)
LTA monthly precipitation (millimeters)		-0.000	0.004**	0.003		0.004***	0.002	0.000
		(0.001)	(0.002)	(0.002)		(0.001)	(0.001)	(0.002)
LTA monthly precipitation ^2		0.000	-0.000**	-0.000*		-0.000***	-0.000	-0.000
		(0.000)	(0.000)	(0.000)		(0.000)	(0.000)	(0.000)
LTA monthly temperature (degree Celsius)		0.003	0.101***	0.075**		0.140***	0.127***	0.127***
		(0.022)	(0.034)	(0.037)		(0.022)	(0.033)	(0.036)
LTA monthly temperature ^2		0.001	-0.001	-0.000		-0.004***	-0.004***	-0.004***
		(0.000)	(0.001)	(0.001)		(0.000)	(0.001)	(0.001)
Share of irrigated crop land				0.000				0.001
				(0.001)				(0.001)
Rural population density (#/sq km)				0.000				-0.000
				(0.000)				(0.000)
Length of growing period (days)				0.002**				0.002***
				(0.001)				(0.001)
Top tercile of cluster-level livestock wealth (index)				-0.011				-0.022
				(0.028)				(0.027)
Travel time to cities with 20K people (minutes)				-0.000				-0.000
				(0.000)				(0.000)
Constant	-0.114	-0.657**	-2.224***	-2.282***	0.108	-1.097***	-1.088***	-1.358***
	(0.127)	(0.287)	(0.414)	(0.484)	(0.120)	(0.273)	(0.371)	(0.434)
Fixed effects for:								
Country	No	No	Yes	Yes	No	No	Yes	Yes
Interview month	No	No	Yes	Yes	No	No	Yes	Yes
Agro-ecological zone	No	No	Yes	Yes	No	No	Yes	Yes
Number of observations	84,818	72,073	66,639	61,274	84,818	72,073	66,639	61,274
R2	0.115	0.115	0.125	0.127	0.034	0.062	0.079	0.080
F	370.489	204.011	101.983	90.985	102.487	75.694	56.509	47.196

note: *** p<0.01, ** p<0.05, * p<0.1. LTA= Long-term average.

Sample includes rural under-five children in the most recent DHS wave (between 1990 and 2010).

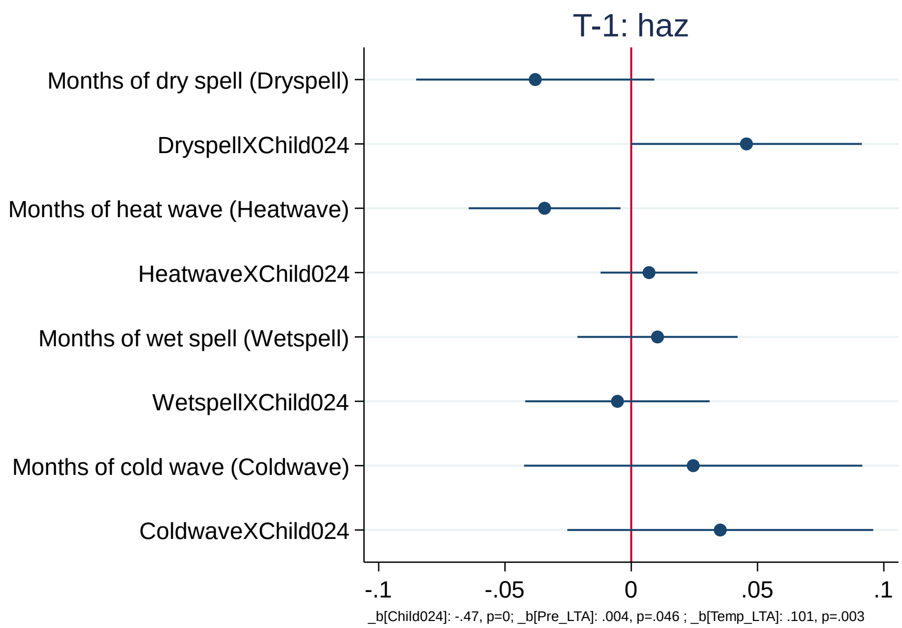
Robust standard errors are reported.

For ease of presentation, coefficient estimate of the T-1 weather variables from columns 3 and 7 of Table 3 are summarized in Figure 5 (5a and 5b). The corresponding estimates on the effects of cumulative (T-1 to T-5) are summarized in Figure 6 (6a and 6b). Effects of shocks by selected farming systems are summarized in Figures 5c (HAZ) and 6c (WHZ). A negative association is found between T-1 as well as cumulative (T-1 to T-5) wet spells and WHZ of older children (5b and 6b). While drought condition negatively affects seed germination, plant growth, yields, and livestock, excess rainfall may lead to surface runoff and soil waterlogging - especially in already degraded areas-, cause damages to crops and livestock, worsen phyto-pathological conditions, and cause overall logistical challenges (Papaioannou and de Haa, 2015). Indeed, flooding was the most prevalent disaster in North Africa, while it was the second and third most prevalent disaster in East, South and Central Africa, and West Africa, respectively (AWDR, 2006). A higher incidence of wasting has previously been linked with (repeated) expose to flooding (Rodriguez-Llanes et al., 2016). Indeed, further analysis of the intensity of expose to above-average precipitation (and possibly flooding) shows a significantly lower predicted WHZ in areas that experienced above-average precipitation in more than 50% of the planting and growing season months in the preceding five years (Figure 7).

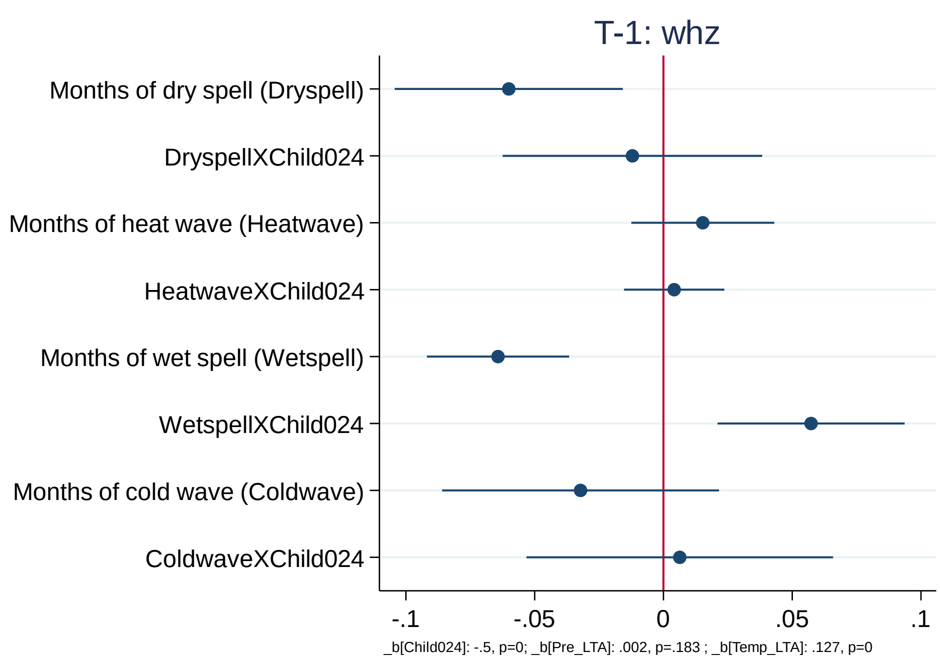
Higher dry spell (drought condition) is negatively associated with HAZ and WHZ of older (25-59 months old) children, although the association is statistically significant in the latter case (Figure 5a-5b). Similar findings are reported by Grace et al (2012) (in Kenya) and Hoddinott and Kinsey (2001) (in Zimbabwe). A stronger negative effect of T-1 heat waves on HAZ is found for highland mixed and roots and tubers systems, relative to maize mixed system (Figure 5c).

Figure 5 T-1 weather shocks and child malnutrition (0-59 months old children)

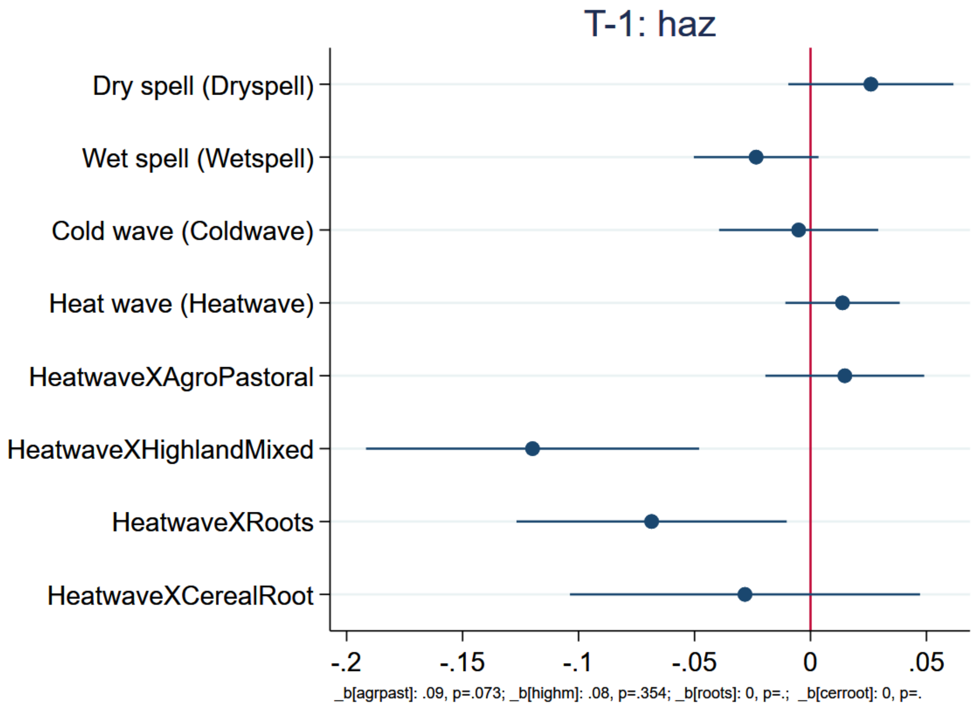
5a. HAZ by age cohort



5b. WHZ by age cohort



5c. HAZ for 24-59 months old children by selected farming systems

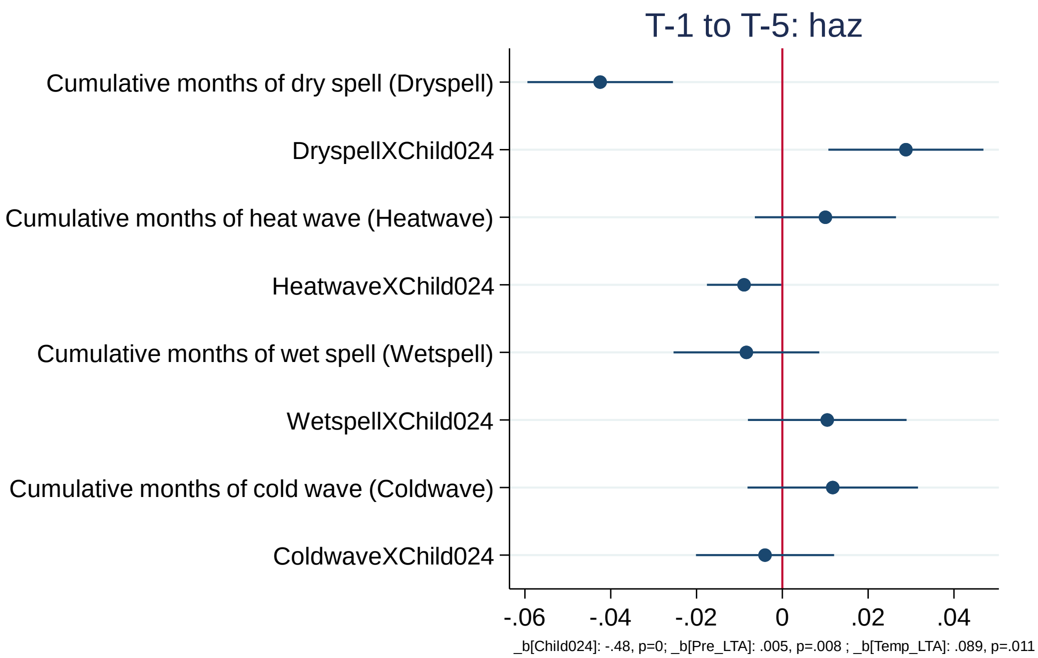


Note: Omitted farming system is maize-mixed system

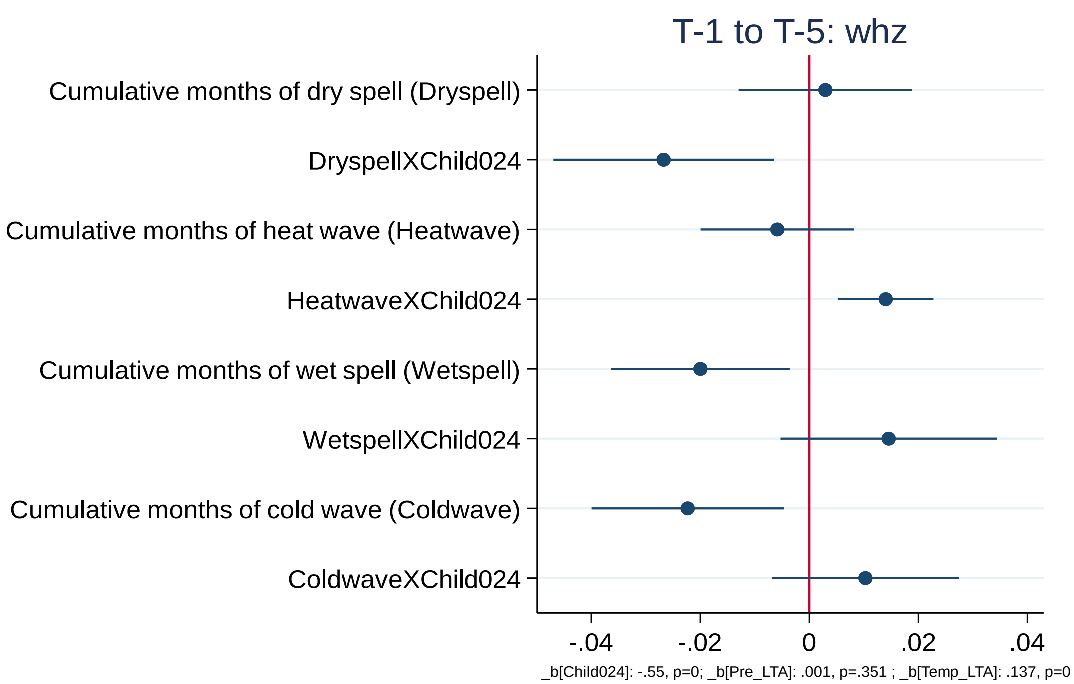
We also find a negative association between T-1 as well as cumulative (T-1 to T-5) wet spells on WHZ of older children. While drought condition negatively affects seed germination, plant growth, yields, and livestock, excess rainfall may lead to surface runoff and soil waterlogging -especially in already degraded areas-, cause damages to crops and livestock, worsen phyto-pathological conditions, and cause overall logistical challenges (Papaioannou and de Haa, 2015). Indeed, flooding was the most prevalent disaster in North Africa, while it was the second and third most prevalent disaster in East, South and Central Africa, and West Africa, respectively (AWDR, 2006). A higher incidence of wasting has previously been linked with (repeated) expose to flooding (Rodriguez-Llanes et al., 2016). Indeed, further analysis of the intensity of expose to above-average precipitation (and possibly flooding) shows a significantly lower predicted WHZ in areas that experienced above-average precipitation in more than 50% of the planting and growing season months in the preceding five years (Figure 7). Finally, Figure 6c shows persistent heat wave in roots and tuber system is associated with higher incidence of stunting, relative to that in a maize-mixed system.

Figure 6 Cumulative weather shocks and child malnutrition

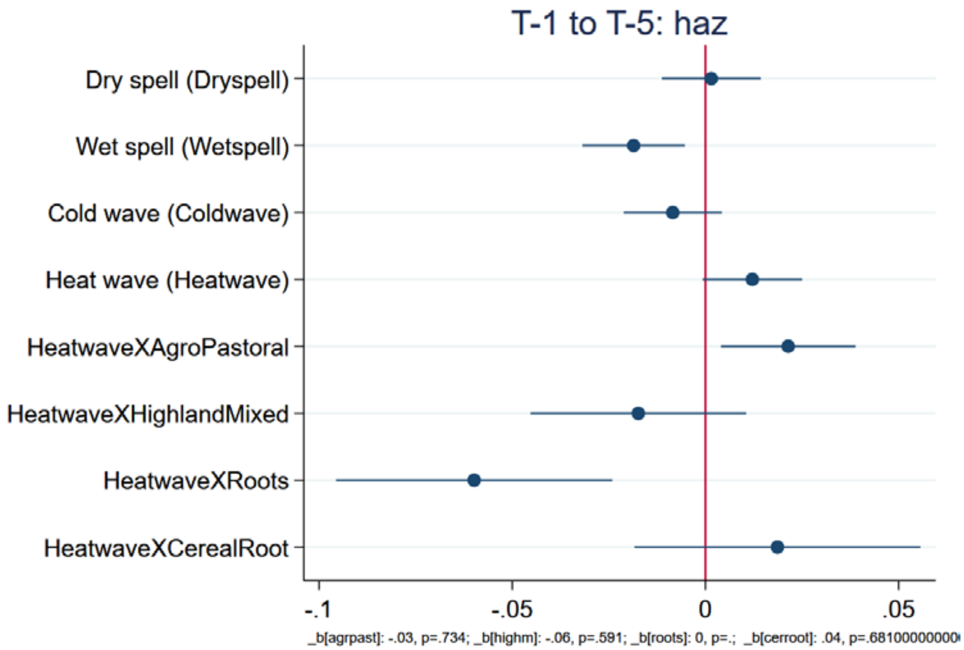
6a. HAZ by age cohort



6b. WHZ by age cohort

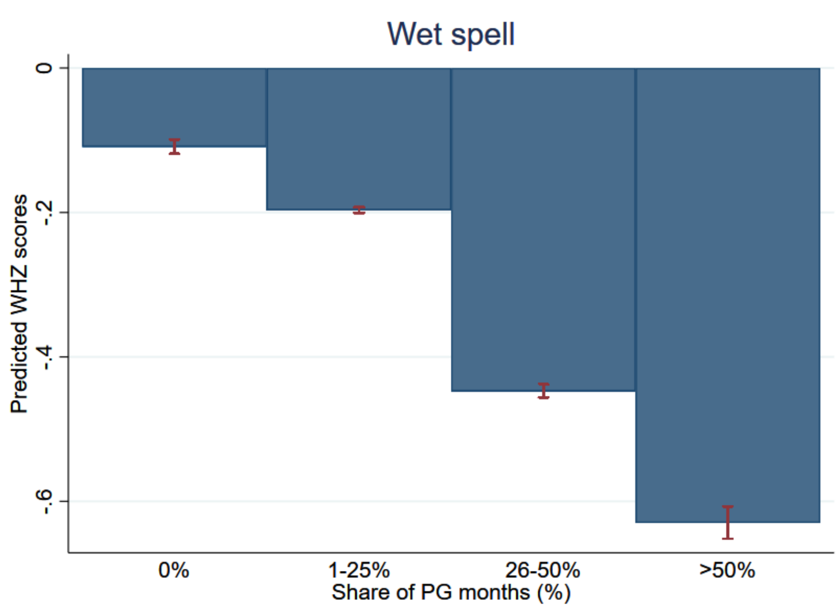


6c. HAZ for 24-59 months old children by selected farming systems



Note: Omitted farming system is maize-mixed system

Figure 7 Cumulative weather shocks and predicted WHZ (under-five children)



Notes: reported are averages of predicted WHZ values from the OLS estimation of Equation 1 along with the 95% confidence interval bands.

5. Conclusion

Millions of substance farmers in Africa south of the Sahara (SSA) find themselves permanently close to the poverty line, swinging above or below it, depending on “good” or “bad” weather conditions. Projected climatic changes will likely shorten the growing seasons, increase the frequency and intensity of weather shocks, and reduce yields, further increasing the vulnerability of subsistence smallholders. Despite progresses made over the last several decades, SSA is among regions with high incidence of food and nutrition insecurity, a phenomenon in turn affected by complex and intertwined socioeconomic, cultural, and bio-physical factors affecting the availability, accessibility, and utilization of food.

This cross-country study analyzes data from 24 countries in SSA to examine the correlates of child (0-59 months old) malnutrition, with special focus on the effects of precipitation and temperature shocks that occurred during the planting and growing (PG) seasons of the respective country. Standardizes height-for-age (stunting) and weight-for-height (wasting) z-scores are used to measure child nutritional outcomes. The study contributes to the growing evidence base on the climate-nutrition linkage through improved measurement of climatic and weather shocks that are relevant to the specific farming system and agro-ecological conditions under investigation.

We document heterogeneity in the incidence of child nutrition as well as the effects of climatic shocks by agro-ecology as well as farming system, that we are currently examining further based daily (versus monthly) climatic data. We find several socioeconomic (policy) variables to reduce the likelihood of stunting and wasting including mother’s education and overall household wealth, the latter proxied by improved water, sanitation, and hygiene condition; better quality of household’s dwelling condition; and ownership of durable assets. We also find suggestive evidence of higher wasting among children of households in the top tercile of livestock wealth. The effects of whether shocks on child nutritional outcomes generally depend on the timing of shock occurrence and hence the stage(s) of child growth. Both below-average (dry spell) and above-average (wet spell) precipitation are positively correlated with under-five wasting in general and those 25-59 months old in particular. Expose to sustained dry spell (drought condition) is also positively correlated with stunting among older children.

These findings highlight that —especially in low-resource or subsistence-farming rural settings— long-lasting child nutritional responses to weather shocks should be seriously considered to counteract detrimental effects both in the short-term—morbidity and mortality—and long-term effects —cognitive development, educational achievement and overall economic productivity. The study also contributes to the growing literature on potential risks to child nutritional outcomes associated with livestock ownership, as well as the role for maternal education and improved water, sanitation and hygiene (WASH) in combating child malnutrition. We are currently conducting further analysis using daily climatic data (versus monthly climatic data) to tease out the mechanisms (agriculture versus health) through which climatic variability affects nutritional status in Africa.

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Appendix

Table A1: Summary of study countries by available phases of DHS

Country	*1990*	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*	*1997*	*1998*	*1999*	*2000*	*2001*	*2003*	*2004*	*2005*	*2006*	*2007*	*2008*	*2009*	*2010*	*Total*
Burundi																				P6	1
Cameroon														P4							1
Ethiopia											P4				P5						2
Ghana				P3					P4				P4					P5			4
Kenya				P3					P3				P4					P5			4
Lesotho														P4					P6		2
Madagascar			P2					P3					P4								3
Malawi			P2								P4			P4						P6	4
Mali						P3										P5					2
Mozambique								P3					P4								2
Namibia			P2								P4					P5					3
Niger									P3							P5					2
Nigeria	P2									P4			P4					P5			4
Rwanda			P2								P4				P5					P6	4
Senegal			P2												P4					P6	3
Swaziland																P5					1
Tanzania		P2					P3			P4				P4						P6	5
Uganda						P3					P4					P5					3
Zambia			P2				P3					P4					P5				4
Zimbabwe					P3					P4					P5					P6	4

Note: P= DHS Phase