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1-1-2021

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Climate impacts associated with reduced diet diversity in children across nineteen countries

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Abstract

It is widely anticipated that climate change will negatively affect both food security and diet diversity. Diet diversity is especially critical for children as it correlates with macro and micronutrient intake important for child development. Despite these anticipated links, little empirical evidence has demonstrated a relationship between diet diversity and climate change, especially across large datasets spanning multiple global regions and with more recent climate data. Here we use survey data from 19 countries and more than 107 000 children, coupled with 30 years of precipitation and temperature data, to explore the relationship of climate to child diet diversity while controlling for other agroecological, geographic, and socioeconomic factors. We find that higher long-term temperatures are associated with decreases in overall child diet diversity, while higher rainfall in the previous year, compared to the long-term average rainfall, is associated with greater diet diversity. Examining six regions (Asia, Central America, North Africa, South America, Southeast Africa, and West Africa) individually, we find that five have significant reductions in diet diversity associated with higher temperatures while three have significant increases in diet diversity associated with higher precipitation. In West Africa, increasing rainfall appears to counterbalance the effect of rising temperature impacts on diet diversity. In some regions, the statistical effect of climate on diet diversity is comparable to, or greater than, other common development efforts including those focused on education, improved water and toilets, and poverty reduction. These results suggest that warming temperatures and increasing rainfall variability could have profound short- and long-term impacts on child diet diversity, potentially undermining widespread development interventions aimed at improving food security.

1. Introduction

Childhood malnutrition and undernourishment can lead to a number of health outcomes, which can negatively impact children's life trajectories [1]. The majority of childhood malnutrition occurs in low and middle income countries in children under the age of five [2]. Diet diversity is an indicator of diet quality, which is typically measured by a count of the diversity of foods eaten in the diet over a given time period. Overall, diet diversity is demonstrated to be a good indicator of micronutrient intake, a lack of which indicates malnutrition [3] including obesity [4]. Poor diet diversity is also associated with undernourishment outcomes including stunting and wasting in children [3, 5–8]. Though childhood malnutrition has decreased over the past several decades globally, there has been an increase in

global undernourishment since 2015, in part associated with climate and extreme events [9]. While there is an abundance of research exploring the relationship of agroecological, geographic, socioeconomic, and demographic factors to child malnutrition [10, 11], the evidence linking climate and child malnutrition is limited, especially across multiple geographic scales [12, 13].

Existing evidence suggests that many factors correlate with child malnutrition, including stunting and wasting. Ecological factors, including increased forest cover, have been associated with better child health outcomes like improved diet diversity and reduced stunting and wasting [11, 14] because of their capacity to provide food sources, forest-based income, and pollination for crops. Geographic factors, including road and transportation infrastructure, which can provide market access and potentially improve incomes [15], are associated with reductions in stunting and wasting, while shorter distance to a water source is associated with reduced stunting [16]. Socioeconomic and demographic factors including wealth [5, 17, 18], improved water sources [19, 20] and improved toilet facilities [20–22] as well as education [8, 23] are also associated with reductions in child stunting. However, with a few exceptions (e.g. [13, 14]), most of these studies focus on a single country or region.

Compared to these factors, the role of climate and its relationship to diet and malnutrition is poorly understood, especially across diverse geographic regions [12]. The way in which climate affects nutritional outcomes is complex, but occurs primarily through an agroecosystems pathway with diverse impacts on crops, pests, diseases, weeds, pollination, forests, livestock, and aquatic food sources [24]. As a result, climate change impacts on these agroecosystems could affect multiple components of food security and diet diversity by changing the availability and quality of food sources within a region. Climate effects on these pathways could occur over short-term timeframes (e.g. extreme weather events or floods) as well as longer-term changes (e.g. increasing temperatures) Climate can also affect nutritional outcomes through indirect pathways such as through heat impacts on pregnant women and children [25, 26], and through changes in food costs, trade, and market availability associated with climate disruptions [27]. Child malnutrition has been associated with decreases in rainfall in Rwanda, Kenya, Mexico and Swaziland [28–31] as well as drought [5, 32–35] and floods [17, 33] at the regional or country level. Associations between temperature and child stunting/wasting are less explored [12], but there is evidence that climate shocks are associated with child stunting via warmer temperatures in the previous dry season in Mexico [30]. Temperature anomalies have also been found to be associated with moderate stunting in Ethiopia [36].

A shortcoming of existing studies linking climate to child malnutrition is both their geographic and their temporal scope. For example, while 80% of studies in a 2015 review found weather variables related to child stunting outcomes, almost all of these studies focused on Africa [12], despite the fact that Asia has 55% of all stunted children globally [37]. Furthermore, the majority of these studies included data from the 1980s and 1990s, with only one-third integrating any data from the early 2000s [12]; a timeframe that might not capture the more recent anomalies and extreme events associated with climate change.

Here we aim to overcome both the geographic and the temporal gaps in the literature by linking demographic health data from 107 000 children under five in 19 low- and middle-income countries across six regions (SI appendix table S1, which is available online at stacks.iop.org/ERL/16/015010/mmedia), with climate data and other agroecological, geographic, socioeconomic, and demographic control variables (table 1) to estimate diet diversity. Our work adds to the current body of research in multiple ways. First, we employ a large primary dataset (Demographic Health Surveys [DHS]) with more recent data (2005–2009) than many existing studies (SI appendix table S1). Second, we integrate geocoded human health data with 30 years of geocoded temperature and precipitation data. Finally, we utilize hierarchical models, which have been suggested to more holistically explore the relationship of climate to child malnutrition outcomes [38], with random effects at multiple levels to facilitate cross-regional analyses. We report our model results in standardized coefficients to enable comparison between and understanding of relative impact across multiple factors.

2. Results

2.1. Diet diversity

On average, we find that diet diversity of children five and under in our dataset is 3.22 (s.d. = 2.43), meaning that in the 24 h prior to the survey interview, children ate on average 3.2 foods groups (out of ten possible). Diet diversity ranged from a high of 4.48 in South America to a low of 2.66 in Southeast Africa (figure 1(a)). Country-level diet diversity ranged from a high of 4.77 in Colombia to a low of 1.80 in Lesotho (SI appendix table S2 and figure S1). Additional information for all variables utilized in this analysis (means and standard deviations) as a whole and across regions is in SI appendix table S3.

2.2. Hierarchical models

A hierarchical model with data from 19 countries and more than 107 000 individual observations finds a number of climate variables and agroecological, geographic, and socioeconomic controls that correlate with child diet diversity (figure 2).

Table 1. Agroecological, geographic, and socioeconomic variables used in the study, with descriptions and sources. Additional details about the variables are described in more complete detail in the methods.

Variable type	Variable name	Variable description	Unit	Source
Diet Diversity	Diet diversity	FAO individual diet diversity score (IDDS), scale ranging from 0 to 10 based on intake of 10 foods including cereal grains, white tubers and root foods, dark leafy greens, vitamin A rich vegetables/tubers, vitamin A rich fruits, other fruits and vegetables, meat and fish foods, eggs, legumes/nuts/seeds, and milk and milk products	Number 0–10	[39]
Agroecological	Tree cover	Percent tree cover within a 20 km radius of cluster	% tree cover	[40]
	Time to water	Time from household to get to water source (min)	Minutes	[39]
	Livestock density	Ruminant livestock density at cluster 10 km grid circa 2000; expressed as tropical livestock units (TLU) (1: less than 1 TLU; 2: 1–5 TLU; 3: 5–10 TLU; 4: 10–20 TLU; 5: 20–50 TLU; 6: 50–100 TLU; 7: 100–200 TLU; 8: more than 200 TLU; 9: water)	Tropical livestock units (TLU)	[41]
Geographic	Distance to urban center	Distance from a cluster to its nearest urban center (settlement with 5000 or more inhabitants) circa 2000	Meters	[42]
	Distance to road	Distance to nearest road	Meters	[43]
	Population density	Average population density within 5 km buffer around cluster (density in 2000 for 2000–2004 surveys, density in 2005 for 2005–2009 surveys, and density in 2010 for 2010–2013 surveys)	People per km^2	[44]
Socioeconomic	Child age	Age of child	Months	
	Education of household head	Education years of head of household	Years	
	Improved toilet	Improved sanitation	Binary	
	Improved water	Improved water based on WHO definitions	Binary	[39]
	Male household head	Household head male	Binary male/female	
	Poorer household	Binary being poorer—as compared to being average		
	Poorest household	Binary being poorest—as compared to being average	Full category is poorest, poorer, average, richer, richest	
	Richer household	Binary—richer—as compared to being average		
	Richest household	Binary—richest—as compared to being average		
Climate	Long-term average temperature	Average of 30 years of CHIRTS monthly data between initial year of data and survey month	Degrees C	[45]
	Long-term average precipitation	Average of 30 years of CHIRPS monthly data between initial year of data and survey month	Centimeters	[46]
	Temperature anomaly—previous year	Number of standard deviations below or above long-term average in the year prior to the survey	Standard deviations	[45]
	Precipitation anomaly—previous year	Number of standard deviations below or above long-term average in the year prior to the survey	Standard deviations	[46]
	Temperature anomaly—current year	Number of standard deviations below or above long-term average in the year of survey	Standard deviations	[45]
	Precipitation anomaly—current year	Number of standard deviations below or above long-term average in the year of survey	Standard deviations	[46]

Factors associated with reductions in diet diversity include greater distance to urban centers and roads, higher livestock density, male-headed households, poor households, and higher long-term average temperatures (SI appendix table S4 and figure 2). Factors associated with increases in diet diversity include child age, years of education for the household head, use of an improved toilet, household wealth, and higher-than-average precipitation in the year prior to the survey (SI appendix table S4 and figure 2). While wealth is the greatest correlate predicting diet diversity, long-term average temperature and higher-than-average precipitation in the previous year correlate with diet diversity at levels equal to or greater than many variables that are often a focus of current development policy, including market access (i.e. distance to urban center), livestock density, education, and gender.
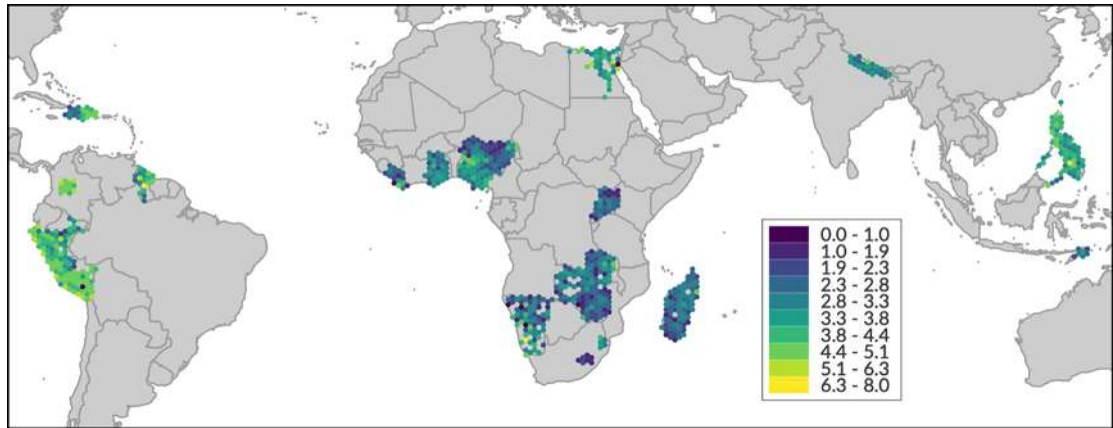
Figure 1. Child individual diet diversity score across 19 countries in the Demographic Health Surveys dataset. Color gradients indicate the number of food groups eaten by children in the household in the last 24 h prior to the survey. Among the surveyed countries, diet diversity is highest in South America and lowest in Southeast Africa.
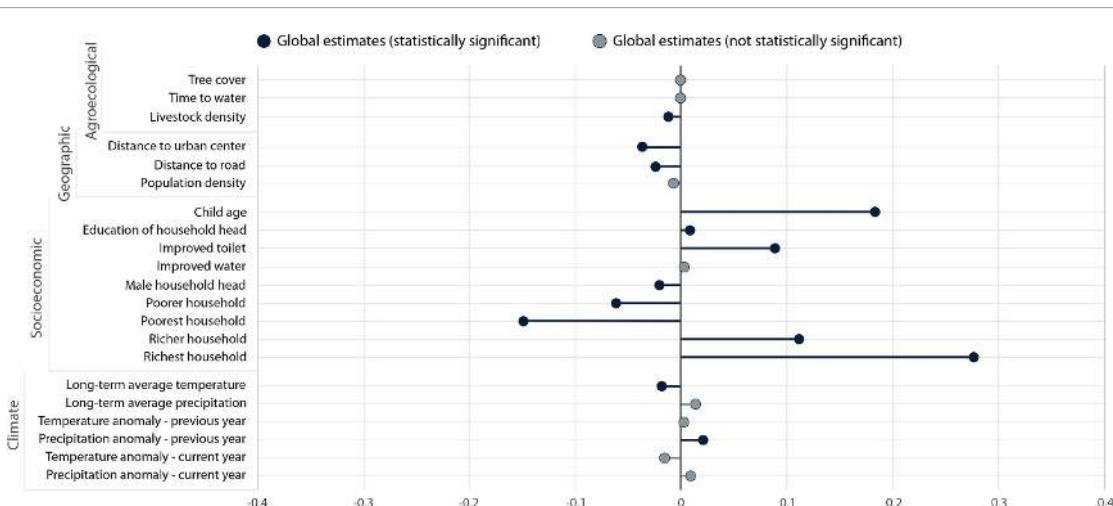

Figure 2. Standardized coefficient effects of different agroecological, geographic, socioeconomic, and climate factors on child diet diversity across 19 countries. Dark circles indicate statistically significant coefficients ($p < 0.05$); grey dots are insignificant. Lines drawn from 0 to a coefficient point are only to clearly highlight the varying level of effects. Points to the left of zero (negative coefficients) indicate the variable is associated with decreased diet diversity while those to the right of zero (positive coefficients) indicate the variable is associated with increased diet diversity. Full model estimates are found in SI appendix table S4.

2.3. Regional models

Regional models demonstrate similar trends as those shown in full dataset models (figure 3). In five out of six regions, higher temperature (either long-term averages or short-term anomalies) have a consistent negative relationship with child diet diversity. Reductions in diet diversity are significantly associated with higher long-term average temperatures in Southeast Africa and West Africa, higher than average temperatures in the year prior to the survey in North Africa and South America, and higher than average temperatures in the year of the survey in Asia, Southeast Africa, and West Africa. In half of our regional models, precipitation variables also had a significant, and consistently positive, relationship to diet diversity. Higher long-term average precipitation was significantly correlated with greater diet diversity in Southeast Africa, while greater precipitation than average in the year

prior to the survey was significantly correlated with greater diet diversity in Central America and West Africa.

Similar to the full dataset model, we find several instances in which climate factors have a relatively large impact on diet diversity outcomes as compared to many control variables. For example, temperature has a greater effect on diet diversity than at least some agroecological, geographic or socioeconomic controls in all regions but Central America. In many cases, these control variables are the focus of development programs, including education, gender-based programs, road and market access, poverty alleviation, and improved sanitation.

2.4. West Africa case study

To explore regional relationships in more detail, we examine West Africa as a case study (figure 4), because
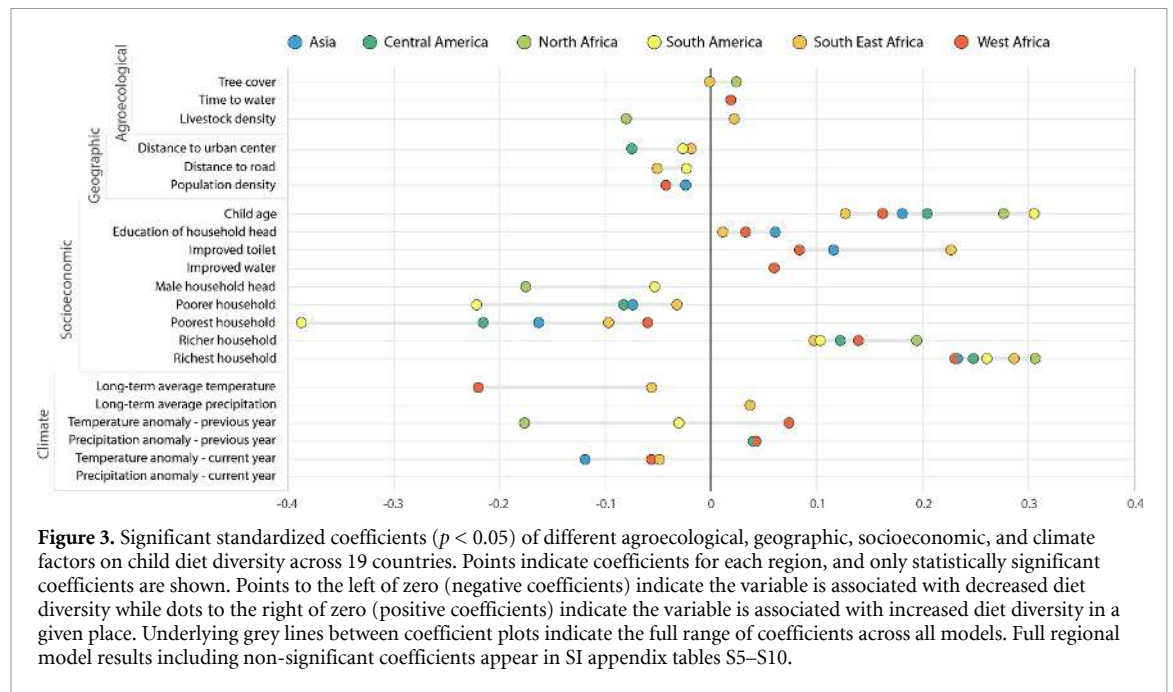
Figure 3. Significant standardized coefficients ($p < 0.05$) of different agroecological, geographic, socioeconomic, and climate factors on child diet diversity across 19 countries. Points indicate coefficients for each region, and only statistically significant coefficients are shown. Points to the left of zero (negative coefficients) indicate the variable is associated with decreased diet diversity while dots to the right of zero (positive coefficients) indicate the variable is associated with increased diet diversity in a given place. Underlying grey lines between coefficient plots indicate the full range of coefficients across all models. Full regional model results including non-significant coefficients appear in SI appendix tables S5–S10.

it had the greatest number of significant climate effects. In West Africa, we find that higher long-term average temperatures have a greater negative relationship to diet diversity than being in the poorest households in the region. Higher temperature also outweighs the positive relationships between diet diversity and education, improved toilets, access to improved water, and wealth. Higher-than-average precipitation in the year prior to the survey also had a greater relationship to diet diversity than population density or education of the household head. Further, it is worth noting that higher-than-average temperatures in the previous year were associated with increases in diet diversity, counter to all other models. However, in West Africa, higher-than-average precipitation in the previous year correlated with greater diet diversity, suggesting that the coupling of both higher temperatures and greater rainfall may explain higher diet diversity in the region.
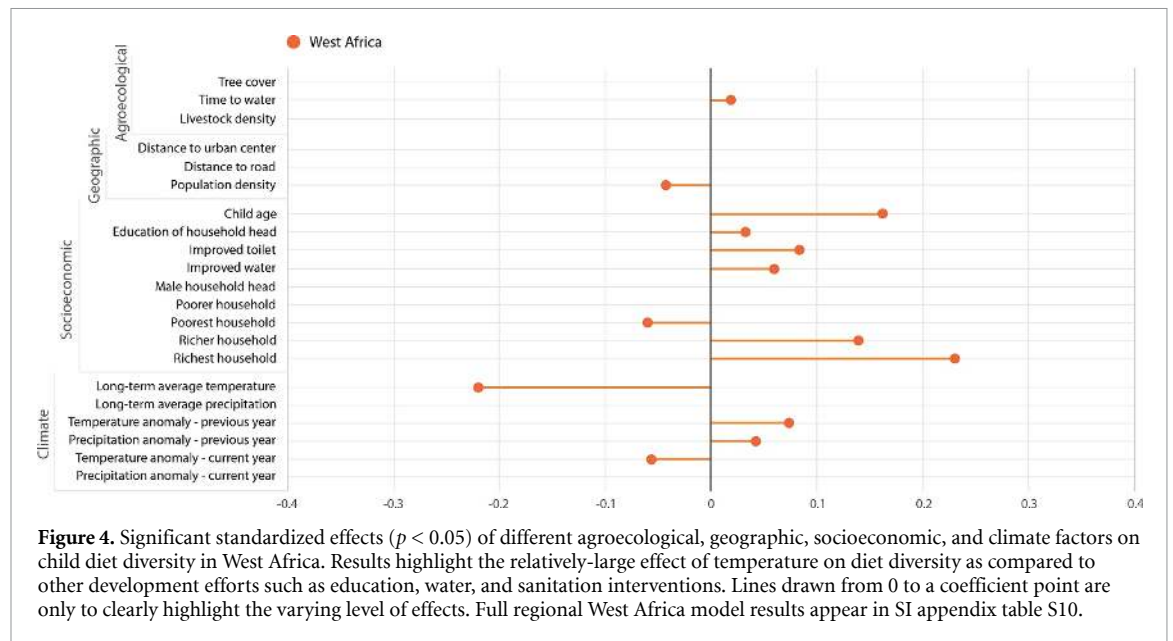
3. Discussion

In the largest global study to date exploring the connections between child diet diversity and recent climate, we find international and regional evidence that temperature and precipitation significantly correlate with diet diversity and in many cases have a larger impact than agroecological, geographic, or sociodemographic variables. Most importantly, we find that climate factors, especially temperature, have a greater relative negative impact on diet diversity than the positive relationship of many factors that are often the target of development interventions, including education, water and sanitation, and poverty alleviation. We also find that overall child diet diversity

within the study is very low, with a global average of children eating slightly more than three varied food groups daily in our sample. While there are no established cut-off points to indicate adequate or inadequate dietary diversity [37], these results are significantly lower, on average, than has been found in middle income countries such as China [47], but is consistent with child diet diversity scores in similar countries in Africa [48, 49].

Our research suggests that both long- and short-term temperature increases have a significant relationship with child diet diversity internationally and regionally. This evidence is important, since the effect of temperature on child malnutrition outcomes has not been extensively explored [12], with the majority of previous studies focusing on rainfall, drought, and floods (e.g. [13, 29, 33, 35]). However, our models indicate consistent relationships between high temperature and lower diet diversity in nearly all regions. In some regions (i.e. Southeast Africa and Western Africa) we find relationships between temperature and diet across multiple temporal scales, with both long-term average temperature increases and acutely hotter-than-average years associated with reductions in child diet diversity. This provides new and broad geographic evidence that both long-term warming temperatures and acutely hot years may consistently negative impacts on diet diversity, which in turn also may negatively affect child stunting and wasting.

There are likely both direct and indirect pathways that influence this relationship. Higher temperatures can directly impact the yield of many globally important staple crops (e.g. [50, 51]). Higher temperatures can also affect the physiology of animals and may reduce livestock productivity and also increase livestock water consumption [52]. Both of these

Figure 4. Significant standardized effects (*p* < 0.05) of different agroecological, geographic, socioeconomic, and climate factors on child diet diversity in West Africa. Results highlight the relatively-large effect of temperature on diet diversity as compared to other development efforts such as education, water, and sanitation interventions. Lines drawn from 0 to a coefficient point are only to clearly highlight the varying level of effects. Full regional West Africa model results appear in SI appendix table S10.

pathways could influence the amount and quality of food available in a given region and thereby affect food prices and access [12]. Higher temperatures also have known physiological impacts on human beings. Women who are pregnant during hot spells often deliver babies with lower birth weights [53]. Indirectly, higher temperatures also have the potential to influence the macro and micronutrient content of a variety of crops, which may not directly affect the overall number of diet categories consumed, but could contribute to micronutrient deficiencies over time [54].

Precipitation's relationship to diet diversity in half of our models was consistently positive, which generally follows the existing evidence that dry conditions are correlated with lower diet diversity and other child malnutrition outcomes [13]. Our models generally show that higher precipitation in the year prior to the survey, as compared to the long-term average of a given region, positively correlates with diet diversity. Others have shown that the opposite can also be true: short-term reductions in rainfall can negatively impact child nutrition [55]. Similar to temperature impacts, there are likely direct and indirect pathways that lead to these outcomes [12]. Mostly obviously, the direct impact of a reduction in rainfall can lead to a reduction in agricultural productivity, with these impacts most profound in drought conditions [35]. Our models suggest that the greater the reduction in precipitation in a given place compared to their long-term average, the greater the impact on diet diversity. Furthermore, the impact of precipitation on diet quality likely has lag effects, with the previous year's precipitation reductions impacting that year's harvest leading to potential impacts on food insecurity and malnutrition the following year when there is not as much food to eat. Indeed, the relationship between climate and weather factors and food security are numerous and not immediate, with availability affecting food prices and access, leading to nutritional impacts over time [12]. As such, we can expect that precipitation changes may have both acute impacts and longer-term anticipated outcomes.

Much of the existing research on climate and its relationship to child malnutrition and diet outcomes suggests that investments in development may help to overcome the negative impacts of a changing climate. For example, both [56] and [29] argue that while a warmer and drier future may lead to malnourished children, education and basic infrastructure may help overcome these outcomes. However, our study suggests that higher temperatures may have greater impacts on diet diversity than the presence of many common development investments including education, water and sanitation improvements, and road infrastructure in low and middle-income countries. This is deeply concerning; it indicates that in many regions these positive socioeconomic and demographic changes may not be adequate to outweigh the negative effects of a changing climate going forward.

While there has been considerable discussion of potential adaptation efforts to safeguard food security and nutritional outcomes, empirical evidence to assess the relationship between climate adaptation and human nutrition is still nascent with inconsistent outcomes. Given both the direct and indirect pathways in which climate can affect agriculture and nutrition, potential adaptation efforts should take a food systems approach [57]. Agricultural adaptations could focus on both agroecological and crop improvement pathways. For example, childhood deficiencies of Vitamin A and zinc have the greatest relative impact on childhood malnutrition

outcomes [58], providing an important area of focus for crop breeding. Furthermore, recent evidence also highlights that agroecological interventions pursued for climate adaptation improved household diet diversity outcomes in Malawi [59]. Other potential adaptation strategies could fall across the suite of the control variables we considered. New evidence highlights the complementary ways in which environmental conservation (e.g. forest preservation) may have beneficial outcomes for child health outcomes including malnutrition [10, 11, 14]; however, the mechanisms for this relationship and possible adaptation interventions remain limited [60]. There is also a rising understanding of the role that social networks can play for improving household food security outcomes [60], which may be particularly critical for marginalized households.

Given the complexity of these relationships, there is an immediate need to increase our poor understanding of climate adaptation efforts to safeguard childhood nutrition [60], especially for vulnerable populations in low and middle-income countries across the tropics where the most profound climate changes are expected. To achieve a better understanding of the potential adaptation strategies that may help improve child nutrition in a changing climate requires a shift away from the ways traditional food security research is conducted. Food assistance or interventions that fail to consider the complexity of food systems as well as the trickle-down effect that climate can have across that system will fall short in response. This requires a need to design studies explicitly for assessing interventions for their climate adaptation potential, rather than purely their nutritional assistance potential in the current state. These efforts could involve a better integration of climate data with health data across global datasets, but there remain many challenges with current data scale and scope, especially with a lack of comprehensive long-term panel data to enable causal inference [12]. Furthermore, statistical approaches may limit capacity to fully assess the social and behavioral aspects of adaptation and household dynamics related to diet diversity in a changing world; agent-based models and other social modeling may help solve this gap. However, it is also critical that as the evidence for action increases, scaling up of any adaptation interventions come with additional resources and support to ensure that programs that expand can achieve the same health and nutrition outcomes as their original focus [61].

4. Conclusion

In this large-scale, multi-country analysis, we demonstrate the relationship between climate on child diet diversity outcomes, including temperature, which has not been previously widely recognized. Our work demonstrates that climate variables in some regions have a relatively greater impact on diet diversity outcomes as compared to other controls variables, including some that are commonly promoted for development-oriented projects. This suggests that safeguarding child diet diversity, and related nutrition outcomes, requires adaptation efforts explicitly considering climate, though our empirical understanding of these remains limited. Future research can explore these potential adaptation strategies and their outcomes, as well as examine the impact of climate on diet diversity outcomes at different scales, and ideally, with long-term panel data.

5. Methods

We utilize multiple datasets, joined together through longitude and latitude, to develop an integrated dataset to assess child diet diversity outcomes across 19 countries and six regions. Below we describe the datasets as well as our statistical approaches. Table 1 provides an overview of all of the variables utilized in this analysis.

5.1. Demographic health surveys

The main basis of our analysis builds off a compilation of DHS datasets, which are nationally representative data on population demography, health and nutrition, from 2000 to 2013 (SI appendix for individual countries and years of surveys). For NSF SESYNC Grant DBI-1052875 we consolidated DHS across 47 countries. We normalized survey responses across these countries for over 200 DHS variables. We used geocoded cluster references to add economic and ecological data to the health and household data of DHS (see [62] for details). Here we compile data across 19 developing countries in Africa, Central and South America, and Southeast Asia for geographic diversity of this original aggregated dataset. The DHS dataset was subsampled to select only the variables of interest (including complete data for diet diversity, which was limited), based on previous research, and some minor data cleaning was applied where necessary (for example, standardizing the encoding of missing values across the dataset). Our key dependent variable—an individual diet diversity score (IDDS)—is constructed through a series of questions in the DHS related to dietary intake of children under five. The IDDS is based on the United Nations Food and Agriculture Organization [63], and is a scale ranging from 0 to 10 based on intake of 10 types of foods including: (a) cereal grains; (b) white tubers and root foods; (c) dark leafy greens; (d) vitamin A rich vegetable/tubers; (e) vitamin A rich fruits; (f) other fruits and vegetables; (g) meat and fish foods; (h) eggs; (i) legumes/nuts/seeds; and (j) milk and milk products. We incorporate other variables of interest as described in table 1, which include variables from both the DHS surveys as well as other global datasets.

5.2. Climate data

The Climate Hazards Group InfraRed Precipitation with Station (CHIRPS) dataset combines 0.05° resolution satellite imagery with *in-situ* station data to generate 30 years of local rainfall timeseries data across most of the globe at a 1 month temporal resolution. The Climate Hazards Group InfraRed Temperature with Station (CHIRTS) dataset uses similar methods to generate gridded timeseries temperature data. We obtained CHIRP/TS data according to the latitude and longitude of each survey location in the DHS dataset. We obtained all available historical timeseries CHIRP/TS datapoints for each geospatial location, and coded each row with latitude, longitude, and DHS date identifiers.

Based on the survey month, we calculated several temperature and precipitation columns from the raw timeseries CHIRP/TS data. We selected current and previous month values from the raw data. We calculated annual means by averaging the 12 months prior to and including the survey month. We calculated long-term averages by averaging monthly values across all full years between the survey month and the beginning of the CHIRP/TS timeseries. For example, if there were 124 months of available data preceding the survey month, only 120 months (10 full years) were included in the long-term average to avoid skewing the result by including an extra set of winter months. In the event that an individual monthly datapoint within the long-term data window was missing, we inputted its value based on the long-term average for that month. We stipulated that the long-term CHIRP/TS average would only be included if 10 full years of data were available prior to the survey month.

We generated columns representing long-term climatic variability by calculating the standard deviation across all monthly datapoints within the long-term temperature and precipitation averages.

Additionally, we include a column representing the average number of months per year within the long-term data in which the temperature was over 32.2 °C (90 °F), and another for average number of months per year in which there was less than 25 cm of precipitation.

Binary anomaly variables were generated indicating whether the survey month and previous month were drier or hotter than the long-term average for that month, and also whether the survey year and previous year were drier/hotter than the annual long-term average. We also calculated columns representing the number of standard deviations above or below the long term average for the survey year and previous year.

5.3. Hierarchical models

To assess the relationship of agroecological, geographic, socioeconomic, and climate variables on IDDS, we utilize a series of regional and full dataset hierarchical linear models with random effects.

We include a random effect for the country and DHS cluster identification number, which is a geographic stratification, chosen by the survey designers, usually containing 25–30 households that are in relatively close proximity. Hierarchical models are structured with nested units [64]; in our case, households, nested in DHS clusters, nested in countries, included as random effects. We run six regional models (West Africa, Southeast Africa, North Africa/Middle East, Asia, South America and Central America) as well as one global model. In total, our models represent the data from 107 741 individual responses across these regions.

Data availability statement

The data that support the findings of this study are available upon reasonable request from the authors. The code supporting this work is available at https://github.com/dbemerydt/climate-diet-diversity. Data will be available from 16 January 2020. June 2020.

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