

Amondo, Emily Injete; Nshakira-Rukundo, Emmanuel; Mirzabaev, Alisher

Article — Published Version

The effect of extreme weather events on child nutrition and health

Food Security

Provided in Cooperation with:

Springer Nature

Suggested Citation: Amondo, Emily Injete; Nshakira-Rukundo, Emmanuel; Mirzabaev, Alisher (2023) : The effect of extreme weather events on child nutrition and health, Food Security, ISSN 1876-4525, Springer Netherlands, Dordrecht, Vol. 15, Iss. 3, pp. 571-596, <https://doi.org/10.1007/s12571-023-01354-8>

This Version is available at:

<https://hdl.handle.net/10419/312509>

Standard-Nutzungsbedingungen:

Die Dokumente auf EconStor dürfen zu eigenen wissenschaftlichen Zwecken und zum Privatgebrauch gespeichert und kopiert werden.

Sie dürfen die Dokumente nicht für öffentliche oder kommerzielle Zwecke vervielfältigen, öffentlich ausstellen, öffentlich zugänglich machen, vertreiben oder anderweitig nutzen.

Sofern die Verfasser die Dokumente unter Open-Content-Lizenzen (insbesondere CC-Lizenzen) zur Verfügung gestellt haben sollten, gelten abweichend von diesen Nutzungsbedingungen die in der dort genannten Lizenz gewährten Nutzungsrechte.

Terms of use:

Documents in EconStor may be saved and copied for your personal and scholarly purposes.

You are not to copy documents for public or commercial purposes, to exhibit the documents publicly, to make them publicly available on the internet, or to distribute or otherwise use the documents in public.

If the documents have been made available under an Open Content Licence (especially Creative Commons Licences), you may exercise further usage rights as specified in the indicated licence.



<https://creativecommons.org/licenses/by/4.0/>



The effect of extreme weather events on child nutrition and health

Emily Injete Amondo¹ · Emmanuel Nshakira-Rukundo^{2,3} · Alisher Mirzabaev^{1,2}

Received: 22 November 2021 / Accepted: 14 February 2023 / Published online: 16 March 2023
© The Author(s) 2023

Abstract

This study traces the causal effects of extreme weather events on nutritional and health outcomes among rural children in Uganda using four waves of individual child survey data (2009–2014). A simultaneous regression model was applied for causal inference while also accounting for households' adaptive responses. The study finds the evidence of a significant negative relationship between extreme weather events and availability of calories and nutrients for children. In particular, droughts reduced calorie, protein and zinc supply, and overall diet diversity by 67%, 37%, 28% and 30%, respectively. We further traced the effects of this reduced calorie and nutrient availability on child health indicators. A 10% decrease in zinc supply decreased height-for-age z-scores (HAZ) by around 0.139–0.164 standard deviations (SD), and increased probability of stunting ranging from 3.1 to 3.5 percentage points. Both boys and girls HAZ and stunting rates were sensitive to nutrient inadequacies. Different coping and adaptation strategies significantly influenced rural households' ability to safeguard children's nutrition and health against the effects of extreme weather. The findings of this study provide specific insights for building ex-ante resilience against extreme weather events, particularly when compared to ex-post, unsustainable, and often costlier relief actions.

Keywords Nutrition · Child stunting · Droughts · Heat waves · Zinc · Livestock

JEL Codes O13 · Q54 · I15 · C3

1 Introduction

The intensity and frequency of extreme weather events has increased globally over the past two decades. The year 2016 was the hottest year on record, whereas the last five years since 2015 were the warmest years in a series (World Meteorological Organization, 2019, 2020). An estimated 712 extreme weather events occurred in 2017 (Watts et al., 2018), and approximately 160 million resided in areas experiencing extreme droughts and 500 million children lived in areas experiencing extreme floods in 2015 (Ghani et al., 2017; United Nations Children's Fund, 2015b). Future climate change projections predict warmer years and more

extreme weather events (Watts et al., 2018; Yobom, 2020), potentially posing severe risks to human well-being and health (Filippelli et al., 2020; Watts et al., 2019). More than half of the world's population will be residing in water stressed areas by the year 2025 (Phalkey & Louis, 2016), and the number of undernourished children is projected to increase by an extra 25 million by 2050, comparing with and without climate change using the A2¹ scenario with the year 2000 as the base year (Phalkey et al., 2015).

Extreme weather events and climate change impact the health of people through injuries, illness, deaths, and under-nutrition (Bell et al., 2018; Filippelli et al., 2020; Franzke & i Sentelles, 2020). Watts et al. (2019) indicate that children born today are likely to experience a warmer world (at least 4°C/39.2°F above the historical average), facing higher climate-related health impacts in all stages of their lives. Compared to other age groups, children are particularly vulnerable, as they are susceptible to undernutrition and infectious diseases

✉ Emily Injete Amondo
s7emamon@uni-bonn.de; emijete@gmail.com

¹ Center for Development Research (ZEF), University of Bonn, Genscherallee, Bonn 3 53117, Germany

² Institute for Food and Resource Economics, University of Bonn, Nußallee, Bonn 19-21 53115, Germany

³ Apata Insights, Kampala, Uganda

¹ This is one of the scenarios families used in the Intergovernmental Panel on Climate Change (IPCC), Special Report on Emissions Scenarios (SRES) (Smith et al., 2014).

(Burke & Lobell, 2010; Smith et al., 2014; Watts et al., 2019), in addition to their underdeveloped metabolism and physiology (Ahdoot & Pacheco, 2015). Bhutta et al. (2019) estimate that nearly 88% of the disease burden arising from climate change and variability is borne by children.

One of the major health impacts of extreme weather and climate change is child undernutrition in the form of low height-for-age z-scores (HAZ) or stunting (Cooper et al., 2019; Hasegawa et al., 2016). Undernutrition is a risk factor for other infectious and respiratory diseases, which are among the leading causes of child death (Aryeetey et al., 2021; Hasegawa et al., 2016; Troeger et al., 2018). These early life health effects have severe consequences on children's physical and cognitive development, hence future human capital and economic productivity (Headey et al., 2018; Phalkey et al., 2015).

Therefore, understanding how extreme weather events affect child health is essential. While direct health effects occur from weather extremes, such as injuries, heat stress and disaster-related mortality (Filippelli et al., 2020), the most detrimental and lifelong impacts on child health are mediated through socioeconomic factors, such as food insecurity, or illness (Phalkey & Louis, 2016; Smith et al., 2014). While child undernutrition is indirectly affected by extreme weather events, there remain few empirical studies focusing on these correlations (Phalkey and Louis 2016; Phalkey et al. 2015). Little is known about the indirect mechanisms such as food and nutrition security. Therefore, we comprehensively study how extreme weather events affect different components of food security, and their effect on chronic undernutrition.

Our study contributes to previous studies assessing the effect of different extreme weather events and climate variability on child nutrition and health, while considering different child development periods of early life, including while still in utero. Hu and Li (2019) found that heat stress experienced during pregnancy had long-term negative effects on the height of the individual born later in life, whereas Deschenes et al. (2009), Grace et al. (2015), and Molina and Saldarriaga (2017) reported a negative relationship between extremely high temperatures and birth weight. Similarly, Blom et al. (2022) found that extreme heat increased both acute and chronic malnutrition while Bratti et al. (2021) found that exposure to heat waves while the child is in utero increased the prevalence of being severely stunted. However, Baker and Anttila-Hughes (2020) study in 30 SSA countries did not document an impact of recent temperatures on HAZ and stunting, even though they report a strong negative effect of average monthly and annual temperatures on weight-based measures of children across regions.

It's important to highlight that the pathways through which heat affect chronic and acute malnutrition may not be similar (Blom et al., 2022). However, the discussion on which mechanism applies for each of the undernutrition measures remain

inconclusive. For instance, while Blom et al. (2022) stated that heat-induced crop failure may lead to long-term insufficient intake of calories resulting into chronic malnutrition, acute malnutrition may result from short-term illness caused by heat-induced food spoilage. Baker and Anttila-Hughes (2020) provide evidence of agriculture as the main channel through which temperature affect child weight, especially among rural children while Bratti et al. (2021) does not provide evidence of food scarcity as the potential mechanisms because of data limitations.

Apart from the indirect agriculture or food availability or nutrition channels, high temperatures may directly cause heat stress which has physiological effects in children, especially among infants less than one year old, mainly because they have least developed thermal regulation systems (Blom et al., 2022). Thermal stress-induced loss in appetite may lead to child's inability to retain available nutrients, increase diarrhea and dehydration, hence result in poor nutrients and calorie absorption causing weight loss (Baker & Anttila-Hughes, 2020). Other food related mechanisms through which temperature or heat may affect child undernutrition include reduced consumption of animal source proteins as a consequence of livestock mortality, decreased egg, milk production and agricultural income as a result of heat stress, (Blom et al., 2022). At longer time scales, nutritional values of food crops may be affected by high temperatures leading to reduced nutritional intake (Baker & Anttila-Hughes, 2020). Furthermore, high temperatures may increase water scarcity, poor sanitation, increase risk of violent conflict and reduced labor productivity, all of which affect food security.

Previous studies demonstrated significant relationships between droughts or low precipitation and child HAZ or stunting (Bahru et al., 2019; Cooper et al., 2019; Dercon & Porter, 2014; Grace et al., 2012; Hagos et al., 2014; Hoddinott & Kinsey, 2001; Muttarak & Dimitrova, 2019; Shively, 2017). Some studies only observed the effects of extreme weather events on HAZ through mediating factors. For instance, Hirvonen et al. (2020) documented that droughts did not significantly lead to undernutrition (stunting or low HAZ) directly, but their effects could only be observed through mediating factors such as poor road network. Other mechanisms through which precipitation, particularly drought may affect child health include; reduced agricultural production and low nutrient intake (Trinh et al., 2021), spread of infectious diseases such as diarrhea and malaria because of lack of safe drinking water and poor mental health of the parents (Rocha & Soares, 2015; Trinh et al., 2021). As earlier highlighted, these mechanisms depend on the child health measure under consideration and weather shock indicators. The disease pathway especially diarrhea has been previously studied by authors focusing on weight-based measures (Omiat & Shively, 2020). Furthermore, Rabassa et al. (2014), provides evidence of disease

environment as an important channel through which rainfall shocks affect child health in the short-run on WHZ scores. However, they indicate that the income effect operating through agriculture was stronger than the effect from the disease environment (Rabassa et al., 2014).

Increased droughts and stunting rates have been previously reported in sub-Saharan Africa (SSA) (Phalkey & Louis, 2016), despite worldwide reductions in undernutrition rates. A high dependence on rainfed agriculture makes households in this region more vulnerable to extreme weather events and climate change (Di Falco et al., 2011; Radeny et al., 2019). As the likelihood of extreme weather events increases, progress toward “a world with food security for all” (von Braun, 2020) is not only in jeopardy but could also reverse the gains in stunting reduction that have been achieved globally (Cooper et al., 2019), unless preemptive adaptation measures and safety nets are in place.

Unpacking the causal mechanisms between climate variables and undernutrition is essential, particularly regarding agriculture-dependent households. We focus on HAZ and other agriculture-related pathways that have received little attention yet are essential to child health for rural households. Our choice of HAZ is informed by the high prevalence of stunting in Uganda in comparison to other undernutrition measures. Furthermore, low HAZ or stunting may have long-term effects on children in their later lives (Cooper et al., 2019; Yamano et al., 2005). We also focus on crop production and the selected nutrients as potential mediators, because crop production is a major determinant of nutrient availability, with 68% of zinc, 81% of iron, and 63% of proteins in human diets derived from vegetable sources globally (Smith & Myers, 2018), and most households in Uganda derive their food from own production. Similarly, livestock products play a key role in children’s nutrition in early life, especially in the first 1,000 days (Alonso et al., 2019).

This study has three key contributions. First, we implement a simultaneous analysis of multiple related channels that are important to rural households’ nutrition and health and are sensitive to weather extremes. Importantly, we assess the relationship between extreme weather events and the supply of calories, macro- and micronutrients that are important to child growth and development, considering both the production side and consumption side. Limited empirical evidence has been produced on the effect of weather extremes on the nutrient composition of food crops and the resulting effect of nutrients on child health. To the best of our knowledge, none of the studies cited above examined the nutrient supply pathways. Secondly, this study uses longitudinal data on children’s anthropometric measures to assess the mechanisms through which extreme weather events affect children’s health in terms of HAZ, and considers lagged effects of shocks on child health. Finally, we examine strategies that households use to minimize the

negative effects of weather extremes, providing practical insights for preemptive planning and policy development.

We find evidence of significant and negative effects of both temperature and precipitation extremes on the quality of food crops produced, food crops consumed, and livestock. However, better and significant child anthropometry outcomes were realized through the crop production channel, particularly through increased supply of zinc, proteins, and calories. We also confirm significant impacts of livestock holding on child HAZ. Therefore, it is evident that child health is affected by droughts and heat waves through the effects of these events on nutrient and crop production. Adaptation and coping strategies helped households mitigate the negative effects of different weather extremes on both crop production and child health.

The remainder of the paper is organized as follows: section 2 outlines literature in the context of Uganda, conceptual and theoretical framework, section 3 describes the materials and methods, section 4 presents the empirical results and relevant discussions are in section 5, and section 6 concludes.

2 Context, conceptual and empirical frameworks

2.1 Extreme weather events, undernutrition and relevant literature for Uganda

Uganda is selected for this study, because it is highly dependent on rainfed agriculture, vulnerable to weather anomalies and infectious diseases, and prone to food and nutritional insecurities (Food and Agriculture Organization of the United Nations, 2020; The Government of Uganda, 2018). Uganda was ranked as the 14th most affected country globally by extreme weather events in terms of economic losses and fatalities in 2018 (Eckstein et al., 2019), and annual temperatures are projected to increase by 3.2°C in some areas in the near future until 2050 as compared to 1960 (Maggio et al., 2021). Furthermore, child undernutrition and mortality rates are high in Uganda. For instance, a third of the total child population in the country (2.4 million) are stunted, and 250,000 deaths of young children that occurred from 2013 to 2015 were attributed to undernutrition (United Nations Children's Fund, 2015a). Hunger is also critical, with the country being ranked in position 104 out of the total 119 countries in 2019 on the hunger index² (von Grebmer et al., 2019). Undernutrition remains a contributory

² Three of the four indicators used to construct the hunger index score are related to child nutrition and health (child stunting, child wasting, and child mortality) and undernourishment.

risk factor to both disability and premature death in Uganda (Food and Agriculture Organization of the United Nations, 2020; Institute for Health Metrics and Evaluation, 2019).

While the relationship between climate shocks and under-nutrition have been extensively studied, very few studies have explored some mechanisms through which this relationship occurs, in Uganda. Some of the mechanisms that have been explored in the country include food production (crop yield) and disease mechanism on wasting or WHZ (Omiat & Shively, 2020), mothers time use on WAZ and WHZ (Boyd, 2021). While the former study provided some evidence of the explored mechanisms where positive, strong and significant effect of crop yields on WHZ were observed, and weak negative associations reported for the disease mechanism, the later study found that mother's time-use in agricultural work or in other off- farm and domestic activities was not a mechanism mediating climate-underweight relationship. Boyd (2021) concludes that in the short run, when affected with rainfall shock mothers adapt their time use as a means of safeguarding their children nutrition so that it is not negatively affected. Most of the abovementioned studies focused on weight-based measures excluding (Shively, 2017) who considered both HAZ and WAZ. Other closely related studies in Uganda such as Antonelli et al. (2020) focused on food consumption mechanism (calories) of climate shocks on labor supply instead of health.

The findings of this study are also highly useful for other developing countries. More information on the location of Uganda and its historical temperature and rainfall trends is shown in Figs. S1 and S2 in the supplementary materials.

2.2 Conceptual framework

Source: Own elaboration

The pathways under study are agricultural and food related and they include; food nutrients produced and consumed, household diet diversity and livestock holdings. The infrastructure component which has effects on food (as illustrated in Fig. 1) is more likely to occur through floods and not necessarily droughts, thus not covered in this study. Failures in seasonal rainfall is directly linked to crop failure, which further leads to not only reduction in household food availability, but also creates limitation to employment possibilities in rural areas (Haile, 2005). If unusual dry conditions occur, water supply to the crops at different phases of crop growth is limited. Dry conditions may also exacerbate soil erosion and soil moisture deficiency (Ding et al., 2011). Lack of sufficient water and nutrients for the crops and pastures may eventually lead to total crop failure or reduction in nutrients supplied in the absence of adaptation or good agricultural practices such as; cultivation of drought resistant

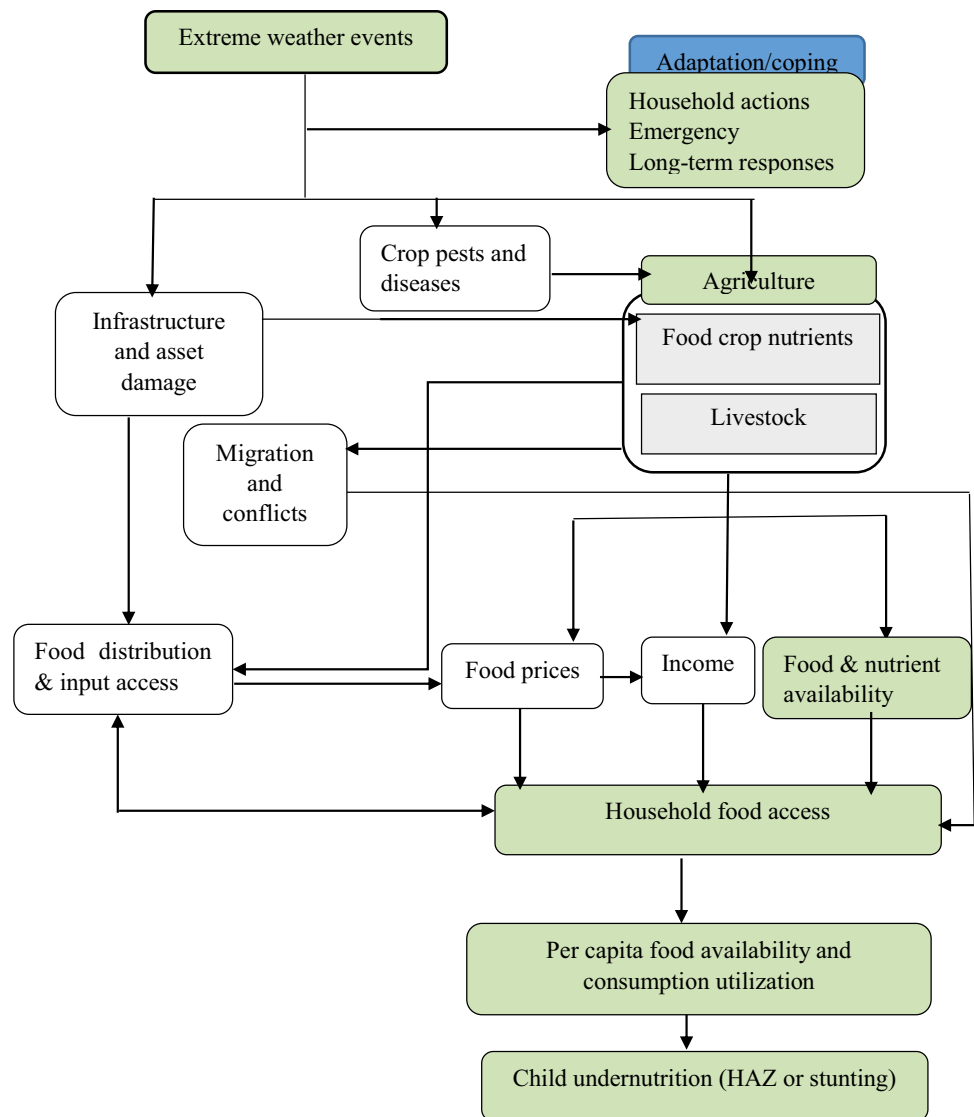
varieties, crop diversification or water harvesting technologies. Extremely high temperatures negatively impact crop growth and development, especially during germination and reproductive phase, potentially leading to low production, nutrient availability and famine (Fahad et al., 2017).

The above-mentioned extreme weather conditions may also be accompanied by pests and diseases that may destroy the crops leading to extremely low production, which in turn affect household food consumption and income. Furthermore, extreme weather events through its effect on crop production may affect food prices and overall stability of food systems (Wheeler & Von Braun, 2013). More importantly extreme weather events may have a negative effect on the quality of food crops in terms of nutrient density. For instance, during drought conditions food nutrient compositions particularly, micronutrients concentration in crops might be negatively affected (Fischer et al., 2019). Furthermore, soil moisture limitations experienced during drought conditions may inhibit acquisition and transportation of plant nutrients, and further allocation of relevant nutrients to sections of the crop that constitute food (Fischer et al., 2019). Some of the micronutrients in plants that have been found to be susceptible to climatic factors include zinc and iron (Nelson et al., 2018; Singh et al., 2012; Smith & Myers, 2018). Extreme weather events and climate change also have negative effects on the supply of calories and macronutrients such as protein (Nelson et al., 2018; Singh et al., 2012; Smith & Myers, 2018) obtained from staple crops, as well as other crops.

Increase in crop output have a direct effect on food, nutrient availability and consumption, thus a positive effect on child nutritional status. Increase in micronutrients are expected to have a positive effect on child health and vice versa for decreases. Micronutrients such as zinc, iron and vitamin A are important nutrients globally and are particularly of public health concern in developing countries (Gibson, 2006; Nelson et al., 2018; Singh et al., 2012). The aforementioned micronutrients are ranked among top ten risk factors for illness (Singh et al., 2012), and are projected to remain a problem in 2050, especially in poorest nations as compared to richer countries (Nelson et al., 2018). Insufficient intake of these mineral nutrients and vitamins, especially zinc deficiency affects human health especially child growth and development thus leading to stunting (Fischer et al., 2019; Gibson, 2006; Rivera et al., 2003). In fact, the prevalence of child stunting is used by International Zinc Nutrition Consultative group as an indirect measure of likelihood of zinc deficiency risk, and interventions related to zinc supplements as treatment of diarrhea and has a positive response on linear growth (Gibson, 2006).

Animal source foods such as poultry, dairy, meat and fish are rich sources of proteins and micronutrients such as iron and zinc. Previous studies show the sensitivity of livestock

Fig. 1 Flowchart effect of extreme weather events on chronic undernutrition, through food channel. The arrows show direction of effect



Source: own elaboration

to extreme weather events (Murray-Tortarolo & Jaramillo, 2019, 2020) which negatively affect livestock productivity and composition of livestock products (Nelson et al., 2018), reproduction, general growth and health of the livestock (Rojas-Downing et al., 2017).

2.3 Theoretical framework

A child health production function framework proposed by the Cebu Study Team (Akin et al., 1992) is adopted for this study. This framework builds on earlier models by (Rosenzweig & Schultz, 1983) and is estimated as follows:

$$H_{it} = f(H_{(t-1)}, Y_{(t-1)}, X_{it}, \mu_{hi}) \quad (1)$$

where H_{it} is the health of child i at time t ; $Y_{(t-1)}$ is health-care usage and nutritional inputs in the previous period; X_{it} is a vector for exogenous variables directly affecting child health, such as gender and age; and μ_{hi} is unobserved variables affecting child health endowment, including child genetic attributes. The inclusion of the lagged values of H and Y implies that current health is also dependent on previous health and nutrition status. Apart from other individual and household variables, the Cebu Study Team indicates that climate variables are among the exogenous variables in growth and morbidity equations, particularly through their effect on health, such as the onset of diarrhea and obtaining proper nutrition (Akin et al., 1992). Therefore, weather variables as covariates for mediators in the health production function are included in this study. We focus on agriculturally

related channels, specifically calorie, proteins and micronutrient supply, and livestock holdings as potential pathways through which extreme weather events affect child health.

3 Materials and methods

3.1 Data sources

3.1.1 Living Standards Measurement Study –Integrated Surveys on Agriculture (LSMS–ISA)

This study examines four waves of data (2009–2014) from the Uganda National Panel Survey (UNPS) /World Bank (LSMS–ISA) conducted by the Uganda Bureau of Statistics (Uganda Bureau of Statistics, 2006, 2013). This study uses household, agriculture, and community questionnaires. The household questionnaire consists of sections covering household socioeconomics, including individual health data, children's anthropometry, household consumption expenditure and other indicators. The agriculture questionnaire captured data on household land holdings, crops grown, input and technology use, quantities of agricultural produce, and livestock data. We only use data on community-level market access from the community questionnaire. Sampling was executed using stratified two-stage cluster sampling, and the survey design in the different waves was maintained. We do not include later waves of the UNPS (after the 2013/2014 round) because of the sample refresh. An important feature of this dataset is that households' geographical locations were geo-referenced³. This enabled us to match households within a given enumeration area with weather-specific information.

These data are representative at the national level, with the samples drawn from all four regions of Uganda. Only rural households with children were considered in this analysis, as they are the most vulnerable to extreme weather events and dependent on agriculture for their livelihoods. Children's HAZ were collected on approximately 5000 child observations. However, with the lagged pathways and covariates, we lose one wave and only obtain 1,397 child observations containing complete information on all variables of interest to the study that are considered in the main regression analysis.

3.1.2 Food composition tables

The second source of data was the food composition table developed for Uganda by HarvestPlus (Hotz et al., 2012),

the primary source of which was the United States Department of Agriculture's National Nutrient Database for Standard Reference. Food composition tables present a comprehensive list of the crops grown and consumed in Uganda, including the relevant nutrient weights per 100 grams of specific foods (Hotz et al., 2012).

3.1.3 Weather data

Rainfall datasets were derived from the Climate Hazards group Infrared Precipitation with Stations (CHIRPS) version 2 for a time period ranging from 1981 (Funk et al., 2015). CHIRPS provide high spatial resolution ($0.05^\circ \times 0.05^\circ$) in addition to representing the only long-term spatial rainfall dataset with both satellite and in situ rainfall station data (Funk et al., 2015; Haile et al., 2018).

Monthly surface temperature data is retrieved from the Moderate Resolution Imaging Spectroradiometer (MODIS). The spatial and temporal extent of the datasets is global, from 2000 to present, and the values are presented in the same 0.05° longitude/latitude climate modeling grid (Hooker et al., 2018; Wan et al., 2015), matching the rainfall dataset. The monthly temperature (2000–2014) and rainfall datasets (1981–2014) downloaded were processed on the QGIS software and used to construct the weather indices described in the next section in STATA.

3.2 Data variables

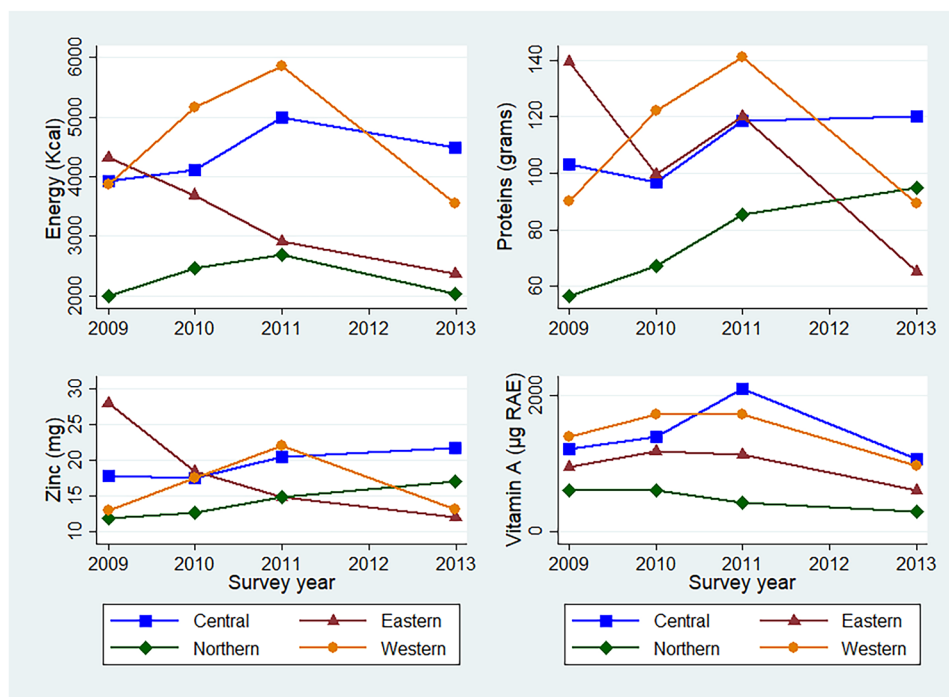
3.2.1 Outcome variables

The main dependent variable is the HAZ and stunting, based on body height or length measurements of children, taken between 6 and 59 months of age. HAZ is usually related to chronic or frequent illness and longer-term nutritional deficiencies (O'Donnell et al., 2010). Low HAZ scores of less than -2 SD are used as cutoff measure of stunting (a dummy variable) which we use in the main regression, alongside the continuous HAZ variable.

The main hypothesized pathways through which weather variables affect child health outcomes include availability of selected calories, macro- and micronutrients key to child growth and development. We use the recommended units of measurements for each nutrient type, transforming them into logarithm values. We use food composition tables (Hotz et al., 2012) to construct the nutrient variables for each household from the list of crops harvested, including cereals/grains, beans, nuts and seeds, vegetables, roots and tubers, and fruits. Additionally, we calculate the exact nutrients consumed by household members from the consumption expenditure module. We consider only plant-based foods from different sources, namely, foods consumed out of

³ In 2013/2014 wave, there was sample refresh. However, since the original identifiers were provided, the georeferenced (GPS) data from previous waves was used to download weather data. For subsequent waves, original identifiers and GPS data was not provided.

Fig. 2 Regional differences in plant-based calories, protein and micronutrient produced in Uganda



home produce, out of purchases and food consumed at home as well as those purchased and consumed away from home.

We focus on calories, protein, and two micronutrients (vitamin A and zinc). The choice of these nutrients was informed by their importance to human nutrition and health, particularly on child growth and development (Gibson, 2006; Nelson et al., 2018; Singh et al., 2012) in low developed countries (Dillon et al., 2019). To enhance comparability across different household sizes and against the recommended daily nutrient intake, in addition to promoting ease of understanding, we compute daily average per adult equivalent nutrient supply for each nutrient type. This variable was calculated by aggregating the nutrient quantities of the selected nutrients from different crops at the household level for both seasons in Uganda for each survey year, divided by adult equivalent and the number of days in a year, and linked to child data. Similar procedure is employed in calculating nutrients consumed from the consumption module where we divide the nutrients by adult equivalent and the number of days in a week since the recall period was 7 days.

Figure 2 presents a declining trend in daily supply of most nutrients over time from the production side. This decline is more evident in regions that experienced extreme weather events. Protein and zinc supply were stable in central Uganda, whereas protein supply in the northern region revealed an increasing trend. The average value of calorie supply over the survey waves was 3,810 kilo calories per adult equivalent per day, while the average calories consumed were 2,737 kilo calories per adult equivalent. This consumed value is consistent with those reported by Antonelli et al. (2020) for Uganda

and by Gebremedhin and Bekele (2021) for East Africa. The average protein supply value of 97 grams per adult equivalent per day and 58 grams per adult equivalent consumed is within the range of Gebremedhin and Bekele (2021) estimated value, whereas a vitamin A supply mean value of 1031 µg retinol activity equivalents (RAE) almost doubles those reported by (Schmidhuber et al., 2018). An average zinc value of 16 mg and 10 mg produced and consumed respectively is slightly above the recommended dietary allowance (Trumbo et al., 2001). The lag values of these nutrients were slightly higher. For convenience and the reduction of skewness, the logarithm values of the lags were used in the different estimations.

An additional food access variable household dietary diversity score (HDDS) was computed from household consumption expenditure section. The different food elements consumed from different food sources in the previous 7 days were grouped into 12 food groups (Swindale & Bilinsky, 2006) and aggregated at household to compute the total count of food groups which was later linked to individual identifiers. The average number of food groups consumed was 7 out of 12. Tropical livestock units (TLU), a weighted measure of all livestock groups, is used for livestock holdings.

3.2.2 Explanatory variables

The main explanatory variables in this study include different extreme weather variables. Since the impacts of extreme weather events on child health, nutrition, and income will

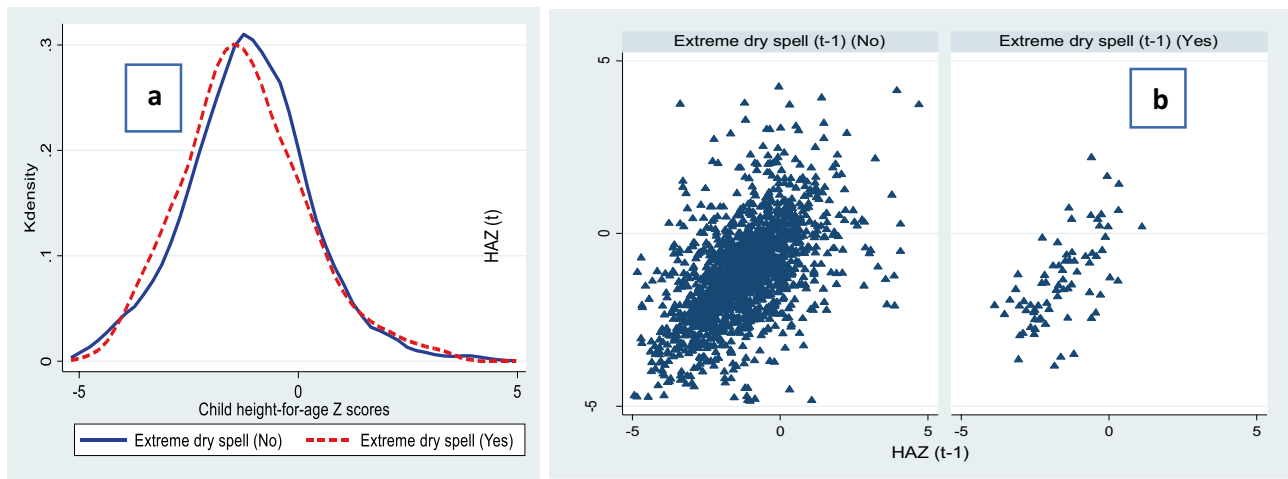


Fig. 3 Distribution of extreme dry spell (t-1) and mean HAZ (a), correlations of lagged HAZ and current HAZ, disaggregated with the extreme dry spell variable (b)

unfold over several seasons and with lags (Thai & Falaris, 2014), several weather indices were created, including the lagged variables and cumulative five-year counts of extreme events. Statistical z-scores were used in the construction of both rainfall and temperature indicators to enhance comparability as follows:

$$z_{it} = \frac{X_{it} - \bar{X}_{it}^{LTM}}{\sigma_{it}^{LT}} \quad (2)$$

where X_{it} represents the monthly temperature or seasonal rainfall amounts (sum of rainfall received in the four-month period) in each season recorded in an enumeration area, household/child i in year t . $\bar{X}_{it}^{LTM}$ indicates the historical monthly average temperature or seasonal rainfall averages corresponding to the specified months of the respective seasons for household/child i in year t , and σ_{it}^{LT} is the long-run standard deviation (SD) of household/child i in year t . The Famine Early Warning Systems Network seasonal calendar⁴ for a typical year in Uganda was used to define the respective months in the planting and growing seasons. For precipitation, we developed the z-scores of the total seasonal rainfall amounts (in millimeters) received during the main planting and growing season (first season) and the second season separately over a long-term mean of the same time periods starting 1981 to the respective survey years. We then adopted z-scores cutoffs from the World Meteorological Organization Standardized Precipitation Index (SPI), with slight modifications, to create a categorical rainfall variable of five instead of seven categories

(World Meteorological Organization, 2012) as shown in Fig. S3a.

Specifically, a dummy variable was created to indicate an extreme dry spell as rainfall below -2 SD in the main season and used in the analysis. The distribution of HAZ in Fig. 3a demonstrates that lower average HAZ was consistently recorded for children exposed to extreme dry conditions. A count variable shows the number of dry spells over a five-year period, derived through the summation of dry spell events in both seasons for the five years preceding the interview year. Positive correlations between lagged HAZ and current HAZ denote catch-up growth, as shown in Fig. 3b.

Regarding temperature, a proxy of heat wave (heat wave months) was created by counting the number of months in both the planting and growing seasons of the year, the first season in March–June and the second season in August–November, separately, wherein the z-scores were equal to or $+1$ for temperature. The respective monthly temperatures with more than 1 SD above the mean had at least an average of 29°C (84.2°F) in monthly temperature. This temperature cutoff is consistent with previous studies' definition of detrimental temperatures (Heal & Park, 2014; Hu & Li, 2019; Traore & Foltz, 2017). The spatial and temporal distribution of heat waves in the sampled areas and households are presented in Fig. 4a–d. Heat waves were consistently experienced in the Karamoja (northeastern) subregion for all time periods. The increase of heat wave events in 2010 is also notable (Fig. 4b), particularly in the southwestern region. Given that heat events exacerbate the occurrence of drought and sometimes occur simultaneously, more heat events being recorded in 2010 is consistent with The World Bank and Global Facility for Disaster Reduction and Recovery (2019) report on drought events in 2010.

⁴ <https://fews.net/file/113534>

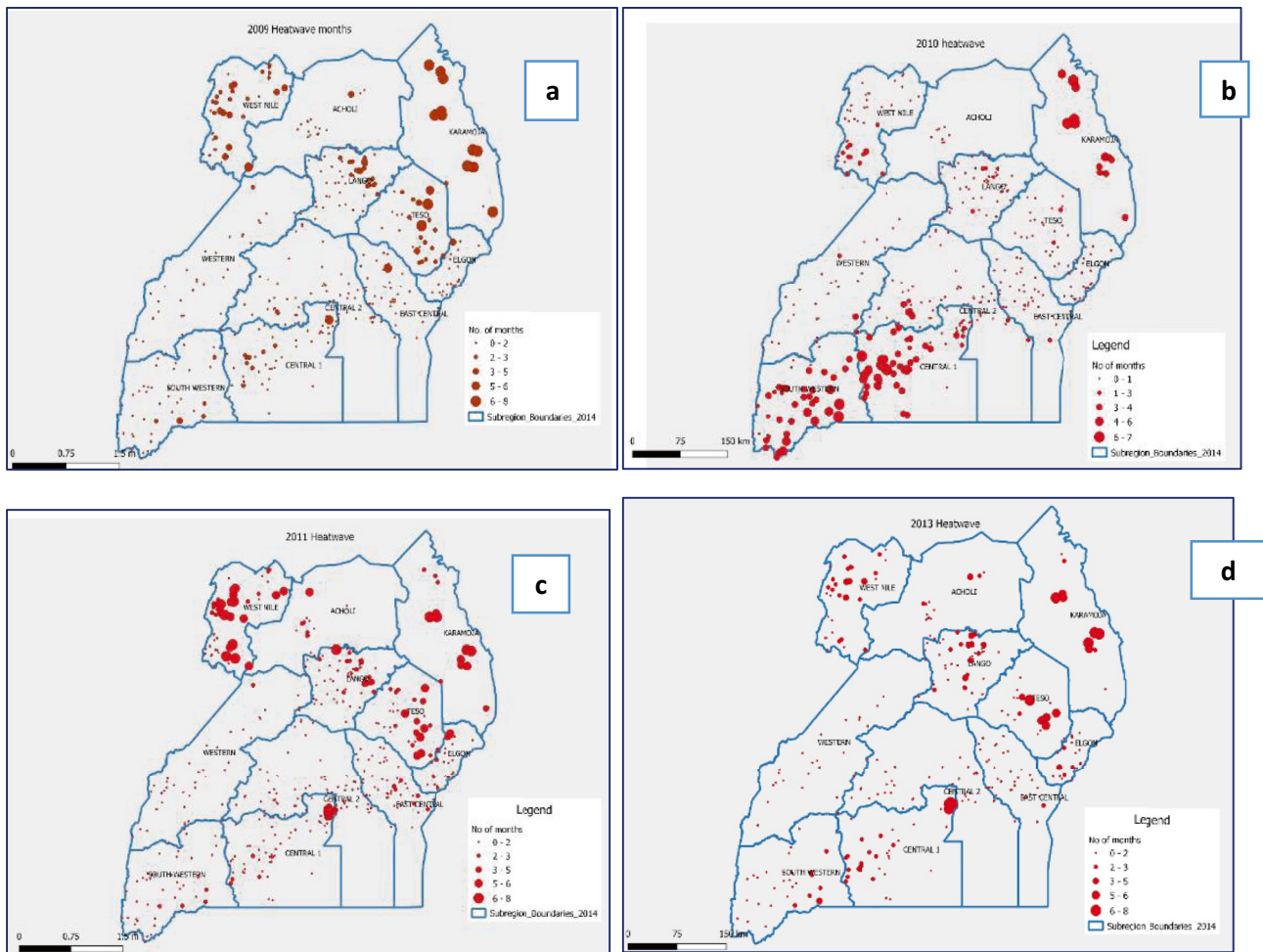


Fig. 4 Maps showing the frequency of heat wave months for the sampled households for 2009 (a), 2010 (b), 2011 (c), and 2013 (d), respectively

3.3 Empirical strategy

We hypothesize that the effect of extreme weather events on the chosen child health measure (HAZ and stunting) is indirect; therefore, we focus on models that explain the impact pathways, with a rural child as the unit of analysis. Extreme weather events will first have a direct effect on child health inputs (crop productivity, nutrient supply, and livestock holding), and the stock of these inputs will affect HAZ and stunting. To demonstrate this causal link, we adopt a simultaneous equation regression approach that simultaneously estimates the effect of weather shocks on child health inputs and the effect of child health inputs on child health in the presence of weather shocks.

Endogeneity is fundamental amid the specification of simultaneous equations, given that some variables in the right hand of the structural equation are dependent variables in the reduced form equation (Greene, 2017). To account for this endogeneity, we adopt an instrumental variable two-stage least squares (2SLS) strategy, and IV probit for robustness

check on stunting outcome variable. However, we use 2SLS results for interpretation since it allows to check the validity of instruments. Our treatment variables in the first stage (weather extremes) are exogenous in the prediction of the different pathways through which weather affects child health equations; thus, they are used as instruments in the different systems of equations. Similar instruments of weather variability have been previously used (Antonelli et al., 2020; Asfaw et al., 2016; Dercon & Porter, 2014; Omiat & Shively, 2020). In the first stage of this process, lagged extreme weather variables are regressed on lagged child health input variables. The predicted values of child health inputs are then obtained in the first stage and used as the key determinant variables in the second stage equation on the effects on HAZ/ stunting. This two-stage procedure is estimated as shown below, presenting the first stage regression in Eq. 3 and second stage regression in Eq. 4.

$$C_{i(t-1)} = \alpha_0 + \beta W_{i(t-1)} + \theta_{1it} CA_{i(t-1)} + \theta_{2it} X_{i(t-1)} + \vartheta_{it} + \varepsilon_{1it} \quad (3)$$

$$Y_{it} = \alpha_0 + \lambda C_{i(t-1)} + \theta_{1it} CA_{i(t-1)} + \theta_{2it} X_{i(t-1)} + \theta_{3it} Ch_{it} + H_{i(t-1)} + \vartheta_{it} + \varepsilon_{2it} \quad (4)$$

The dependent variables in the two equations include $C_{i(t-1)}$, which is the mediator variable representing child health inputs (nutrient supply and livestock holding), and Y_{it} is the main outcome variable estimated as a continuous measure of overall child health, and also a binary variable for stunting. The predicted inputs $C_{i(t-1)}$, appear in the second stage estimation as explanatory variables. Child health inputs, $C_{i(t-1)}$, in the first stage are influenced by extreme weather events denoted by $W_{i(t-1)}$. This variable denotes both the occurrence and frequency of extreme weather events over the previous five years. Only drought variables are treated as instruments and are simultaneously controlled for, to avoid the problem of omitted-variable bias (Letta et al., 2018; Meierrieks, 2021). On the other hand, heat variables ($H_{i(t-1)}$) are included in both equations to capture both the possible direct and indirect effect. Additional determinants of child health include child characteristics, such as gender and age squared (Ch_{it}). Other factors incorporated in both models include coping and adaptation⁵ strategies, $CA_{i(t-1)}$, such as savings; credit access; nonfarm work for coping and improved input use; and cropping patterns for adaptation, such pesticide use and crop diversification. $X_{i(t-1)}$ represents a vector of other socioeconomic controls, such as land size, asset index, market access, and household head's/mother's characteristics. ϑ_{it} , ε_{1it} , and ε_{2it} are the unobserved time-invariant differences across locations and the error term, respectively. More details on the definitions of variables are shared in the supplementary materials in Table S1. Endogeneity tests and statistics on the relevance of the instruments used in the first stage are shown in the respective tables of empirical results.

4 Results and discussion

4.1 Descriptive statistics

Table S1 in the supplementary materials summarizes the descriptive statistics of children aged between 6 and 59 months, extreme weather events, and other socioeconomic covariates. In general, children had an average HAZ of -1.16 , with a stunting prevalence of 26%, and about half of them were female. Boys had lower HAZ scores (-1.32),

and a higher stunting prevalence (30%) compared to girls where only 21% were stunted. Children were, on average, 39 months of age. The proportion of children born in each quarter of the year was similar, and at least 90% of the children lived in households with their biological mothers. Since our estimations were based at an individual level, children were linked with household social and economic factors. The average mother or female household head age was about 35 years, whereas household heads dominated by men were older with 41 years and had 6 years of education. The average farm size and TLU in the prior year was 2.6. Only 42% of the households with children resided in districts where input and output markets were within Local Council 1⁶.

Approximately 6% of the sampled children experienced extreme dry spell conditions (rainfall amounts of less than -2 SD) in the prior year main season. On average, children's households recorded at least one month with a heat wave event in the main season of the previous year. Because of the negative effects of extreme weather events, the households of the sampled children engaged in different anticipatory and proactive adaptation strategies. Undesirable coping strategies, such as an involuntary change in diet, were the most common strategy used by 30% of the respondents. Other coping strategies were savings, nonfarm work, sale of assets, and credit access, which was used by 19%, 15%, 4%, and 3% of the respondents, respectively. Formal and informal safety nets from the government and friends/relatives averaged 0.8% and 7%, respectively. Households also engaged in multiple adaptation activities, for instance, crop diversification, wherein households cultivated 5 crops on average. The use of improved seed, pesticides, and organic and inorganic fertilizers was practiced by 21%, 12%, 14%, and 5% of the respondents, respectively.

4.2 Effect of extreme weather events on HAZ through the nutrient supply pathway

The main empirical findings on the impact estimates of extreme weather events on HAZ and stunting through the crop nutrient production and supply mechanisms are presented in Tables 1 and A1. The effect of extreme weather events on HAZ is indirect, through the various food channels. First, we will discuss the effect of weather extremes on these channels, which represent inputs into child health production. We find each of the weather extremes studied to have a negative and statistically significant effect on caloric

⁵ The coping and adaptation strategies controlled for such as crop diversification, safety nets, savings, fertilizers and pesticides are mentioned in the IPCC report on Impacts, Adaptation, and Vulnerability as potential adaptation options (IPCC, 2014). We define adaptation based on the usage of these options in the years examined.

⁶ Local council 1 is the lowest administrative unit (equivalent to a village) for Uganda

Table 1 (a). Effect of extreme weather events on stunting, through calorie and nutrient supply channels (2SLS) – Consumption side (b). Effect of extreme weather events on stunting, through calorie and nutrient supply channels (2SLS) – Production side

(A) Variables	1 st stage InCalories (t-1)	2 nd stage Stunting	1 st stage InProtein (t-1)	2 nd stage Stunting	1 st stage InZinc (t-1)	2 nd stage Stunting	1 st stage InVitamin A (t-1)	2 nd stage Stunting
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
InCalories (t-1)		-0.101** (0.040)						
InProtein (t-1)				-0.214** (0.089)				
InZinc (t-1)						-0.309** (0.135)		
InVitamin A (t-1)								-0.077 (0.063)
Extreme weather events								
Dry spell (5-year counts)a	-0.295*** (0.038)		-0.133*** (0.032)		-0.087*** (0.028)		-0.225*** (0.069)	
Dry spell main season (t-1)	-0.666*** (0.155)		-0.365*** (0.131)		-0.282** (0.114)		0.383 (0.279)	
Heatwave main season (t-1)	-0.010 (0.045)	-0.013 (0.016)	-0.014 (0.038)	-0.015 (0.017)	-0.015 (0.033)	-0.017 (0.018)	0.265*** (0.080)	0.006 (0.026)
Heatwave (5-year counts)	-0.029*** (0.007)	-0.003 (0.003)	-0.020*** (0.006)	-0.004 (0.004)	-0.014*** (0.005)	-0.004 (0.004)	-0.062*** (0.013)	-0.003 (0.006)
Coping and adaptation								
L1. Savings	0.137 (0.089)	0.020 (0.034)	0.041 (0.075)	0.015 (0.036)	0.008 (0.065)	0.009 (0.037)	0.034 (0.161)	0.007 (0.034)
L1. Nonfarm work	-0.098 (0.099)	-0.094** (0.037)	-0.131 (0.084)	-0.112*** (0.041)	-0.077 (0.073)	-0.108** (0.042)	0.170 (0.179)	-0.072* (0.041)
L1. Government aid	-1.160*** (0.387)	-0.236 (0.156)	-0.858*** (0.326)	-0.300* (0.179)	-0.526* (0.283)	-0.277 (0.184)	-0.850 (0.697)	-0.160 (0.164)
L1. Credit access	0.164 (0.209)	0.044 (0.078)	0.132 (0.176)	0.056 (0.084)	0.058 (0.153)	0.045 (0.088)	0.091 (0.377)	0.037 (0.081)
L1. Sell off assets	0.196 (0.166)	0.002 (0.063)	0.140 (0.140)	0.012 (0.068)	0.051 (0.122)	-0.003 (0.070)	0.067 (0.299)	-0.022 (0.064)
L1. Involuntary diet change	-0.103 (0.082)	0.025 (0.030)	-0.020 (0.069)	0.031 (0.032)	0.016 (0.060)	0.040 (0.034)	-0.070 (0.147)	0.029 (0.032)
L1. Friends & relatives aid	0.043 (0.136)	-0.049 (0.050)	0.010 (0.115)	-0.051 (0.054)	0.000 (0.100)	-0.053 (0.057)	-0.638*** (0.245)	-0.103 (0.066)

Table 1 (continued)

(A)		1 st stage	2 nd stage	1 st stage	2 nd stage	1 st stage	2 nd stage	1 st stage	2 nd stage
Variables		InCalories (t-1)	Stunting (t-1)	InProtein (t-1)	Stunting	InZinc (t-1)	Stunting	InVitamin A (t-1)	Stunting
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)		
L1. Number of crops		0.122*** (0.020)	-0.002 (0.009)	0.115*** (0.017)	0.011 (0.013)	0.098*** (0.015)	0.016 (0.015)	0.377*** (0.036)	0.015 (0.024)
L1. Improved seed		0.155* (0.085)	0.026 (0.032)	0.126* (0.071)	0.037 (0.035)	0.107* (0.062)	0.043 (0.038)	-0.051 (0.152)	0.006 (0.033)
L1. Pesticides		0.504*** (0.105)	0.030 (0.045)	0.568*** (0.089)	0.100 (0.067)	0.503*** (0.077)	0.134 (0.083)	0.112 (0.190)	-0.014 (0.041)
L1. Organic fertilizer		-0.024 (0.101)	-0.026 (0.038)	-0.078 (0.085)	-0.041 (0.041)	-0.115 (0.074)	-0.060 (0.046)	0.343* (0.182)	0.007 (0.044)
L1. Inorganic fertilizer		0.044 (0.157)	0.025 (0.058)	0.014 (0.132)	0.023 (0.062)	0.010 (0.115)	0.023 (0.066)	-0.162 (0.283)	0.007 (0.061)
Other variables									
L1. Market access		0.556*** (0.101)	0.005 (0.045)	0.291*** (0.085)	0.012 (0.049)	0.191** (0.074)	0.009 (0.051)	0.729*** (0.181)	-0.004 (0.059)
L1. Farm area		0.025*** (0.008)	-0.001 (0.003)	0.016** (0.007)	-0.000 (0.004)	0.018*** (0.006)	0.002 (0.004)	0.013 (0.015)	-0.003 (0.003)
L1. HH head education		0.031*** (0.011)	-0.001 (0.004)	0.031*** (0.009)	0.003 (0.005)	0.024*** (0.008)	0.004 (0.006)	0.041** (0.019)	-0.001 (0.005)
L1. Mothers age		-0.059*** (0.017)	-0.017** (0.007)	-0.055*** (0.015)	-0.022*** (0.009)	-0.049*** (0.013)	-0.026** (0.010)	-0.007 (0.031)	-0.011 (0.007)
L1. Mothers age squared		0.001** (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)
Child, mother, HH, year & region factors		Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
First stage F statistics b of instruments		42.908***	13.822***	13.822***	13.822***	8.860***	13.822***	5.788***	13.822***
Endogeneity tests: Durban		8.522***	7.178***	7.178***	7.178***	7.171***	7.178***	2.146	7.178***
Wu-Hausman F statistics		8.322***	7.003***	7.003***	7.003***	6.996***	7.003***	2.087	7.003***
Observations		1,397	1,397	1,397	1,397	1,397	1,397	1,397	1,397
(B)		1 st stage	2 nd stage	1 st stage	2 nd stage	1 st stage	2 nd stage	1 st stage	2 nd stage
Variables		InCalories (t-1)	Stunting (t-1)	InProtein (t-1)	Stunting	InZinc (t-1)	Stunting	InVitamin A (t-1)	Stunting
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
InCalories (t-1)			-0.376** (0.162)						
InProtein (t-1)					-0.503**				

Table 1 (continued)

Variables	1 st stage InCalories (t-1) (1)	2 nd stage Stunting (2)	1 st stage InProtein (t-1) (3)	2 nd stage Stunting (4)	1 st stage InZinc (t-1) (5)	2 nd stage Stunting (6)	1 st stage InVitamin A (t-1) (7)	2 nd stage Stunting (8)	1 st stage HDDS (t-1) (9)	2 nd stage Stunting (10)
InZinc (t-1)				(0.231)						
InVitamin A (t-1)						-0.345** (0.148)				
HDDS (t-1)								-0.090** (0.039)		-0.095** (0.048)
Extreme weather events										
Dry spell (5-year counts)a	-0.073*** (0.022)		-0.055*** (0.020)		-0.089*** (0.020)		-0.348*** (0.057)		-0.295*** (0.056)	
Dry spell main season (t-1)	-0.227** (0.087)		-0.165** (0.079)		-0.175** (0.083)		-0.277 (0.229)		0.039 (0.226)	
Heatwave main season (t-1)	0.074*** (0.025)	0.015 (0.023)	0.027 (0.023)	0.001 (0.021)	0.056* (0.024)	0.007 (0.021)	0.017 (0.066)	-0.010 (0.017)	0.020 (0.065)	-0.011 (0.017)
Heatwave (5-year counts)	0.001 (0.004)	0.000 (0.003)	0.003 (0.004)	0.001 (0.003)	0.005 (0.004)	0.001 (0.003)	-0.004 (0.011)	-0.001 (0.003)	0.006 (0.010)	0.001 (0.002)
Adaptation and coping										
L1. Savings	0.124** (0.050)	0.053 (0.042)	0.102** (0.046)	0.057 (0.046)	0.067 (0.047)	0.029 (0.037)	0.128 (0.132)	0.017 (0.034)	0.241* (0.130)	0.028 (0.035)
L1. Nonfarm work	-0.026 (0.056)	-0.094** (0.041)	-0.053 (0.051)	-0.111** (0.045)	-0.008 (0.053)	-0.086** (0.040)	-0.261* (0.147)	-0.106*** (0.038)	0.111 (0.145)	-0.072* (0.038)
L1. Government aid	-0.335 (0.218)	-0.241 (0.173)	-0.264 (0.198)	-0.248 (0.186)	-0.303 (0.206)	-0.223 (0.166)	-0.774 (0.571)	-0.188 (0.152)	0.460 (0.562)	-0.069 (0.142)
L1. Credit access	0.006 (0.118)	0.030 (0.086)	0.029 (0.107)	0.042 (0.092)	0.054 (0.111)	0.047 (0.084)	-0.345 (0.309)	-0.002 (0.079)	-0.382 (0.304)	-0.006 (0.079)
L1. Sell off assets	0.012 (0.093)	-0.014 (0.068)	-0.028 (0.085)	-0.032 (0.072)	-0.007 (0.088)	-0.020 (0.066)	-0.164 (0.245)	-0.033 (0.062)	0.577** (0.241)	0.034 (0.070)
L1. Involuntary diet change	-0.084* (0.046)	0.004 (0.036)	-0.072* (0.042)	-0.001 (0.039)	-0.037 (0.043)	0.022 (0.033)	0.042 (0.120)	0.039 (0.031)	-0.327*** (0.119)	0.003 (0.034)
L1. Friends & relatives	-0.073 (0.077)	-0.080 (0.057)	-0.028 (0.070)	-0.067 (0.060)	-0.071 (0.072)	-0.078 (0.055)	-0.269 (0.201)	-0.078 (0.052)	-0.342* (0.198)	-0.086 (0.053)
L1. Number of crops	0.002 (0.011)	-0.013* (0.008)	0.010 (0.010)	-0.009 (0.009)	0.020* (0.011)	-0.007 (0.008)	0.017 (0.029)	-0.013* (0.007)	0.054* (0.029)	-0.009 (0.008)
L1. Improved seed	-0.014	0.005	-0.036	-0.008	-0.077*	-0.017	-0.065	0.004	0.054	0.015

Table 1 (continued)

(B)	1 st stage	2 nd stage	1 st stage	2 nd stage	1 st stage	2 nd stage	1 st stage	2 nd stage	1 st stage	2 nd stage
Variables	InCalories (t-1)	Stunting	InProtein (t-1)	Stunting	InZinc (t-1)	Stunting	InVitamin A (t-1)	Stunting	HDDS (t-1)	Stunting
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	(0.048)	(0.035)	(0.043)	(0.038)	(0.045)	(0.036)	(0.125)	(0.032)	(0.123)	(0.031)
L1. Pesticides	0.083 (0.059)	0.010 (0.046)	0.074 (0.054)	0.016 (0.050)	0.114** (0.056)	0.018 (0.046)	0.220 (0.155)	-0.001 (0.041)	0.049 (0.153)	-0.016 (0.039)
L1. Organic fertilizer	0.006 (0.057)	-0.022 (0.042)	0.037 (0.052)	-0.006 (0.045)	-0.053 (0.054)	-0.042 (0.041)	0.169 (0.150)	-0.007 (0.038)	0.124 (0.147)	-0.009 (0.038)
L1. Inorganic fertilizer	0.212** (0.088)	0.100 (0.073)	0.126 (0.080)	0.083 (0.075)	0.161* (0.083)	0.076 (0.067)	-0.158 (0.231)	0.006 (0.059)	0.790** (0.228)	0.095 (0.070)
<i>Other variables</i>										
L1. Market access	0.167*** (0.057)	0.013 (0.051)	0.105** (0.051)	0.003 (0.052)	0.108** (0.054)	-0.014 (0.044)	0.414*** (0.148)	-0.017 (0.042)	0.132 (0.146)	-0.044 (0.038)
L1. Farm area	0.013*** (0.005)	0.001 (0.004)	0.004 (0.004)	-0.002 (0.004)	0.006 (0.005)	-0.002 (0.004)	0.017 (0.013)	-0.002 (0.003)	0.011 (0.012)	-0.003 (0.003)
L1. HH head education	-0.010* (0.006)	-0.008* (0.005)	-0.003 (0.005)	-0.005 (0.005)	-0.005 (0.006)	-0.006 (0.004)	0.003 (0.016)	-0.004 (0.004)	0.052*** (0.016)	0.001 (0.005)
L1. Mothers age	-0.010 (0.010)	-0.015* (0.007)	-0.016* (0.009)	-0.019** (0.009)	-0.018* (0.009)	-0.017** (0.008)	-0.062** (0.026)	-0.016** (0.007)	0.015 (0.025)	-0.009 (0.006)
L1. Mothers age squared	0.000 (0.000)	0.000*** (0.000)	0.000 (0.000)	0.000*** (0.000)	0.000 (0.000)	0.000*** (0.000)	0.001* (0.000)	0.000*** (0.000)	0.000 (0.000)	0.000*** (0.000)
Child, mother, HH, year & region factors	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
First stage F statistics b of instruments	10.117***		6.831***		12.897***		20.652***		14.034***	
Endogeneity tests: Durban	7.199***		7.337***		7.129***		4.957**		2.833*	
Wu-Hausman F statistics	7.023***		7.160***		6.956***		4.829**		2.756*	
Observations	1,397	1,397	1,397	1,397	1,397	1,397	1,397	1,397	1,397	1,396

Standard errors in parentheses

* $p < 0.01$, ** $p < 0.05$, *** $p < 0.1$ ^aWe also lag this to match previous year production^bMeasures relevance of the instruments

supply (column 1). Caloric supply is measured in logarithms, implying that a dry spell in a previous main planting season reduced caloric supply by 67%, and an additional dry spell in the previous five years reduced caloric supply by about 30%. Columns 3, 5, and 7 present the effect of weather extremes on protein, zinc, and vitamin A supply, respectively. In all the models, we observe statistically significant negative effects. The largest negative effect was from dry spells in the previous season, which reduced protein and zinc supply by 37% and 28%, respectively. An additional dry spell in the previous five years reduced protein and zinc supply by 13% and 9%, respectively. Similar results are reported in the consumption estimates where extreme weather events, especially droughts significantly affect nutrients consumed negatively, even though the magnitude of coefficients is lower.

We find that the negative effect of extreme weather events on vitamin A supply is only for the longer-term measures of weather extremes and not for short-term measures. An additional dry spell in the last five years reduced vitamin A supply by 23%, and an additional heat wave in the last five years reduced vitamin A supply by 6%. However, a heat wave in the previous planting season increased vitamin A supply significantly by 27%, whereas a dry spell increased vitamin A supply insignificantly by 38%. A possible explanation for this positive effect could be the resistance and tolerance to drought stress of some of vitamin A-rich foods, such as leafy vegetables, pumpkins, and fruits. Amaranth is one of the leafy vegetables being promoted in East Africa as a drought-tolerant crop (Alemayehu et al., 2015). Furthermore, ripened mangoes thrive in warm temperatures, and some varieties can tolerate short-term weather stress, such as drought, for up to eight months (Bally, 2006). A study on effect of drought on nutrient concentrations in East Africa found similar findings. Specifically, they found increased micronutrients concentrations especially calcium under moderate drought conditions, while severe drought led to reduced nutrient concentrations (Fischer et al., 2019). Some of the nutrients that increased under moderate drought include calcium (Fischer et al., 2019).

In the second stage estimations, we assess the effect of various weather-affected child health inputs on HAZ following Equation 4 above. We find that a 10% increase in caloric supply increases HAZ by 0.047 SD, and a 10% increase in protein supply increase HAZ by 0.098 SD as shown in Table A1. In terms of stunting, a 10% increase in calorie and protein supply reduced stunting rates by 1 and 2 percentage points respectively as shown in Table 1(a). The biggest increase in HAZ is from zinc, for which a 10% increase in supply increases HAZ by 0.139 SD or reduces stunting by 3 percentage points. Even though Vitamin A has a positive and significant effect on HAZ, the effect of vitamin A on stunting is insignificant for the production-side. The results from 2SLS are similar to

the IV probit model estimated manually, with average marginal effects in the second stages as shown in Table A3.

The coefficients of the different nutrients mentioned above are qualitatively similar to the estimates from the consumption module, except for vitamin A consumption which reduces stunting significantly by 0.9 percentage points. Quantitatively, the estimates from production and consumption of the nutrients are different. For instance, a 10% increase in calorie consumed reduces stunting by 4 percentage points, a 10% increase in protein consumption reduces stunting by 5 percentage points and a 10% increase in zinc consumption reduces stunting by 3% as shown in Table 1(b). Additionally, an increase in unique food groups consumed reduces stunting by 1 percentage points. Effects of different nutrients on HAZ from consumption side are shown in Table A2.

4.2.1 The effect of extreme weather events on HAZ through livestock channels

Table 2 presents the estimates of the effect of extreme weather events TLU in the first stage and the resulting effect of TLU on both child HAZ and stunting in the second stage. The first stage results of 2SLS indicate that an increase in dry spell frequency was weakly associated with lower livestock holdings of rural households by 0.26 livestock units, as shown in columns 1, 3 and 5. However, the effect of other extreme weather events remained insignificant in most estimations. Since the first stage F-test for the joint significance of the instrument was very small, and the 2SLS estimates may be biased. Therefore, we report the separate OLS estimations, with robust standard errors in a seemingly unrelated framework (SUEST). These results are presented in columns 3-6. The results indicate negative and significant associations between increased drought frequency. The fact that only the cumulative dry spell variables were significant, whereas the short-term variables were insignificant implies that livestock is more adaptable to short-term extreme weather events and thus does not appear to respond to immediate changes on extreme weather events. Moreover, most rural households in districts experiencing more frequent weather extremes tend to derive their livelihoods from livestock activities as opposed to crop-related activities.

Turning to the association between livestock and HAZ in the second stage, we find positive effects of livestock holdings on HAZ, as shown in column 6. In particular, an increase in one unit of livestock holding in the prior year increased HAZ by 0.024 SD, and reduced stunting by 0.6 percentage points as shown in column 4. The positive effect of TLU on HAZ demonstrates the importance of livestock in supplying food products and nutrients that are essential to child growth, thus decreasing the likelihood of stunting.

Table 2 Effect of weather extremes on HAZ through livestock

VARIABLES	2SLS		SUEST			
	TLU (t-1)	Stunting	TLU (t-1)	Stunting	TLU (t-1)	HAZ
	(1)	(2)	(3)	(4)	(5)	(6)
TLU (t-1)		-0.108 (0.098)		-0.006*** (0.001)		0.024*** (0.006)
<i>Extreme weather events</i>						
Dry spell (5 year)	-0.260 (0.216)		-0.259* (0.141)		-0.259* (0.141)	
Dry spell (t-1)	0.055 (0.872)		-0.007 (0.984)		-0.007 (0.984)	
Heatwave (t-1)	0.088 (0.250)	-0.003 (0.032)	0.085 (0.156)	-0.018 (0.016)	0.085 (0.156)	-0.025 (0.049)
Heatwave (5year)	0.012 (0.040)	0.002 (0.004)	0.011 (0.026)	0.003 (0.002)	0.011 (0.026)	-0.002 (0.007)
<i>Adaptation and coping</i>						
L1. Savings	0.862* (0.502)	0.098 (0.103)	0.845 (0.577)	0.010 (0.031)	0.845 (0.577)	0.101 (0.101)
L1. Nonfarm work	1.509 (2.174)	0.051 (0.278)	1.568 (1.531)	-0.065 (0.116)	1.568 (1.531)	-0.329 (0.282)
L1. Government aid	0.588 (1.176)	0.093 (0.151)	0.617 (0.831)	0.033 (0.078)	0.617 (0.831)	0.165 (0.252)
L1. Credit access	7.053*** (0.933)	0.740 (0.712)	7.022*** (2.136)	0.008 (0.056)	7.022*** (2.136)	0.122 (0.204)
L1. Sell off assets	0.322 (0.559)	-0.048 (0.076)	0.282 (0.527)	-0.086*** (0.033)	0.282 (0.527)	0.241** (0.103)
L1. Involuntary diet change	-0.764* (0.459)	-0.048 (0.092)	-0.747 (0.462)	0.030 (0.030)	-0.747 (0.462)	-0.160* (0.088)
L1. Friends & relatives aid	0.667 (0.764)	0.018 (0.112)	0.626 (1.176)	-0.050 (0.048)	0.626 (1.176)	0.047 (0.148)
L1. Number of crops	-0.150 (0.111)	-0.030 (0.020)	-0.142 (0.116)	-0.014** (0.007)	-0.142 (0.116)	0.024 (0.023)
L1. Improved seed	0.153 (0.476)	0.026 (0.058)	0.128 (0.469)	0.011 (0.029)	0.128 (0.469)	0.001 (0.095)
L1. Pesticides	0.222 (0.592)	0.003 (0.075)	0.219 (0.579)	-0.024 (0.036)	0.219 (0.579)	0.039 (0.110)
L1. Organic fertilizer	1.184** (0.569)	0.107 (0.133)	1.149* (0.591)	-0.013 (0.035)	1.149* (0.591)	0.036 (0.110)
L1. Inorganic fertilizer	-0.192 (0.882)	-0.001 (0.106)	-0.234 (0.525)	0.018 (0.055)	-0.234 (0.525)	-0.275** (0.133)
<i>Other variables</i>						
L1. Market access	-0.088 (0.566)	-0.066 (0.067)	-0.126 (0.814)	-0.060 (0.036)	-0.126 (0.814)	0.150 (0.105)
L1. Farm area	0.092* (0.048)	0.006 (0.011)	0.088 (0.056)	-0.004 (0.003)	0.088 (0.056)	0.013 (0.010)
L1. HH head education	-0.039 (0.060)	-0.008 (0.008)	-0.035 (0.067)	-0.005 (0.004)	-0.035 (0.067)	0.007 (0.012)
L1. Mothers age	0.030 (0.098)	-0.007 (0.012)	0.033 (0.071)	-0.010 (0.006)	0.033 (0.071)	0.022 (0.021)
L1. Mothers age squared	-0.002 (0.001)	0.000 (0.000)	-0.002 (0.001)	0.000** (0.000)	-0.002 (0.001)	-0.000 (0.000)

Table 2 (continued)

VARIABLES	2SLS		SUEST			
	TLU (t-1)	Stunting	TLU (t-1)	Stunting	TLU (t-1)	HAZ
	(1)	(2)	(3)	(4)	(5)	(6)
Child, mother, HH, year & region factors	Yes	Yes	Yes	Yes	Yes	Yes
First stage F statistics	0.7307					
Durbin (score)	3.870**					
Wu-Hausman F statistics	3.767*					
Observations	1,397	1,397	1,422	1,422	1,422	1,422

Standard errors in parentheses

* p<0.01, ** p<0.05, *** p<0.1

4.2.2 Effect of nutrients supply and livestock pathways on HAZ among boys and girls

Table 3 presents results of different mediator variables on child HAZ, disaggregated by gender of the child, while holding other factors constant. The 2SLS findings indicate that calories, proteins and zinc had significant effects on HAZ of both boy and girls as shown in columns 5-8. However, the magnitude of coefficients of these nutrients were larger among girls than boys, and significantly reduced stunting in girls.

4.2.3 Adaptation strategies, coping strategies, and the role of markets

Despite the negative effects of temperature and precipitation extremes on nutrient supply and crop productivity, households used different adaptation strategies to reduce the deleterious effects of weather extremes on crop production and enhance consumption resilience. The results of coping and adaptation strategies are presented in Tables 1a, b, 2 and Table A1 of the appendix. Coping strategies such as precautionary savings were positively and significantly associated

Table 3 Second stage estimations (2SLS) of calorie and nutrient pathway on child HAZ, among boys and girls

VARIABLES	Stunting				HAZ			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Boys								
InCalories (t-1)	-0.072* (0.043)				0.279** (0.129)			
InProtein (t-1)		-0.154 (0.096)				0.601** (0.297)		
InZinc (t-1)			-0.248 (0.161)				0.959* (0.511)	
InVitamin A (t-1)				-0.118 (0.092)				0.484 (0.303)
Other variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	721	721	721	721	721	721	721	721
Girls								
InCalories (t-1)	-0.222** (0.105)				1.002*** (0.377)			
InProtein (t-1)		-0.404* (0.217)				1.634** (0.787)		
InZinc (t-1)			-0.451* (0.244)				1.747** (0.860)	
InVitamin A (t-1)				-0.016 (0.072)				0.375 (0.277)
Other variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	676	676	676	676	676	676	676	676

with calorie supply, protein consumption and HDDS as shown in consumption-side estimates. However, savings had no effect on HAZ and stunting. Other strategies, such as nonfarm work reduced stunting rates significantly as shown in Tables 1a, b and Table A1, whereas involuntary change of diet had negative and significant effects in both nutrients and HAZ models, even though the results were only significant in the nutrients equations as shown in Table 1b.

Although we control for adaptation in both stages of estimations, our discussion is based on the first stage estimates on crop pathways, because adaptation is more relevant and has a direct effect on crop nutrient production. Generally, the coefficients of crop diversification, improved seed, and pesticide use were positive and significant in most estimations, as shown in Tables 1. For instance, an increase in one more crop planted increased calorie, protein, zinc and vitamin A by 12%, 12%, 10% and 38% respectively. Additionally, crop diversification reduced stunting as shown in the consumption side estimation. Households that used improved seed recorded significantly higher protein, and zinc production, and pesticide use was positively associated with nutrients, except vitamin A. In contrast, organic fertilizers led to significantly higher vitamin A supply and TLU.

Additional results indicate increased nutrient production for children in districts where input and output markets were easily accessible. Market access increased vitamin A and calorie production by 73% and 56%, respectively as shown in Table 2. Similar results in terms of coefficient sign and significance level were observed on protein and zinc, although the effect sizes were lower. Furthermore, we found positive and significant associations of market access and nutrient consumed as shown in Table 1b. These results indicate the critical importance of coping, adaptation strategies, and local market access in increasing crop and nutrient production and child HAZ in the presence of weather extremes.

Household education was important in increasing nutrient production and consumption while maternal age that denotes experience in child care was associated with a reduction in stunting rates.

4.3 Robustness checks and interactions

We reported and elaborated on the results taking into consideration adaptation strategies since they are important predictors of nutrient production as well as consumption. However, these strategies might be endogenous to weather shocks. We conducted alternative estimations without adaptation strategies from the production side and found similar results qualitatively with minimal differences on the coefficients in the second stage, as shown in Table S2. Furthermore, we estimated models with interaction terms between dry spell (dummy) and heatwave count in the previous planting and growing season as shown in Tables S3

and S4. Estimations were done manually in a twostep procedure since the heat variables were excluded from the list of instruments in the 2SLS estimations. The coefficients of the interaction terms were consistently negative and significant in all estimations from the production side as shown in Table S3. Even though the different components of nutrients significantly reduced the stunting rates in the consumption module estimations, and only zinc was significant in the production estimates, we are cautious to draw conclusions from these results because interaction terms weaken the relevance of instruments used. We also checked for correlations between the instruments used in our estimation and diarrhea (which is a possible mechanism), and also correlations between instrument and stunting, and results are presented in Tables S5 and S6.

5 Discussion

Child anthropometry indicators reflect the general health and dietary adequacy of children and are further used in tracking child growth and development trends over time (Fryar et al., 2016). Child health is affected by weather extremes through different mechanisms. Overall, the results demonstrated negative effects of extreme dry spells on access to calories, proteins, minerals, and vitamins in the first stage. Furthermore, positive impacts were found for the selected nutrients and TLU on child HAZ in the second stage. Our findings on the negative associations of extreme weather events on food nutrients are consistent with previous empirical studies (Antonelli et al., 2020; Arlappa et al., 2011; Carpena, 2019; Fischer et al., 2019). From the production side, Fischer et al. (2019) research determined that severe droughts decreased nutrient concentrations in most food parts of crops in Kenya and Uganda. In particular, negative and significant associations were found between droughts and zinc concentration in crops.

Focusing on nutrient consumption, Antonelli et al. (2020) and Carpena (2019) reported that long-term weather events had negative effects on calorie consumption. The latter study also reported a decrease in protein intake in Indian diets as a result of droughts. Similarly, Arlappa et al. (2011) demonstrated that vitamin A dietary intake was lower and below the recommended intake during drought conditions, particularly for rural children in India. Another study conducted by Singh et al. (2006) revealed that droughts increased the prevalence of protein–energy malnutrition and protein and calorie deficiencies in the diets in India.

Heat stress is one of the major limiting factors in crop production (Block et al., 2021). Siebert and Ewert (2014) argued that high temperatures result into seed abortion, leaf senescence due to decreased photosynthesis, low pollen production, and decreased viability, leading to low production. The findings on the negative effect of heat and droughts

on nutrient supply indicate that lack of adequate rainfall and high temperatures are detrimental to crop growth and development, during the planting and growing periods in particular, with observed effects on the quality of crops. Therefore, in the absence of floods, high rainfall translates into the availability of an abundance and food varieties for households, thus good nutritional status. This is evidenced through a positive direct link between nutrients supplied and consumption on child HAZ, and negative effect on stunting. Our results are consistent with Yamano et al. (2005), who reported detrimental effect of crop damage on child growth in terms of height. Strong evidence on the relationship between zinc deficiency and growth faltering, especially in children, has been reported (Brown et al., 2002; Rivera et al., 2003), whereas vitamin A deficiency resulted in stunting only when the deficiencies were severe (Rivera et al., 2003).

On livestock, counts of dry spell events had a negative effect on TLU. However, there was no significant effect on the dry spell dummy coefficient. The results of the dry spell dummy are consistent with Hoddinott & Kinsey (2001), who reported that livestock holdings were not affected by the occurrence of a drought, but rather, livestock was used as a principal coping strategy to manage the effects of a drought. The result on the positive effect of heat on livestock contrasts with Letta et al., (2018), who found an insignificant effect of temperature shocks on TLU. Sejian et al. (2015) assert that animals are more adaptable to hot weather and extreme climates; thus, the direct effect of heat is observed through milk and meat production. The significant associations observed between livestock units and HAZ are consistent with Hoddinott & Kinsey (2001), who demonstrated the positive impact of livestock holdings on child height growth rates in Zimbabwe. Additionally, Headey et al. (2018) reported strong relationship between consumption of ASF and child growth in most countries while Kabunga et al. (2017) revealed that the probability of child stunting was lower in the households that adopted improved dairy cows in Uganda. Conversely, Azzarri et al. (2015) study showed that livestock in Uganda did not have significant effect on child stunting.

Households implemented different adaptation and coping strategies in response to extreme weather events. Most of the adaptation strategies adopted led to increased nutrient production, with significant effects observed on crop diversification, improved seed, pesticides, and organic fertilizers. Similar findings on crop diversification were reported by Makate et al. (2016). Furthermore, farms' agricultural diversity has been shown to translate into household dietary diversity (Koppmair et al., 2017). The results of the positive and significant effect of access to credit and nonfarm work is consistent with Asfaw et al. (2015), who reported that credit access enabled households to cope with the negative weather effects on food expenditures. Similarly, credit access facilitated adaptation

to climate change in Ethiopia and enabled households to increase their food productivity (Di Falco et al., 2011). Concerning non-farm work, a study by Cunguara et al. (2011) argued that households were more involved in non-farm activities during drought years.

6 Conclusion and policy implications

Calories, macro- and micronutrient deficiencies at early stages of life might have long-term effects on individuals. This study investigates the effects of extreme weather shocks and events on child health through the effect on child health inputs. We find the significant and negative effects of extreme weather events on caloric intake, protein, zinc, vitamin A and HDDS, which are essential inputs in the production of child health. The increased production of these inputs significantly improved HAZ and reduced stunting. Additionally, livestock holdings were positively associated with improved child nutrition.

The results further showed that coping strategies, such as precautionary savings increased nutrients availability while nonfarm work and government safety nets were associated with better HAZ and a reduction in stunting. The households involved in best agronomic practices, such crop diversification, pesticide use, organic fertilizers, and improved seed, registered higher nutrient production, despite extreme weather events. Furthermore, access to markets matters for improved nutrient production and improved child health. These results indicate that adequate adaptation strategies have the capacity to increase nutrient production and indirectly minimize health effects resulting from extreme weather events; thus, rural households should be sensitized to the same. Furthermore, policymakers should advocate the right approaches—both *ex ante* and anticipatory-based measures—to improve crop, livestock and nutrition access, and protect households from other climate-related health risks, given the future projections of increasing extreme climate events. Investment in child-centered strategies will surely pay off, now and in the future.

Our study had the following limitations: First, considering that we used secondary data, some key variables were lacking on certain age groups, thus, not included in the regressions. Second, anthropometrics was not collected for children beyond the age of five, thus limiting study of long-term effects of weather effects on the different outcomes. Thirdly even though we carefully used weighted outcome measures which minimizes bias, some of these measures were constructed from self-reported variables thus prone to measurement errors. Finally, we only controlled for one endogenous variable in each estimate, as opposed to having all nutrients in one equation given that we used 2SLS. We recommend that future studies to employ methodologies that allow all nutrients to be estimated together.

Appendices

Table A1 The effect of extreme weather events on stunting through calorie and nutrient supply channels (2SLS estimation)- Production

VARIABLES	InCalories (t-1)	HAZ	InProtein (t-1)	HAZ	InZinc (t-1)	HAZ	InVitamin A (t-1)	HAZ
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
InCalories (t-1)		0.477*** (0.129)						
InProtein (t-1)				0.984*** (0.307)				
InZinc (t-1)						1.391*** (0.480)		
InVitamin A (t-1)								0.518** (0.237)
Extreme weather events								
Dry spell (5 year)	-0.295*** (0.038)		-0.133*** (0.032)		-0.087*** (0.028)		-0.225*** (0.069)	
Dry spell (t-1)	-0.666*** (0.155)		-0.365*** (0.131)		-0.282** (0.114)		0.383 (0.279)	
Heatwave (t-1)	-0.010 (0.045)	-0.046 (0.053)	-0.014 (0.038)	-0.035 (0.060)	-0.015 (0.033)	-0.026 (0.065)	0.265*** (0.080)	-0.184* (0.098)
Heatwave (5year)	-0.029*** (0.007)	0.028** (0.011)	-0.020*** (0.006)	0.033** (0.014)	-0.014*** (0.005)	0.032** (0.015)	-0.062*** (0.013)	0.040* (0.021)
Adaptation and coping								
L1. Savings	0.137 (0.089)	0.051 (0.109)	0.041 (0.075)	0.075 (0.122)	0.008 (0.065)	0.104 (0.132)	0.034 (0.161)	0.106 (0.130)
L1. Nonfarm work	-0.098 (0.099)	0.275** (0.119)	-0.131 (0.084)	0.359*** (0.139)	-0.077 (0.073)	0.340** (0.150)	0.170 (0.179)	0.136 (0.153)
L1. Government aid	-1.160*** (0.387)	0.470 (0.505)	-0.858*** (0.326)	0.750 (0.617)	-0.526* (0.283)	0.624 (0.650)	-0.850 (0.697)	0.299 (0.620)
L1. Credit access	0.164 (0.209)	0.109 (0.252)	0.132 (0.176)	0.058 (0.288)	0.058 (0.153)	0.109 (0.310)	0.091 (0.377)	0.128 (0.305)
L1. Sell off assets	0.196 (0.166)	0.124 (0.203)	0.140 (0.140)	0.083 (0.234)	0.051 (0.122)	0.154 (0.249)	0.067 (0.299)	0.210 (0.243)
L1. Involuntary diet change	-0.103 (0.082)	-0.135 (0.099)	-0.020 (0.069)	-0.164 (0.111)	0.016 (0.060)	-0.207* (0.121)	-0.070 (0.147)	-0.143 (0.120)
L1. Friends & relatives aid	0.043 (0.136)	0.040 (0.163)	0.010 (0.115)	0.050 (0.185)	0.000 (0.100)	0.059 (0.201)	-0.638*** (0.245)	0.398 (0.250)
L1. Number of crops	0.122*** (0.020)	-0.034 (0.028)	0.115*** (0.017)	-0.090** (0.044)	0.098*** (0.015)	-0.114** (0.055)	0.377*** (0.036)	-0.172* (0.092)
L1. Improved seed	0.155* (0.085)	-0.068 (0.103)	0.126* (0.071)	-0.118 (0.122)	0.107* (0.062)	-0.143 (0.135)	-0.051 (0.152)	0.036 (0.124)
L1. Pesticides	0.504*** (0.105)	-0.217 (0.145)	0.568*** (0.089)	-0.534** (0.231)	0.503*** (0.077)	-0.673** (0.293)	0.112 (0.190)	-0.032 (0.157)
L1. Organic fertilizer	-0.024 (0.101)	0.097 (0.122)	-0.078 (0.085)	0.163 (0.141)	-0.115 (0.074)	0.247 (0.162)	0.343* (0.182)	-0.111 (0.168)
L1. Inorganic fertilizer	0.044 (0.157)	-0.308 (0.188)	0.014 (0.132)	-0.300 (0.214)	0.010 (0.115)	-0.301 (0.232)	-0.162 (0.283)	-0.202 (0.231)
Other variables								
L1. Market access	0.556*** (0.101)	-0.155 (0.145)	0.291*** (0.085)	-0.178 (0.170)	0.191** (0.074)	-0.159 (0.182)	0.729*** (0.181)	-0.226 (0.224)

Table A1 (continued)

VARIABLES	InCalories (t-1)	HAZ	InProtein (t-1)	HAZ	InZinc (t-1)	HAZ	InVitamin A (t-1)	HAZ
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
L1. Farm area	0.025*** (0.008)	0.001 (0.011)	0.016** (0.007)	-0.003 (0.013)	0.018*** (0.006)	-0.013 (0.016)	0.013 (0.015)	0.008 (0.013)
L1. HH head education	0.031*** (0.011)	-0.015 (0.014)	0.031*** (0.009)	-0.030 (0.018)	0.024*** (0.008)	-0.033 (0.021)	0.041** (0.019)	-0.018 (0.019)
L1. Mothers age	-0.059*** (0.017)	0.055** (0.023)	-0.055*** (0.015)	0.080*** (0.030)	-0.049*** (0.013)	0.095*** (0.036)	-0.007 (0.031)	0.029 (0.025)
L1. Mothers age squared	0.001** (0.000)	-0.001*** (0.000)	0.000** (0.000)	-0.001*** (0.000)	0.000** (0.000)	-0.001*** (0.000)	0.000 (0.000)	-0.001* (0.000)
Child, mother, HH, year & region factors	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
First stage F statistics	42.908***		13.822***		8.860***		5.788***	
Durbin (score)	16.212***		15.042***		14.628***		8.762***	
Wu-Hausman F statistics	15.921***		14.759***		14.349***		8.558***	
Observations	1,397	1,397	1,397	1,397	1,397	1,397	1,397	1,397

Table A2 Second stage estimations on effects of calorie and nutrients on HAZ (2SLS estimation) – Consumption side

Variables	HAZ				
	(1)	(2)	(3)	(4)	(5)
InCalories (t-1)	1.701*** (0.578)				
InProtein (t-1)		2.287*** (0.854)			
InZinc (t-1)			1.643*** (0.522)		
InVitamin A (t-1)				0.462*** (0.136)	
HDDS (t-1)					0.532*** (0.169)
Heatwave (t-1)	-0.172** (0.082)	-0.109 (0.078)	-0.143** (0.073)	-0.063 (0.058)	-0.065 (0.059)
Heatwave (5year)	0.011 (0.010)	0.006 (0.010)	0.007 (0.009)	0.017* (0.010)	0.010 (0.009)
Adaptation and coping	Yes	Yes	Yes	Yes	Yes
Child, mother, HH, year & region factors	Yes	Yes	Yes	Yes	Yes
Observations	1,397	1,397	1,397	1,397	1,396

Table A3 The effect of extreme weather events on stunting through calorie and nutrient supply channels (IV probit)– Production side

VARIABLES	InCalories (t-1) (1)	Stunting (2)	InProtein (t-1) (3)	Stunting (4)	InZinc (t-1) (5)	Stunting (6)	InVitamin A (t-1) (7)	Stunting (6)
InCalories (t-1)		-0.095** (0.038)						
InProtein (t-1)				-0.198** (0.080)				
InZinc (t-1)						-0.280** (0.113)		
InVitamin A (t-1)								-0.062 (0.059)
Dry spell (5 year)	-0.279*** (0.038)		-0.125*** (0.032)		-0.081*** (0.028)		-0.207*** (0.068)	
Dry spell (t-1)	-0.663*** (0.153)		-0.368*** (0.128)		-0.291*** (0.112)		0.422 (0.275)	
Heatwave (t-1)	-0.010 (0.044)	-0.014 (0.016)	-0.012 (0.037)	-0.016 (0.015)	-0.014 (0.032)	-0.018 (0.015)	0.266*** (0.080)	0.001 (0.024)
Heatwave (5year)	-0.030*** (0.007)	-0.003 (0.003)	-0.021*** (0.006)	-0.004 (0.004)	-0.015*** (0.005)	-0.004 (0.004)	-0.065*** (0.013)	-0.002 (0.005)
v2hat		0.107*** (0.039)		0.200** (0.081)		0.281** (0.114)		0.070 (0.060)
Coping and adaptation	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Child, mother, HH, year & region factors	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,422	1,397	1,422	1,397	1,422	1,397	1,422	1,397

Supplementary Information The online version contains supplementary material available at <https://doi.org/10.1007/s12571-023-01354-8>.

Acknowledgements This study received funding from the German, Deutscher Akademischer Austauschdienst (DAAD) and Stiftung Fiat Panis. We thank Prof. Joachim von Braun for his supervision and guidance. Special thanks also to Prof. Arjun Bedi who reviewed and provided valuable comments to the earlier versions of this paper. Center for Development Research (ZEF) researchers, former colleagues and participants of the various conferences where the paper was presented (3rd Symposium on Climate Change Adaptation in Africa 2020, Agriculture, Nutrition and Health (ANH) Academy 2020 Research, Tropentag 2020, Annual Conference of the European Association of Environmental and Resource Economists (EAERE, 2021)) for their valuable comments.

Funding Open Access funding enabled and organized by Projekt DEAL.

Data availability The datasets analyzed in the study are available from the corresponding author on reasonable request. Data are publicly available and can also be downloaded at <https://microdata.worldbank.org/index.php/catalog/1001>, <https://data.chc.ucsb.edu/products/CHIRPS-2.0/>, <https://lpdaac.usgs.gov/data/get-started-data/collection-overview/missions/modis-overview/>.

Declarations

Conflict of interest The authors have no competing interests to declare that are relevant to the content of this article.

Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by/4.0/>.

References

- Ahdoot, S., & Pacheco, S. E. (2015). Global climate change and children's health. *Pediatrics*, 136(5), e1468–e1484.
- Akin, J., Guilkey, D., Popkin, B., Flieger, W., Briscoe, J., Black, R., & Adair, L. S. (1992). A child health production function estimated from longitudinal data. Cebu Study Team. *Journal of development economics*, 38(2), 323–351.
- Alemayehu, F. R., Bendevis, M., & Jacobsen, S. E. (2015). The potential for utilizing the seed crop amaranth (*Amaranthus* spp.) in East Africa as an alternative crop to support food security and climate change mitigation. *Journal of Agronomy and Crop Science*, 201(5), 321–329.
- Alonso, S., Dominguez-Salas, P., & Grace, D. (2019). The role of livestock products for nutrition in the first 1,000 days of life. *Animal Frontiers*, 9(4), 24–31. <https://doi.org/10.1093/af/vfz033>

- Antonelli, C., Coromaldi, M., Dasgupta, S., Emmerling, J., & Shayegh, S. (2020). Climate impacts on nutrition and labor supply disentangled—an analysis for rural areas of Uganda. *Environment and Development Economics*, 1–26.
- Arlappa, N., Venkaiah, K., & Brahmam, G. (2011). Severe drought and the vitamin A status of rural pre-school children in India. *Disasters*, 35(3), 577–586.
- Aryeetey, R., Atuobi-Yeboah, A., Billings, L., Nisbett, N., van den Bold, M., & Toure, M. (2021). Stories of Change in Nutrition in Ghana: a focus on stunting and anemia among children under-five years (2009–2018). *Food Security*, 1–25.
- Asfaw, S., Di Battista, F., & Lipper, L. (2016). Agricultural technology adoption under climate change in the Sahel: Micro-evidence from Niger. *Journal of African Economies*, 25(5), 637–669.
- Asfaw, S., Mortari, A. P., Arslan, A., Karfakis, P., & Lipper, L. (2015, August 9–14, 2015). Welfare impacts of climate shocks: evidence from Uganda. International Conference of Agricultural Economists, Milan, Italy.
- Azzarri, C., Zezza, A., Haile, B., & Cross, E. (2015). Does livestock ownership affect animal source foods consumption and child nutritional status? Evidence from rural Uganda. *The Journal of Development Studies*, 51(8), 1034–1059.
- Bahru, B. A., Bosch, C., Birner, R., & Zeller, M. (2019). Drought and child undernutrition in Ethiopia: A longitudinal path analysis. *PLoS One*, 14(6), e0217821. <https://doi.org/10.1371/journal.pone.0217821>
- Baker, R. E., & Anttila-Hughes, J. (2020). Characterizing the contribution of high temperatures to child undernourishment in Sub-Saharan Africa. *Scientific reports*, 10(1), 1–10.
- Bally, I. S. (2006). *Mangifera indica* (mango). *Species profiles for pacific island agroforestry*, 1–25.
- Bell, J. E., Brown, C. L., Conlon, K., Herring, S., Kunkel, K. E., Lawrimore, J., Luber, G., Schreck, C., Smith, A., & Uejio, C. (2018). Changes in extreme events and the potential impacts on human health. *Journal of the Air & Waste Management Association*, 68(4), 265–287.
- Bhutta, Z. A., Aimone, A., & Akhtar, S. (2019). Climate change and global child health: what can paediatricians do? *Archives of Disease in Childhood*, 104(5), 417–418. <https://doi.org/10.1136/archdischild-2018-316694>
- Block, S., Haile, B., You, L., & Headey, D. (2021). Heat shocks, maize yields, and child height in Tanzania. *Food Security*, 1–17.
- Blom, S., Ortiz-Bobea, A., & Hoddinott, J. (2022). Heat exposure and child nutrition: Evidence from West Africa. *Journal of Environmental Economics and Management*, 115, 102698.
- Boyd, C. (2021). Climate, Mothers' Time-Use, and Child Nutrition: Evidence from Rural Uganda.
- Bratti, M., Frimpong, P. B., & Russo, S. (2021). Prenatal Exposure to Heat Waves and Child Health in Sub-saharan Africa.
- Brown, K. H., Pearson, J. M., Rivera, J., & Allen, L. H. (2002). Effect of supplemental zinc on the growth and serum zinc concentrations of prepubertal children: a meta-analysis of randomized controlled trials. *The American journal of clinical nutrition*, 75(6), 1062–1071.
- Burke, M., & Lobell, D. (2010). Climate Effects on Food Security: An Overview. In *Climate Change and Food Security* (pp. 13–30). https://doi.org/10.1007/978-90-481-2953-9_2
- Carpena, F. (2019). How do droughts impact household food consumption and nutritional intake? A study of rural India. *World Development*, 122, 349–369.
- Cooper, M. W., Brown, M. E., Hochrainer-Stigler, S., Pflug, G., McCallum, I., Fritz, S., Silva, J., & Zvoleff, A. (2019). Mapping the effects of drought on child stunting. *Proceedings of the National Academy of Sciences USA*, 116(35), 17219–17224. <https://doi.org/10.1073/pnas.1905228116>
- Cunguara, B., Langyintuo, A., & Darnhofer, I. (2011). The role of nonfarm income in coping with the effects of drought in southern Mozambique. *Agricultural Economics*, 42(6), 701–713.
- Dercon, S., & Porter, C. (2014). Live Aid Revisited: Long-Term Impacts of the 1984 Ethiopian Famine on Children. *Journal of the European Economic Association*, 12(4), 927–948. <https://doi.org/10.1111/jeea.12088>
- Deschenes, O., Greenstone, M., & Guryan, J. (2009). Climate Change and Birth Weight. *American Economic Review*, 99(2), 211–217. <https://doi.org/10.1257/aer.99.2.211>
- Di Falco, S., Veronesi, M., & Yesuf, M. (2011). Does adaptation to climate change provide food security? A micro-perspective from Ethiopia. *American Journal of Agricultural Economics*, 93(3), 829–846.
- Dillon, A., Arsenault, J., & Olney, D. (2019). Nutrient Production and Micronutrient Gaps: Evidence from an Agriculture-Nutrition Randomized Control Trial. *American Journal of Agricultural Economics*, 101(3), 732–752.
- Ding, Y., Hayes, M. J., & Widhalm, M. (2011). Measuring economic impacts of drought: a review and discussion. *Disaster Prevention and Management: An International Journal*.
- Eckstein, D., Künzel, V., Schäfer, L., & Winges, M. (2019). Global climate risk index 2020. *Bonn: Germanwatch*.
- Fahad, S., Bajwa, A. A., Nazir, U., Anjum, S. A., Farooq, A., Zohaib, A., Sadia, S., Nasim, W., Adkins, S., & Saud, S. (2017). Crop production under drought and heat stress: plant responses and management options. *Frontiers in plant science*, 8, 1147.
- Filippelli, G. M., Freeman, J. L., Gibson, J., Jay, S., Moreno-Madriñán, M. J., Ogashawara, I., Rosenthal, F. S., Wang, Y., & Wells, E. (2020). Climate change impacts on human health at an actionable scale: a state-level assessment of Indiana, USA. *Climatic Change*. <https://doi.org/10.1007/s10584-020-02710-9>
- Fischer, S., Hilger, T., Piepho, H.-P., Jordan, I., & Cadisch, G. (2019). Do we need more drought for better nutrition? The effect of precipitation on nutrient concentration in East African food crops. *Science of The Total Environment*, 658, 405–415.
- Food and Agriculture Organization of the United Nations. (2020). *Uganda at a glance*. Food and Agriculture Organization of the United Nations <http://www.fao.org/uganda/fao-in-uganda/uganda-at-a-glance/en/>
- Franzke, C. L., & i Sentelles, H. T. (2020). Risk of extreme high fatalities due to weather and climate hazards and its connection to large-scale climate variability. *Climatic Change*, 162(2), 507–525.
- Fryar, D., Cheryl, Qiuping, G., L., O. C., & M., F. K. (2016). Anthropometric Reference Data for Children and Adults: United States, 2011–2014 [Report]. *National Center for Health Statistics. Vital Health Statistics*, 3(39).
- Funk, C., Peterson, P., Landsfeld, M., Pedreros, D., Verdin, J., Shukla, S., Husak, G., Rowland, J., Harrison, L., Hoell, A., & Michaelsen, J. (2015). The climate hazards infrared precipitation with stations—a new environmental record for monitoring extremes. *Scientific Data*, 2, 150066. <https://doi.org/10.1038/sdata.2015.66>
- Gebremedhin, S., & Bekele, T. (2021). Evaluating the African food supply against the nutrient intake goals set for preventing diet-related non-communicable diseases: 1990 to 2017 trend analysis. *PLoS One*, 16(1), e0245241.
- Ghani, I., Zubair, M., & Nissa, R. (2017). Climate Change and Its Impact on Nutritional Status and Health of Children. *British Journal of Applied Science & Technology*, 21(2), 1–15. <https://doi.org/10.9734/bjast/2017/33276>
- Gibson, R. S. (2006). Zinc: the missing link in combating micronutrient malnutrition in developing countries. *Proceedings of the Nutrition Society*, 65(1), 51–60.
- Grace, K., Davenport, F., Funk, C., & Lerner, A. M. (2012). Child malnutrition and climate in Sub-Saharan Africa: An analysis of recent trends in Kenya. *Applied Geography*, 35(1–2), 405–413. <https://doi.org/10.1016/j.apgeog.2012.06.017>
- Grace, K., Davenport, F., Hanson, H., Funk, C., & Shukla, S. (2015). Linking climate change and health outcomes: Examining the

- relationship between temperature, precipitation and birth weight in Africa. *Global Environmental Change*, 35, 125–137. <https://doi.org/10.1016/j.gloenvcha.2015.06.010>
- Greene, W. H. (2017). *Econometric analysis* (Eight Edition). In: New York: Pearson.
- Hagos, S., Lunde, T., Mariam, D. H., Woldehanna, T., Lindtjörn, B., & SpringerLink. (2014). Climate change, crop production and child under nutrition in Ethiopia; a longitudinal panel study. *BMC Public Health* 14(1). <https://doi.org/10.1186/1471-2458-14-884>
- Haile, B., Signorelli, S., Azzarri, C., & Johnson, T. (2018). Welfare effects of weather variability: Multi-country evidence from Africa south of the Sahara. *PLoS One*, 13(11), e0206415. <https://doi.org/10.1371/journal.pone.0206415>
- Haile, M. (2005). Weather patterns, food security and humanitarian response in sub-Saharan Africa. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 360(1463), 2169–2182.
- Hasegawa, T., Fujimori, S., Takahashi, K., Yokohata, T., & Masui, T. (2016). Economic implications of climate change impacts on human health through undernourishment. *Climatic Change*, 136(2), 189–202. <https://doi.org/10.1007/s10584-016-1606-4>
- Headey, D., Hirvonen, K., & Hoddinott, J. (2018). Animal sourced foods and child stunting. In: Wiley Online Library.
- Heal, G., & Park, J. (2014). *Feeling the heat: temperature, physiology & the wealth of nations*
- Hirvonen, K., Sohnesen, T. P., & Bundervoet, T. (2020). Impact of Ethiopias 2015 drought on child undernutrition. *WD World Development*, 131.
- Hoddinott, J., & Kinsey, B. (2001). Child growth in the time of drought. *Oxford Bulletin of Economics and statistics*, 63(4), 409–436.
- Hooker, J., Duveiller, G., & Cescatti, A. (2018). A global dataset of air temperature derived from satellite remote sensing and weather stations. *Scientific Data*, 5, 180246. <https://doi.org/10.1038/sdata.2018.246>
- Hotz, C., Abdelrahman, L., Sison, C., Moursi, M., & Loechl, C. (2012). *A food composition table for Central and Eastern Uganda*. International Food Policy Research Institute and International Center for Tropical Agriculture.
- Hu, Z., & Li, T. (2019). Too hot to handle: The effects of high temperatures during pregnancy on adult welfare outcomes. *Journal of Environmental Economics and Management*, 94, 236–253. <https://doi.org/10.1016/j.jeem.2019.01.006>
- Institute for Health Metrics and Evaluation. (2019). *Measuring what matters?* Retrieved 13 February from <http://www.healthdata.org/uganda>
- IPCC. (2014). Climate Change 2014: Impacts, adaptation, and vulnerability. Part A: Global and sectoral aspects. In C. B. Field, V. R. Barros, D. J. Dokken, K. J. Mach, M. D. Mastrandrea, T. E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E. S. Kissel, A. N. Levy, S. MacCracken, P. R. Mastrandrea, & L. L. White (Eds.), Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (p. 1132). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
- Kabunga, N. S., Ghosh, S., & Webb, P. (2017). Does ownership of improved dairy cow breeds improve child nutrition? A pathway analysis for Uganda. *PLoS One*, 12(11), e0187816.
- Koppmair, S., Kassie, M., & Qaim, M. (2017). Farm production, market access and dietary diversity in Malawi. *Public health nutrition*, 20(2), 325–335.
- Letta, M., Montalbano, P., & Tol, R. S. J. (2018). Temperature shocks, short-term growth and poverty thresholds: Evidence from rural Tanzania. *World Development*, 112, 13–32. <https://doi.org/10.1016/j.worlddev.2018.07.013>
- Maggio, G., Mastrotrillo, M., & Sitko, N. J. (2021). Adapting to High Temperatures: Effect of Farm Practices and Their Adoption Duration on Total Value of Crop Production in Uganda. *American Journal of Agricultural Economics*.
- Makate, C., Wang, R., Makate, M., & Mango, N. (2016). Crop diversification and livelihoods of smallholder farmers in Zimbabwe: adaptive management for environmental change. *SpringerPlus*, 5(1), 1–18.
- Meerrieks, D. (2021). Weather shocks, climate change and human health. *World Development*, 138, 105228.
- Molina, O., & Saldarriaga, V. (2017). The perils of climate change: In utero exposure to temperature variability and birth outcomes in the Andean region. *Economics & Human Biology*, 24, 111–124. <https://doi.org/10.1016/j.ehb.2016.11.009>
- Murray-Tortarolo, G. N., & Jaramillo, V. J. (2019). The impact of extreme weather events on livestock populations: the case of the 2011 drought in Mexico. *Climatic Change*, 153(1), 79–89.
- Murray-Tortarolo, G. N., & Jaramillo, V. J. (2020). Precipitation extremes in recent decades impact cattle populations at the global and national scales. *Science of The Total Environment*, 736, 139557.
- Muttarak, R., & Dimitrova, A. (2019). Climate change and seasonal floods: potential long-term nutritional consequences for children in Kerala, India. *BMJ Global Health*, 4(2), e001215. <https://doi.org/10.1136/bmjgh-2018-001215>
- Nelson, G., Bogard, J., Lividini, K., Arsenault, J., Riley, M., Sulser, T. B., Mason-D'Croz, D., Power, B., Gustafson, D., & Herrero, M. (2018). Income growth and climate change effects on global nutrition security to mid-century. *Nature Sustainability*, 1(12), 773–781.
- O'Donnell, O., Van Doorslaer, E., Wagstaff, A., & Lindelow, M. (2010). Analyzing health equity using household survey data: a guide to techniques and their implementation. 2008. *Washington, DC: The World Bank*, 220.
- Omiat, G., & Shively, G. (2020). Rainfall and child weight in Uganda. *Economics & Human Biology*, 38, 100877. <https://doi.org/10.1016/j.ehb.2020.100877>
- Phalkey, R., & Louis, V. (2016). Two hot to handle: How do we manage the simultaneous impacts of climate change and natural disasters on human health? *The European Physical Journal Special Topics*, 225(3), 443–457.
- Phalkey, R. K., Aranda-Jan, C., Marx, S., Hofle, B., & Sauerborn, R. (2015). Systematic review of current efforts to quantify the impacts of climate change on undernutrition. *Proceedings of the National Academy of Sciences USA*, 112(33), E4522–E4529. <https://doi.org/10.1073/pnas.1409769112>
- Rabassa, M., Skoufias, E., & Jacoby, H. (2014). Weather and Child Health in Rural Nigeria. *Journal of African Economies*, 23(4), 464–492. <https://doi.org/10.1093/jae/eju005>
- Radeny, M., Desalegn, A., Mubiru, D., Kyazze, F., Mahoo, H., Recha, J., Kimeli, P., & Solomon, D. (2019). Indigenous knowledge for seasonal weather and climate forecasting across East Africa. *Climatic Change*, 156(4), 509–526. <https://doi.org/10.1007/s10584-019-02476-9>
- Rivera, J. A., Hotz, C., González-Cossío, T., Neufeld, L., & García-Guerra, A. (2003). The effect of micronutrient deficiencies on child growth: a review of results from community-based supplementation trials. *The Journal of nutrition*, 133(11), 4010S–4020S.
- Rocha, R., & Soares, R. R. (2015). Water scarcity and birth outcomes in the Brazilian semiarid. *Journal of development economics*, 112, 72–91.
- Rojas-Downing, M. M., Nejadhashemi, A. P., Harrigan, T., & Woznicki, S. A. (2017). Climate change and livestock: Impacts, adaptation, and mitigation. *Climate Risk Management*, 16, 145–163.
- Rosenzweig, M. R., & Schultz, T. P. (1983). Estimating a household production function: Heterogeneity, the demand for health inputs, and their effects on birth weight. *Journal of political economy*, 91(5), 723–746.
- Schmidhuber, J., Sur, P., Fay, K., Huntley, B., Salama, J., Lee, A., Cornaby, L., Horino, M., Murray, C., & Afshin, A. (2018). The Global Nutrient Database: availability of macronutrients and

- micronutrients in 195 countries from 1980 to 2013. *The Lancet Planetary Health*, 2(8), e353–e368.
- Sejian, V., Gaughan, J., Baumgard, L., & Prasad, C. S. (2015). *Climate change impact on livestock : adaptation and mitigation*.
- Shively, G. E. (2017). Infrastructure mitigates the sensitivity of child growth to local agriculture and rainfall in Nepal and Uganda. *Proceedings of the National Academy of Sciences U S A*, 114(5), 903–908. <https://doi.org/10.1073/pnas.1524482114>
- Siebert, S., & Ewert, F. (2014). Future crop production threatened by extreme heat. *Environmental Research Letters*, 9(4). <https://doi.org/10.1088/1748-9326/9/4/041001>
- Singh, M. B., Lakshminarayana, J., Fotedar, R., & Anand, P. (2006). Childhood illnesses and malnutrition in under five children in drought affected desert area of western Rajasthan. *India. Journal of Communicable Diseases*, 38(1), 88.
- Singh, S., Gupta, A. K., & Kaur, N. (2012). Influence of drought and sowing time on protein composition, antinutrients, and mineral contents of wheat. *The Scientific World Journal*, 2012.
- Smith, K., Woodward, A., Campbell-Lendrum, D., Chadee, D., Honda, Y., Liu, Q., Olwoch, J., Revich, B., Sauerborn, R., & Aranda, C. (2014). Human health: impacts, adaptation, and co-benefits. In *Climate Change 2014: impacts, adaptation, and vulnerability. Part A: global and sectoral aspects. Contribution of Working Group II to the fifth assessment report of the Intergovernmental Panel on Climate Change* (pp. 709–754). Cambridge University Press.
- Smith, M. R., & Myers, S. S. (2018). Impact of anthropogenic CO₂ emissions on global human nutrition. *Nature Climate Change*, 8(9), 834–839.
- Swindale, A., & Bilinsky, P. (2006). *Household Diet Diversity Score (HDDS) for Measurement of Household Food Access: Indicator Guide* (Vol. 2). FANTA-USAID.
- Thai, T. Q., & Falaris, E. M. (2014). Child Schooling, Child Health, and Rainfall Shocks: Evidence from Rural Vietnam. *The Journal of Development Studies*, 50(7), 1025–1037. <https://doi.org/10.1080/00220388.2014.903247>
- The Government of Uganda. (2018). *National Adaptation Plan for the Agricultural Sector. Ministry of agriculture, animal industry and fisheries*. Retrieved December 20, 2020, from <https://www.agriculture.go.ug/wp-content/uploads/2019/09/National-Adaptation-Plan-for-the-Agriculture-Sector-1.pdf>
- The World Bank, & Global Facility for Disaster Reduction and Recovery. (2019). *Disaster risk profile Uganda*. The world Bank. Retrieved 14 September from
- Traore, N., & Foltz, J. (2017). *Temperatures, productivity, and firm competitiveness in developing countries: Evidence from Africa*.
- Trinh, T.-A., Feeny, S., & Posso, A. (2021). Rainfall shocks and child health: the role of parental mental health. *Climate and Development*, 13(1), 34–48.
- Troeger, C., Colombara, D. V., Rao, P. C., Khalil, I. A., Brown, A., Brewer, T. G., Guerrant, R. L., Houpt, E. R., Kotloff, K. L., Misra, K., Petri, W. A., Platts-Mills, J., Riddle, M. S., Swartz, S. J., Forouzanfar, M. H., Reiner, R. C., Hay, S. I., & Mokdad, A. H. (2018). Global disability-adjusted life-year estimates of long-term health burden and undernutrition attributable to diarrhoeal diseases in children younger than 5 years. *The Lancet Global Health*, 6(3), e255–e269. [https://doi.org/10.1016/s2214-109x\(18\)30045-7](https://doi.org/10.1016/s2214-109x(18)30045-7)
- Trumbo, P., Yates, A. A., Schlicker, S., & Poos, M. (2001). Dietary reference intakes: vitamin A, vitamin K, arsenic, boron, chromium, copper, iodine, iron, manganese, molybdenum, nickel, silicon, vanadium, and zinc. *Journal of the American Dietetic Association*, 101(3), 294–301.
- Uganda Bureau of Statistics. (2006). *Uganda national household survey, 2005/2006 : report on the [name of the module]*. Uganda Bureau of Statistics.
- Uganda Bureau of Statistics. (2013). *Uganda national household survey 2011/2012*.
- United Nations Children's Fund. (2015a). *2015a situation analysis of children in Uganda*. Retrieved December 20, 2020, from <https://www.unicef.org/uganda/media/1791/file/Situation%20analysis%20of%20children%20in%20Uganda%20.pdf>
- United Nations Children's Fund. (2015b). *Unless we act now : the impact of climate change on children* (9789280648263 9280648268). Retrieved December 20, 2020, from http://www.unicef.org/publications/files/Unless_we_act_now_The_impact_of_climate_change_on_children.pdf
- von Braun, J. (2020). Climate change risks for agriculture, health, and nutrition. In V. R. Wael K. Al-Delaimy, Marcelo Sánchez Sorondo (Ed.), *Health of people, health of planet and our responsibility: Climate change, air pollution and health* (pp. 135–148). Springer. <https://doi.org/10.1007/978-3-030-31125-4>
- von Grebmer, K., Bernstein, J., Mukerji, R., Patterson, F., Wiemers, M., Ni Chéilleachair, R., Foley, C., Gitter, S., Ekstrom, K., & Fritschel, H. (2019). Global hunger index: the challenge of hunger and climate change. *Bonn: Welthungerhilfe and Dublin: Concern Worldwide*.
- Wan, Z., Hook, S., & Hulley, G. (2015). *MOD11C3 MODIS/Terra Land Surface Temperature/Emissivity Monthly L3 Global 0.05Deg CMG V006* NASA EOSDIS Land Processes DAAC.
- Watts, N., Amann, M., Arnell, N., Ayeb-Karlsson, S., Belesova, K., Berry, H., Bouley, T., Boykoff, M., Byass, P., Cai, W., Campbell-Lendrum, D., Chambers, J., Daly, M., Dasandi, N., Davies, M., Depoux, A., Dominguez-Salas, P., Drummond, P., Ebi, K. L., & Costello, A. (2018). The 2018 report of the Lancet Countdown on health and climate change: shaping the health of nations for centuries to come. *The Lancet*, 392(10163), 2479–2514. [https://doi.org/10.1016/s0140-6736\(18\)32594-7](https://doi.org/10.1016/s0140-6736(18)32594-7)
- Watts, N., Amann, M., Arnell, N., Ayeb-Karlsson, S., Belesova, K., Boykoff, M., Byass, P., Cai, W., Campbell-Lendrum, D., Capstick, S., Chambers, J., Dalin, C., Daly, M., Dasandi, N., Davies, M., Drummond, P., Dubrow, R., Ebi, K. L., Eckelman, M., & Montgomery, H. (2019). The 2019 report of The Lancet Countdown on health and climate change: ensuring that the health of a child born today is not defined by a changing climate. *The Lancet*, 394(10211), 1836–1878. [https://doi.org/10.1016/s0140-6736\(19\)32596-6](https://doi.org/10.1016/s0140-6736(19)32596-6)
- Wheeler, T., & Von Braun, J. (2013). Climate change impacts on global food security. *Science*, 341(6145), 508–513.
- World Meteorological Organization. (2012). *Standardized Precipitation Index: User Guide*.
- World Meteorological Organization. (2019). *The Global Climate in 2015–2019*.
- World Meteorological Organization. (2020). *WMO Provisional Statement on the State of the Global Climate in 2019*.
- Yamano, T., Alderman, H., & Christiaensen, L. (2005). Child growth, shocks, and food aid in rural Ethiopia. *American Journal of Agricultural Economics*, 87(2), 273–288.
- Yobom, O. (2020). Climate change and variability: empirical evidence for countries and agroecological zones of the Sahel. *Climatic Change*, 159(3), 365–384. <https://doi.org/10.1007/s10584-019-02606-3>



Emily Injete Amondo is a postdoctoral researcher at the Center for Development Research (ZEF), University of Bonn at the department of Economic and Technological Change. Before joining ZEF, Emily was a Monitoring, Evaluation and Learning Officer at the International Maize and Wheat Improvement Center (CIMMYT). She has at least

five years of work experience in agricultural research and development, in sub-Saharan Africa. Her research interests include climate variability, food and nutritional security, health, gender and agricultural technologies.



Dr Emmanuel Nshakira-Rukundo is Development Economist, currently a Research Associate at the Institute for Food and Resource Economics, the University of Bonn. His main research is on health and labour, specifically on enrolment and effects of health insurance on health outcomes and labour markets in East Africa as well as general evaluation of development interventions. He has a Bachelor in Development Economics (Makerere University), a Masters of Arts in International Development (IDS Sussex University) and a PhD in Development Economics (University of Bonn). He is also a co-founder of Apata

Insights, a development research organisation in Kampala, Uganda.



Dr. Alisher Mirzabaev is the Interim Professor for Production Economics at the Institute for Food and Resource Economics and also a Senior Researcher at the Center for Development Research (ZEF), University of Bonn. Before joining ZEF, he was an economist with the International Center for Agricultural Research in the Dry Areas (ICARDA). Dr. Mirzabaev was a Coordinating Lead Author of the

Chapter on Desertification of the IPCC Special Report on Climate Change and Land Use. He has a PhD Degree on Agricultural Economics from the University of Bonn, Germany. His research interests include climate change impacts and adaptation, economics of land degradation, and water-energy-food security nexus.