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Abstract

Children's nutritional status is expected to be negatively impacted by global climate change given their relative vulnerability to food insecurity shocks. The developing countries in Africa are relatively even more vulnerable to these negative impacts. This study investigates the impact of climate change on the geographical variation of the prevalence of stunting among children under the age of five in the Nile basin region using the Demographic and Health Surveys of the three countries Egypt, Ethiopia and Uganda. Survey data is spatially and temporally merged with high resolution climate change datasets to investigate whether and how the change in temperatures and precipitation has an influence on children's malnutrition. The prevalence of stunting among children under five years of age and its socioeconomic determinants are modelled using Bayesian geospatial regression model. The prevalence and determinants of stunting varied across Egypt, Ethiopia, and Uganda. The result of this paper highlights the fact that social policies and public health interventions targeted to reduce the burden of childhood stunting should consider geographical heterogeneity and adaptable risk factors.

JEL Classification: I1, I3, Q3

Keywords: Climate change, child malnutrition, food insecurity, Egypt

ملخص

من المتوقع أن تتأثر تغذية الأطفال سلبا بتغير المناخ العالمي نظرا لضعفهم النسبي أمام صدمات انعدام الأمن الغذائي. وتعد الدول النامية في أفريقيا أكثر عرضة نسبيا لهذه الآثار السلبية. تبحث هذه الدراسة في تأثير تغير المناخ على التباين الجغرافي لانتشار التقزم بين الأطفال دون سن الخامسة في منطقة حوض النيل باستخدام المسوح الديموغرافية والصحية في ثلاثة دول هي: مصر،وإثيوبيا وأوغندا. يتم دمج بيانات المسح مكانيا وزمنيا مع مجموعات بيانات تغير المناخ عالية الدقة للتحقيق فيما إذا كان للتغير في درجات الحرارة وهطول الأمطار تأثير على سوء تغذية الأطفال وكيف يؤثر على ذلك. يتم نمذجة انتشار التقزم بين الأطفال دون سن الخامسة ومحدداته الاجتماعية والاقتصادية باستخدام نموذج الانحدار الجغرافي المكاني. وتباين انتشار التقزم ومحدداته في جميع أنحاء مصر، وإثيوبيا وأوغندا. وتسلط نتيجة هذه الورقة الضوء على حقيقة أن السياسات الاجتماعية وتدخلات الصحة العامة التي تستهدف الحد من عبء التقزم في مرحلة الطفولة ينبغي أن تأخذ في الاعتبار عدم التجانس الجغرافي وعوامل الخطر القابلة للتكيف.

1. Introduction

Most land areas will experience more frequent hot temperature days and heat waves by 2100 according to the Intergovernmental Panel on Climate Change (IPCC, 2014). These changes in the weather have direct and indirect implications on health and well-being. Climate change can have a direct impact on people's health through changing exposure to heat and cold, air pollution, emerging infections, and respiratory and water-borne diseases (Li et al., 2015; Mayrhuber et al., 2018; Greena et al., 2019). Children are even more vulnerable than adults to these changes; as they have greater metabolic rate, lower cardiac output, and greater body surface area-to-mass-ratio, which makes their bodies more sensitive to temperature changes (Bunyavanich et al., 2003; Sheffield et al., 2014; Varela et al., 2020). The indirect impacts of high temperature on human's health have also been identified through the effects of climate change on agriculture, water sources and general productivity levels (Hasegawa et al., 2016). Such disturbances in nutritional sources and income levels can eventually threaten food security and hence increase the risk of children malnutrition (Mayrhuber, et al., 2018).

There is now evidence from middle- and high-income countries (Deschênes et al., 2009; Gasparrini et al., 2015; Barreca, 2018) that high temperatures are associated with increased mortality and malnutrition rates among children. Yet, little is known about the impacts of high temperatures in developing countries, although the problem is becoming more salient in these countries. Poor populations are less capable of confronting exposure to heat waves and its health associated effects. This is mainly attributed to their weak hospitalization and medical assistance, weak nutritional status and their strong dependence on agriculture and natural resources which are subject to higher climate risks (Varela et al., 2020; Xu et al., 2017). Therefore, quantifying the impacts of climate change on children's health in the developing countries is vital to mitigate them efficiently. But the scarcity of data in most developing countries, is the main challenge limiting such studies. This study examines the impact of climate change on children's heath in Egypt, Ethiopia, and Uganda. The choice of the studied countries is not only driven by data availability, but these countries also offer a good diversity and representation in the exploration of the Nile Basin and the discrepancies across it.

Malnutrition is one of the many health inequalities facing governments which can be exacerbated with climate change. It is, therefore, important to control for the impacts of the socio-economic disparities while investigating the impacts of climate change on malnutrition. The social gradients for health outcomes and the usage of health systems are revealed by disaggregating the under-five morbidity patterns across countries. This study aims at examining the association between temperature and precipitation anomalies and under-five child malnutrition in the Nile Basin countries namely, Egypt, Ethiopia, and Uganda, at a smaller spatial scale; and analyzing the spatial variations in climate change effects and under-five stunting across different areas of the studied countries while taking into consideration the socioeconomic factors of health such as education, urban-rural, and wealth disparities. This will help policy makers evaluate the impacts of changes in climate on the prevalence of poor health conditions among infants and children across the Nile Basin and identify regions that are less resilient to high temperatures. This, in turn, can be used as an early warning system to guide social policies and the public health sector on where and how to distribute its resources to save young generations.

In sum, this paper broadly contributes to a multitude of literature by applying it to a region that received little research attention. It adds to the body of knowledge on the role of socioeconomic factors in shaping child health, as well as possible routes and biological aspects that could explain their impacts. It further contributes to the climate change literature by elucidating the complex relationship between climate change and children's nutritional status, which encompasses several direct and indirect pathways. The paper is organized as follows. Sections 2 presents the research problem and a review of the studies performed to examine the impacts of weather and climate change variables on children malnutrition at both the global and regional levels. This is followed by a description of the survey data used in the study in Section 3. Then, Section 4 briefly explains the Bayesian geo-spatial model used to evaluate malnutrition among under-five children in relation to climate at the sub-national level of Egypt, Ethiopia, and Uganda. Next, Section 5 report the study empirical results; and finally, Section 6 concludes and offers policy implications.

2. Background and Literature Review

Climate change and its impact on nutrition has been considered one of the most pressing global challenges. Continuous increase in surface temperature and more intense and frequent heatwaves and precipitation events are expected to have a global impact through reducing water availability, food security, infrastructure, and agricultural incomes. However, the impact on low and middle-income countries is expected to be stronger due to the fact that these countries are more vulnerable to slower economic growth and food shortages which will make poverty reduction more difficult and may increase the risk of violent conflicts (Louis and Hess, 2008). Climate change results in a loss in aggregate crop production, but this impact is stronger in tropical and temperate regions that rely on rainfed agriculture to meet their food and nutrition needs (Brown et al., 2015; Challinor et al., 2014). Developing countries in Africa are one of the most vulnerable regions in which agricultural production are negatively highly affected by inconsistent rainfall and extremely high temperatures (Davenport et al., 2017). The frequent flooding and drought events in addition to extremely high temperatures make it more difficult for families that rely on subsistence agriculture to meet their nutritional and caloric demand. The fact that children in the developing world, and more specifically in poor communities, are more vulnerable to food and nutritional food insecurity provokes research into how climate change may impact the nutritional status of children living in these regions.

Understanding the impact of climate change on children's nutritional status is becoming more pressing due to the short-term and long-term negative impacts of malnutrition. Malnutrition before conception and during early pregnancy has adverse effects on maternal, neonatal, and child health outcomes (Ramakrishnan et al., 2012). Malnutrition in-utero also increases the incidence of disability and lower years of schooling (Almond and Mazumder, 2001; Meng and Qian, 2009). Studies have also shown that malnutrition during early childhood has a negative impact on adult stature and years of schooling, adult health, and mortality rates (Alderman et al., 2006; Hoddinot and Kinsey, 2001; Currie and Vogl, 2013; Van den Berg et al., 2009). The rates of stunting in children in addition to higher risks of maternal and child malnutrition are relatively higher in low- and middle- income populations (Black et al., 2020). This makes focusing on the investigation of climate change impacts on children's malnutrition in the developing countries of significance importance.

The adverse impact on agricultural production does not only directly increase the risk of famines and malnourishment, but it also impacts nutrition indirectly by reducing the incomes of food producers and labor in the agricultural sector (Maccini and Yang, 2009). It also increases the prices of food, which in turn reduces access to food and increases the likelihood of child malnourishment. These extreme weather events also increase the spread of vector-borne diseases such as diarrhea and malaria among children which reduce their biological ability of food utilization, lower the capability of exclusive breast-feeding, and make parents less capable of working and taking care of their children, and hence adversely impact their nutritional status (Louis and Hess, 2008; Randell et al., 2021).

Previous literature attempted to capture the relationship between exposure to climate changes in-utero and as children under the age of five and their short-term and long-term health status measured by their height-for-age and weight-for-age. Some studies have examined the effects of climate variability during pregnancy on child health outcomes and found that pregnancies conceived in months with lowest precipitation have shorter gestation periods and increased risk of having pre-term babies (Rayco-Solon et al., 2005; Davenport et al., 2020). Grace et. al (2021) show that high temperatures and low levels of agricultural production in Mali are associated with lower birth weights and that living in malarias conditions may increase the likelihood of non-live birth outcomes. While McMahon and Gray (2021) find that precipitation extremes in South Asia in the first year of life reduces children's height-for-age with the highest impact concentrated in under-resourced households, such as those lacking access to proper sanitation and households with women with lower education. Thiede and Strube (2020) examine the impact of temperature and precipitation anomalies on the weight and wasting of children below the age of five in Sub-Saharan Africa concluding that high temperatures are associated with lower weights and increased risk of wasting, whereas low precipitation is associated with reductions in weight. Hoddinott and Kinsey (2001) reach similar results by investigating the impact of rainfall shocks on children growth finding that children aged 12 to 24 months are the most vulnerable as they lose 1.5-2cm of growth in the aftermath of a drought. Whereas Grace et al. (2012) show that the drying and warming conditions in Kenya are associated with increasing stunting levels for children aged 1 to 5. Another study tests the relationship between temperature, precipitation and stunting in Ethiopia and concludes that increasing rainfall during rainy seasons is associated with increasing height-for-age, while exposure to higher temperature during the first and third trimester is positively associated with severe stunting (Randell et al., 2020). In brief, several studies have shown that lower precipitation and higher temperature are associated with increased stunting, wasting, and other adverse health outcomes.

Conversely, Singh et al. (2001) examine the relationship between extreme rainfall and incidence of diarrhea in Fiji concluding that there is a positive association between both variables. In addition, Tiwari and Skoufias (2017) examine the relationship between monsoon rainfall shocks and height and weight in early childhood in rural Nepal. Their results indicate that more rainfall is associated with higher weight in children due to more agricultural production "positive income effect", but it also results in lower weight due to higher transmission of disease "negative disease effect". However, the positive income effects outweigh the negative disease effects resulting in positive net weight gain for children during the higher precipitation episodes. Cornwell and Inder (2015) also find that rainfall has a positive impact on height-for-age but also a negative impact through higher transmission of disease in urban children aged 10 and under in Indonesia.

Previous literature indicates contradicting results when examining the relationship between climate change and children's nutritional status. One possible justification for this contradiction is that relationship between precipitation and height and weight in children is non-linear. This is because too little rainfall negatively impacts child health by affecting agricultural incomes and food availability, but also too much rainfall results in more disease transmission which in turn increases child malnourishment. The relationship between climate and nutrition also tends to differ from one region to another. To our knowledge, there have not been any previous studies that explored or compared the relationship between climate change and stunting among infants and children across the Nile Basin countries. Our study examines the geographical distribution of stunting and the non-linear relationship between temperature and precipitation anomalies and stunting among children aged from birth to 5 years old sub-nationally in Egypt, Ethiopia, and Uganda using spatial Bayesian regression modeling. This modelling approach enables us to control spatial confounders more rigorously by accounting for the within-country spatial variations. To analyze the impact of climate change on height-for-age and stunting in children aged 5 and under in the three countries under study, we used the last available Demographic and Health Survey (DHS) datasets of Egypt, Ethiopia and Uganda for children aged 0-59 months with valid anthropometric measurements and geographic coordinates. DHS provides high quality nationally representative datasets with high resolution geographic identifiers; see details below.

3. Data and Method

3.1. Data Description

Child anthropometric and socio-economic data are obtained from the latest available Demographic and Health Surveys (DHS) in Egypt, Ethiopia and Uganda; which were accessed using the DHS program database (https://dhsprogram.com/). DHS data are considered among the highest quality population health surveys in the developing countries. One advantage of DHS data is that they are collected using standardized core questionnaire that facilitates comparisons across countries (Headey, 2013). Another advantage of DHS data is that they include the latitude and longitude of DHS clusters which allows linking individual records to high-resolution temperature and precipitation data.

It is worth noting here that the DHS program randomly displaces cluster geo-coordinates (0-2 km for urban clusters; and 0-5 km for rural clusters with 1-5% of all clusters shifted by 10 km) to protect respondent confidentiality. This can introduce bias in the estimates but proved to be of relatively small magnitude. To account for this location shift, climate data in and around the community cluster location are aggregated. That is, households are linked with climate data for an approximate 10 square kilometer grid cell, including where the DHS cluster lies and all grid cells congruent to the cluster grid cell (Grace et al., 2012). Linking the cluster grid cell to the climate information of the cluster itself and its neighboring grid cells accounts for the location shift and the fact that temperature and precipitation outside of a household’s immediate area may still influence that household’s ability to meet the nutritional requirements of its children.

The analysis in this paper is restricted to the children under 5 for which anthropometric measures are available and to children born to mothers who had usually resided in their cluster of enumeration for at least 2 years and as a result have been exposed to the climatic conditions in these clusters. Twins and observations with biologically impossible height-for-age z-score (HAZ) values (>|5|) were excluded from the sample. After these restrictions, the analysis in this paper is based on a sample that includes 11995 child records from Egypt 2014 DHS, 8000 from Ethiopia 2016 DHS and 3536 from Uganda 2016 DHS. As recommended by the DHS program, sampling weights are applied to all analyses. The sample characteristics are illustrated in Table 1 and the geographic distribution of the clusters included in the sample is depicted in Figure 2.

Climate variability is measured using data from the University of East Anglia Climate Research Unit’s Time Series (CRU TS). CRU TS is a global dataset of monthly weather conditions (Harris et al., 2014) constructed at a grid of $0.5^{o} \times 0.5^{o}$ resolution based on statistical interpolations of data from over 4000 weather stations across the globe. Maximum temperature and precipitation records are extracted from January 1951 through December 2015 (and December 2013 for Egypt) for grid cells that DHS clusters fall in, and maximum temperature and precipitation anomalies are calculated as described below.

3.2. Variables

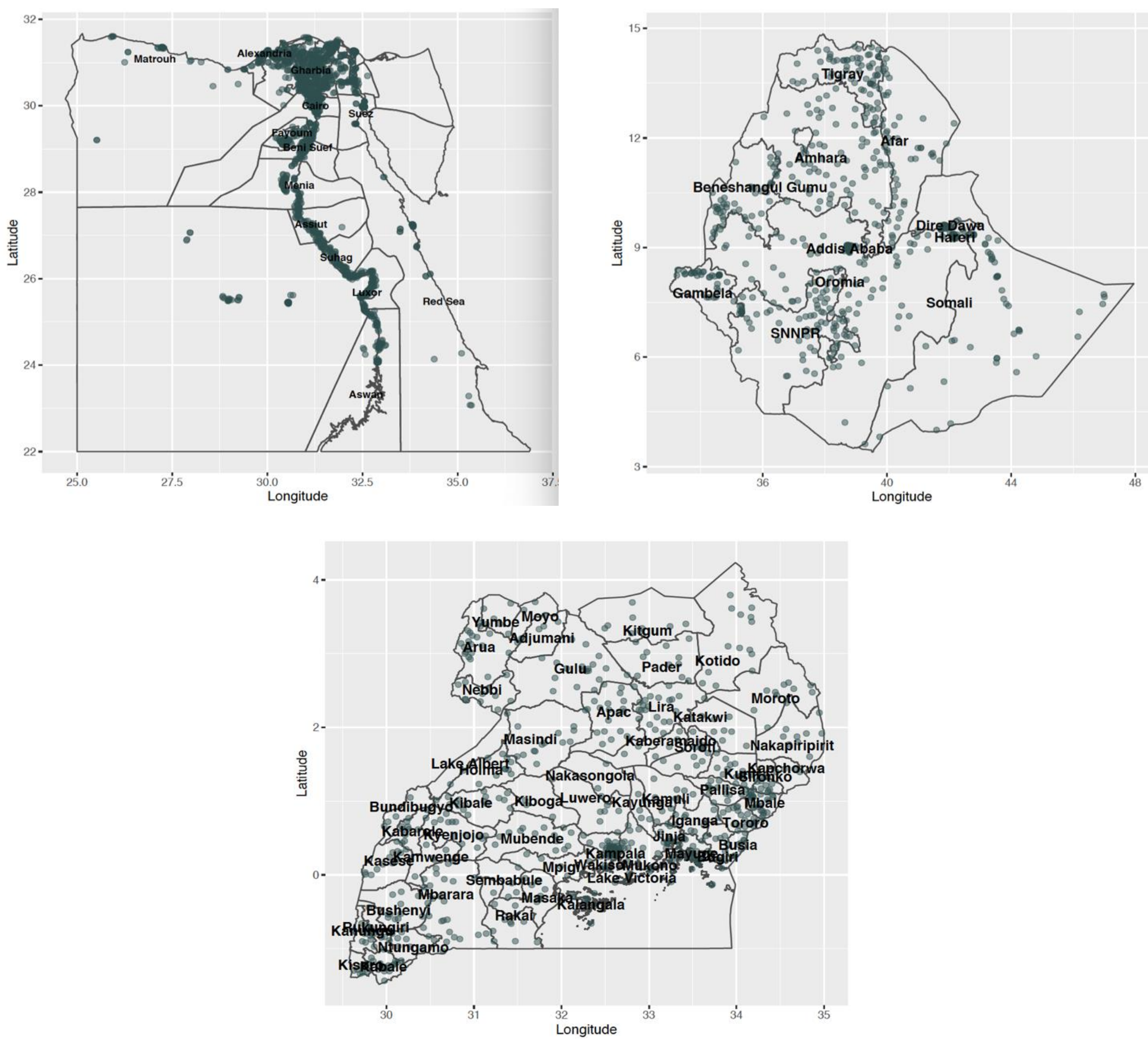
The dependent variable in this study is stunting, defined as having a height-for-age z-score (HAZ) less than -2. HAZ z-score is calculated by subtracting an age- and sex-appropriate median value from a standard population and dividing by the standard deviation (SD) of the standard population. The z-scores are calculated using the World Health Organization (WHO) standards (World Health Organization, 2006). The nutritional status of children is then classified on a binary scale, “1 = Yes/stunted” if HAZ < -2 or “0 = No/not stunted” if HAZ >-2. Stunting is often associated with several negative outcomes, including suppressed immunity, increased risk of morbidity and mortality, and lower school performance. This, in turn, has implications on human development over both the short- and long-run terms.

Table 1. Summary of Variables

	Ethiopia				Egypt				Uganda			
Variables	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**
Average lifetime climate anomalies												
Temperature	1.803	0.006	1.21	3.27	1.993	0.006	0.65	3.38	1.795	0.006	1.04	2.35
Precipitation	0.261	0.009	-1.18	1.84	-0.480	0.004	-1.38	1.00	0.548	0.007	-0.32	1.43
Historical average climate												
Temperature	26.247	0.041	20.29	35.96	28	0.019	24.25	33.93	28.827	0.03	22.59	31.71
Precipitation	91.705	0.346	15.57	149.63	4.099	0.048	0.20	23.96	107.34	0.228	56.56	139.76
Child characteristics												
Age (months)	28.822	0.28	0	59	28.589	0.17	0	59	29.103	0.32	0	59
%Females	0.490	-	0	1	0.473	-	0	1	0.496	-	0	1
Birth order	4.018	0.04	1	14	2.457	0.01	1	15	4.041	0.05	1	18
Mother characteristics												
%Primary education	0.061	-	0	1	0.183	-	0	1	0.321	-	0	1
%Secondary & higher education	0.026	-	0	1	0.587	-	0	1	0.067	-	0	1
BMI	20.576	0.04	11.73	46.43	28.896	0.05	10	49.96	23.135	0.09	14.16	48.63
Age (years)	27.135	0.10	13.33	48.17	26.199	0.05	13.17	47.17	26.876	0.13	13.50	45.75
%Working	0.446	-	0	1	0.133	-	0	1	0.841	-	0	1
Household Characteristics												
%Urban	0.105	-	0	1	0.305	-	0	1	0.196	-	0	1
%Middle income group	0.213	-	0	1	0.255	-	0	1	0.202	-	0	1
%Rich income group	0.319	-	0	1	0.372	-	0	1	0.356	-	0	1
%With protected water source	0.524	-	0	1	0.974	-	0	1	0.693	-	0	1
%With improved toilet facility	0.082	-	0	1	0.916	-	0	1	0.330	-	0	1

The main goal of this study is to investigate whether and how climate change impacts the rates of stunting in the Nile Basin countries: Egypt, Ethiopia and Uganda. Therefore, the independent variables of interest here are temperature and precipitation anomalies that capture the deviations of the climate patterns over each child’s lifetime from the long-term average conditions within each cluster in the sample. These variables are calculated respectively as the yearly mean temperature and yearly total precipitation observed for a given cluster averaged over the age of each child prior to the year of each DHS survey. These averages are then standardized over all consecutive 12-month periods from 1950 to 2000 for that location. This approach is used to assess the irreversible impacts of climatic variability on the child's health and nutritional status throughout his life.

Figure 2. Maps of the location of under five children in the investigative sample in Egypt (top left), Ethiopia (top right) and Uganda (bottom)



Evidence has accumulated that socioeconomic factors including dwelling conditions, wealth, and education as root causes of a variety of health consequences. In this paper, the model take into consideration other independent variables, as control variables, which are the socioeconomic determinants of child health including child gender, birth order and age in months; maternal age, Body Mass Index (BMI) and school attainment; the place of residence controlling for rural/urban disparities, wealth, toilet facility and water source status of the household's cluster of residence; and the historical climate of the cluster of residence as measured by the respective means and standard deviations of temperature and precipitation across history (1950-2015). These variables may be correlated with child malnutrition (Behrman and Skoufias, 2004; Grace et al., 2012; Rieger and Trommlerova, 2016; Thiede and Strube, 2020), and hence their inclusion in the model increases the estimates precision. We further attempt to expand climate exposure in the model by including the enhanced vegetation index (EVI), as a proxy for the average productivity and yield of a cereal crop in each cluster, which is expected to positively contribute to child nutrition. In addition to the control variables described above, we included a series of random effects to control for the cluster effect, as well as spatially structured random effects. These latter random effects are incorporated into the model to account for the geographical dependence between clusters, assuming that spatial autocorrelation decays as the distance between clusters increases.

3.3. Statistical Modelling

To evaluate the effects of temperature and precipitation variability on children's stunting status while accounting for the spatial dependence between DHS clusters within each of the three Nile Basin countries, a Bayesian spatial modelling approach is used. In this modelling approach, the stunting status of child i is estimated as a function of temperature and precipitation anomalies in the cluster of residence c throughout the life span of child i until the year of the survey; while controlling for the child characteristics including the maternal and household corresponding characteristics and the historical climate in cluster c. That is, let Y_i be the binary variable taking value 1, if the i-th child is stunted and 0 if not. This variable can thus be assumed to be distributed as a Bernoulli random variable with unknown probability π_i that the child is stunted, i.e. $Y_i \sim Bern(\pi_i)$. Thus, the risk of being stunted can be modelled using a spatial logistic regression model that accounts for excess heterogeneity and spatial dependence between areas within the same country as follows:

$$\text{logit}(\pi_i) = \log\left(\frac{\pi_i}{1-\pi_i}\right) = \beta_0 + X_i^{\top}\beta + X_{c_i}^{\top}\alpha + f_s(c_i) + f_u(c_i),$$

where $\beta = (\beta_1, \ldots, \beta_p)^{\top}$ is the $(p \times 1)$ vector of regression coefficients that corresponds to the vector of child specific covariates and socioeconomics determinants of health X_i, $\alpha = (\alpha_1, \ldots, \alpha_k)^{\top}$ is the $(k \times 1)$ vector of regression coefficients that corresponds to the vector of cluster covariates X_{c_i} such as temperature and precipitation anomalies, $f_u(c_i)$ is a spatially unstructured random component which is independent and identically normally distributed with zero mean and unknown precision[4], τ_u, and $f_s(c_i)$ is a spatially structured component which is assumed to vary smoothly from one location to another. The smoothness of $f_s(c_i)$ is accounted for by modelling it as an intrinsic Gaussian Markov random field with a stationary and isotropic Matérn covariance matrix with unknown precision, τ_s and range ρ parameters. This Matérn covariance matrix is defined as follows:

$$cov\left(f_s(c_i), f_s(c_j)\right) = \frac{\sigma_s^2}{2^{v-1}\Gamma(v)}\left(\kappa|c_i - c_j|\right)^v K v\left(\kappa|c_i - c_j|\right),$$

where $|c_i - c_j|$ denotes the distance between locations c_i and c_j, $\sigma_s^2 = 1/\tau_s$ is the variance of the spatial field, and $K(\cdot)$ is the modified Bessel function of second kind and order $v > 0$. The integer value of v determines the mean square variability of the process. $\kappa > 0$ is a parameter related to the range ρ, the distance at which the correlation between two points is approximately zero and referred to as a spatial decay parameter. A similar modelling approach that accounts for the geographic dependence between DHS clusters was used to examine associations between stunting and other potential health, socio-economic and environmental factors in Ethiopia (Ahmed et al., 2021), Mali (Benedict et al., 2020) and Rwanda (Uwiringiyimana, 2019).

The spatial model described above is fitted within a Bayesian framework by specifying non-informative priors for estimating the posterior distribution of fixed effects and spatial random effects' variance parameters. For the fixed effects' regression coefficients, non-informative priors with normal distributions of mean and precision N(0, 0.001) are specified. Whereas, for the spatially structured random effects, vague gamma prior of (1, 0.00005) for the spatial decay parameter and inverse gamma prior for the precision parameter are specified. Another highly dispersed inverse gamma distribution is specified to the variance of the spatially unstructured random effects. The Bayesian inference is carried out using the R library INLA which implements the Integrated Nested Laplace Approximation (INLA) approach for latent Gaussian models (Rue et al., 2009). Bayesian inference using INLA is a computationally efficient alternative to the Markov Chain Monte Carlo (MCMC) that is designed to approximate the MCMC estimations in latent Gaussian models, including generalized linear mixed models and spatial models (Rue et al., 2009).

4. Results

4.1. Model Validation

For model comparison and selection, the deviance information criterion (DIC), developed by Spiegelhalter et al. (2002) as a measure of model complexity and fit, is used. Smaller values of DIC indicate a better trade-off between the model complexity and fit. The models with spatially

[4] Precision (τ) =1/variance

structured and unstructured random effects yielded the smallest DIC relative to the traditional logistic models with independent random errors and logistic models with random intercepts (Table 2). For the final logistic spatial models, the odds ratio of stunting associated with 95% credible intervals are estimated and reported for the different child, maternal, household, and climatic factors in Table 3. A credible interval is the Bayesian equivalent of the confidence interval, in which an unobserved parameter value falls with a given probability. However, unlike confidence intervals, credible intervals are dependent on the prior distribution specified for the parameter (Edwards et al., 1963).

Table 2. DIC of logistic regression, logistic regression with independent random intercept for clusters and logistic regression with spatially random effects

	Basic Logistic	Logistic + IREE	Logistic + IRE+SRE
Ethiopia	11578	11120	11099
Egypt	12498	11228	11042
Uganda	3913	3842	3833

4.2. Overall estimates

The average effects of climatic variability as well as the child, mother and household characteristics and socioeconomic determinants of health which the child live in, on stunting status are estimated across each country's population using different models with different sets of climatic covariates. That is, for each country, a series of models are fitted to test for non-linearities in temperature and precipitation and interactions between them. This includes the estimation of models that include only linear temperature and precipitation terms, models that include quadratic climate terms, and models that include quadratic climate terms and temperature-precipitation interaction term. Also, models with historical average temperature and precipitation are examined. By evaluating these models, the preferred model specification appeared to be the one with quadratic temperature and precipitation anomalies terms, which excludes the interaction term and the average historical climate averages that appeared to be not statistically significant. The effect of the enhanced vegetation index (EVI) is also tested but turned to be insignificant in the three countries. One possible reason for this result is that EVI is considered as a mediator variable between climate and malnutrition.

Figure 3 compares the parameter estimates and their corresponding 95% credible intervals for the preferred model specification across the three studied countries and Table 3 reports the corresponding odds ratio (OR) estimated from the geospatial regression model accounting for the spatial autocorrelation structure. The analysis demonstrates that there are additional elements at play. The disparities in health between rich and poor, and advantaged and marginalized sectors of society are remarkable. In Ethiopia and Uganda, middle- and high-income households have the lowest rates of stunting in children under the age of five relative to poor households. In Egypt, expanding protected water resource coverage to the population tends to significantly improve child nutrition. The results show that mother education plays a significant role in child nutritional status.

Children with at least secondary educated mothers (OR = 0.73; CI: 0.63, 0.84), (OR = 0.64; CI: 0.42, 0.96) and (OR = 0.36; CI: 0.22, 0.57) are less likely to be stunted compared to their counterparts for Egypt, Ethiopia, and Uganda, respectively. The mother's Body Mass Index (BMI) seems to be significantly important only in Ethiopia and Uganda in reducing the probability of under five children stunting. Child's age depicts a quadratic relationship with the log odds of stunting in Ethiopia and Uganda, in contrast to Egypt where the association is linear in the sense that stunting is more prevalent among older children. The model also indicates that female children are less likely to be stunted relative to male children in the three countries. Although the child's birth order and the mother's age at pregnancy and working status have no significant effect in Egypt and Uganda, they are significant determinants of stunting in Ethiopia. That is, the odds of stunting in Ethiopia are significantly higher among later born than firstborn children; but significantly decreases as maternal age increases and is significantly lower among working mothers.

For the relationship between the climatic variables and children's stunting, it is found that children in Egypt who reside in geographic areas with precipitation anomalies below the long-term average conditions (OR = 1.66; CI: 1.11, 2.47) are less likely to be stunted compared to their counterparts. Maintaining the influence of spatial autocorrelation and other covariates constant, children who live in warmer clusters (OR = 3.2; CI: 1.17, 8.85), are more likely to be stunted compared to their counterparts in Egypt. In Ethiopia, children from rich households (OR = 0.65; CI: 0.57, 0.75), and those with working mothers (OR = 0.87; CI: 0.78, 0.97) have lower odds of stunting. The model results highlight also that Ethiopian children who resided in the "arid" geographic locations are more likely to be stunted compared to those who resided in the "wet" geographic locations. However, no significant impacts of climate anomalies on stunting were detected in Uganda.

Figure 3. Parameter estimates along with 95% credible intervals for the preferred model specification

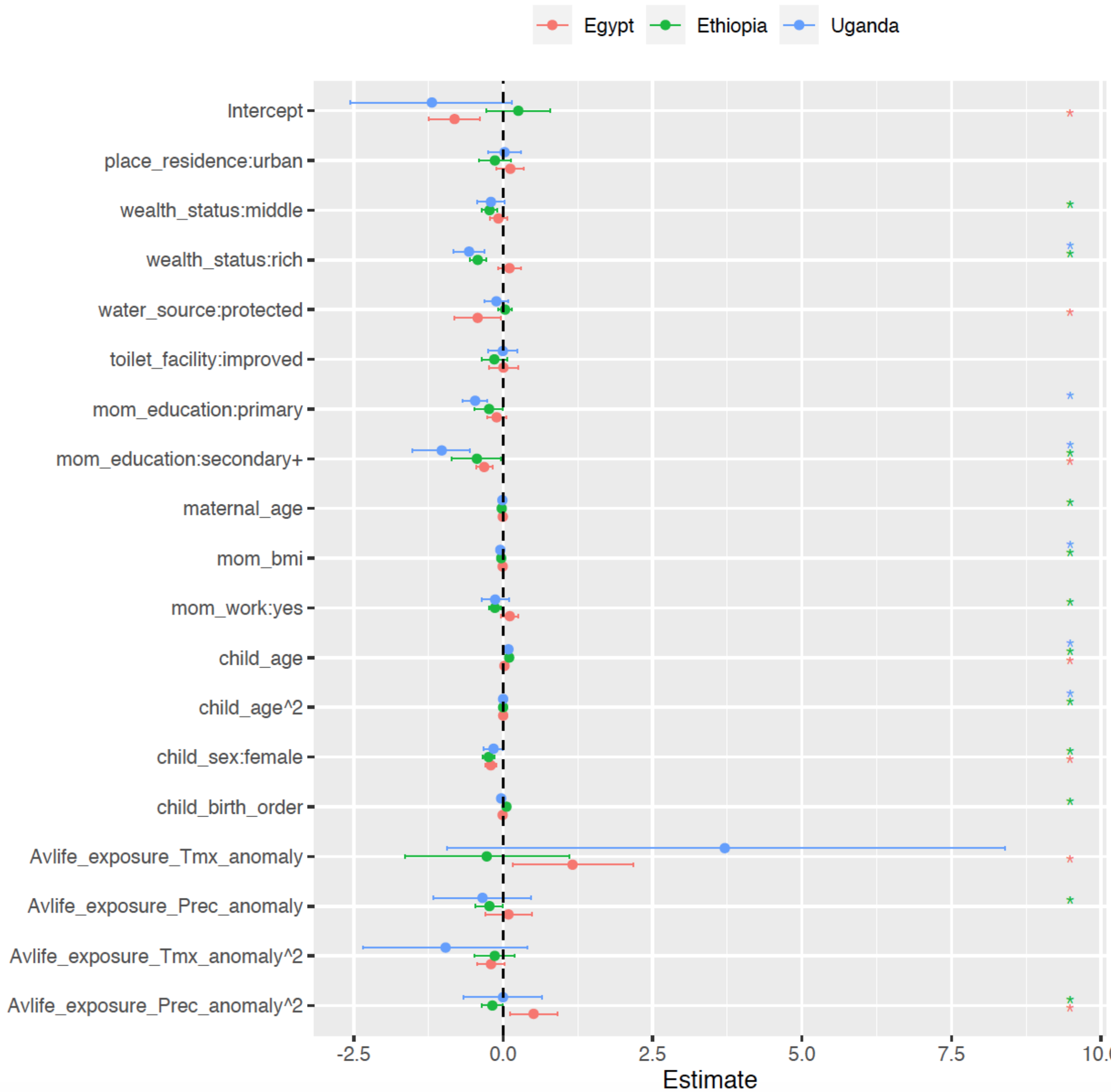
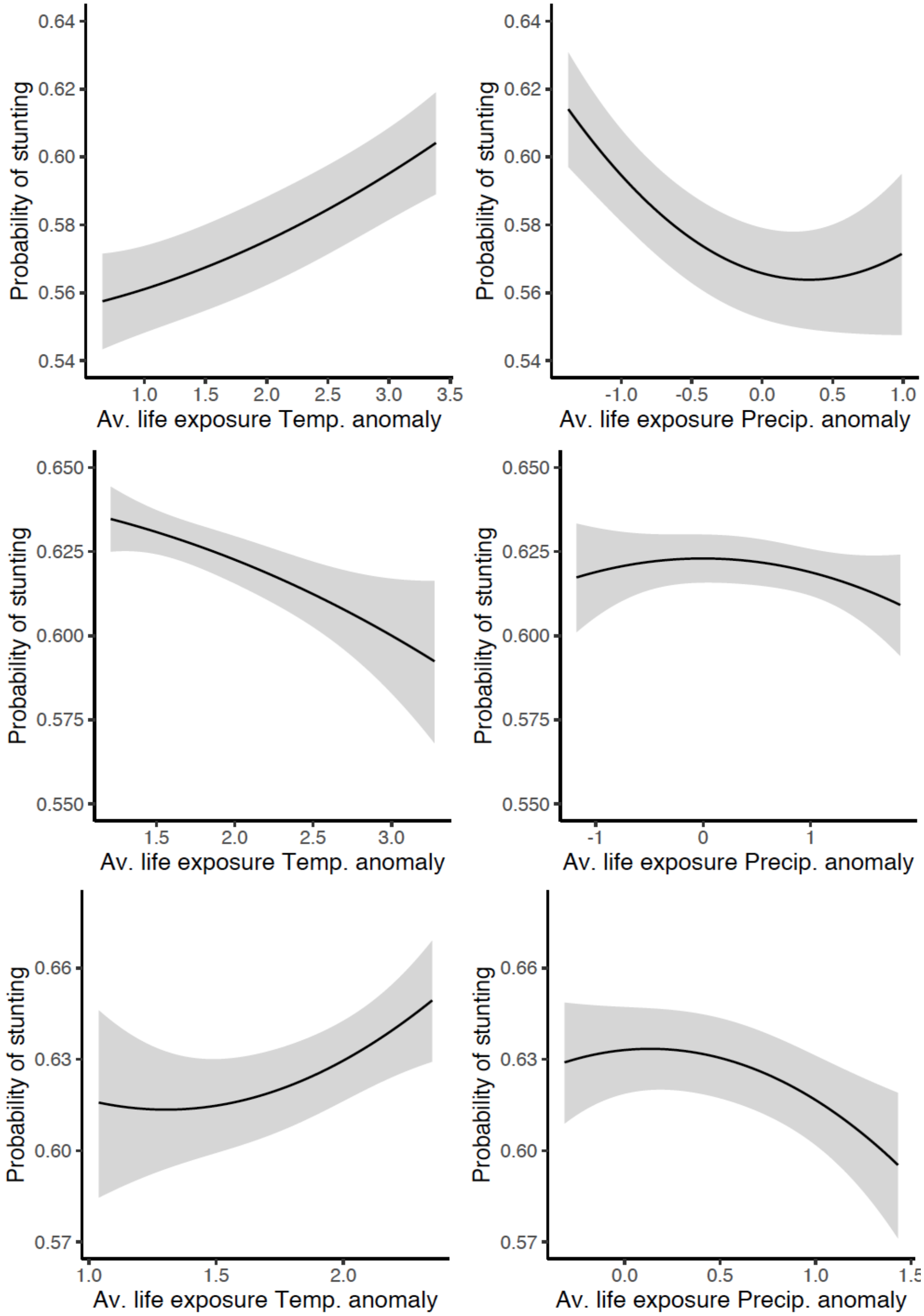


Table 3. Odds ratios and associated 95% Credible Intervals (CI) for the association between stunting and the climate variables as well as the child, mother and household characteristics

	Ethiopia			Egypt			Uganda		
Variables	**Mean**	**0.025**	**0.975**	**Mean**	**0.025**	**0.975**	**Mean**	**0.025**	**0.975**
Place of residence (reference: Rural)									
Urban	0.87	0.66	1.14	1.13	0.90	1.42	1.02	0.77	1.35
Wealth Status (reference: Poor)									
Middle	0.80*	0.70	0.90	0.92	0.80	1.07	0.81	0.65	1.02
Rich	0.65*	0.57	0.75	1.11	0.91	1.35	0.56*	0.44	0.73
Water Source (reference: Not protected)									
Protected	1.03	0.92	1.16	0.65*	0.44	0.97	0.89	0.73	1.09
Toilet facility (reference: Not improved)									
Improved	0.86	0.69	1.07	1.00	0.78	1.29	0.99	0.78	1.27
Mom Education (reference: No education)									
Primary	0.79*	0.62	0.99	0.9	0.76	1.05	0.63*	0.51	0.77
Secondary or higher	0.64*	0.42	0.96	0.73*	0.63	0.84	0.36*	0.22	0.57
Maternal age	0.98*	0.96	0.99	0.99	0.98	1.01	0.99	0.96	1.01
Mother's BMI	0.97*	0.95	0.99	0.99	0.98	1.002	0.95*	0.93	0.97
Mother is working (reference: No)									
Yes	0.87*	0.78	0.97	1.12	0.96	1.29	0.87	0.69	1.10
Child's age (months)	1.11*	1.09	1.12	1.02*	1.01	1.03	1.09*	1.05	1.13
Child's age^2	0.999	0.998	0.999	0.999*	0.998	1.00	0.999*	0.998	1.00
Child's gender (reference: Boy)									
Girl	0.78*	0.71	0.86	0.81*	0.74	0.90	0.85*	0.72	0.9999
Child's birth order	1.06*	1.02	1.09	0.99	0.94	1.04	0.97	0.91	1.03
Average lifetime temp anomaly	0.76	0.19	3.05	3.20*	1.17	8.85	40.8	0.39	4404.5
Average lifetime temp anomaly^2	0.87	0.62	1.21	0.82	0.65	1.02	0.38	0.096	1.50
Average lifetime precip anomaly	0.79*	0.63	0.996	1.09	0.74	1.61	0.71	0.31	1.60
Average lifetime precip anomaly^2	0.83*	0.70	0.999	1.66*	1.11	2.47	0.997	0.52	1.92
Random Effects									
Unstructured variance	5.7×10^{-5}	0.0008	1.5×10^{-5}	0.699	0.561	0.884	0.016	0.015	0.017
Structured variance	0.371	0.278	0.528	0.719	0.529	0.992	0.887	0.873	0.899
Range (in Km)	50.00	31.77	74.17	27.33	19.5	39.31	122.1	115.6	124.0

(*) indicates the significance of the coefficient at 0.05 level of significance.

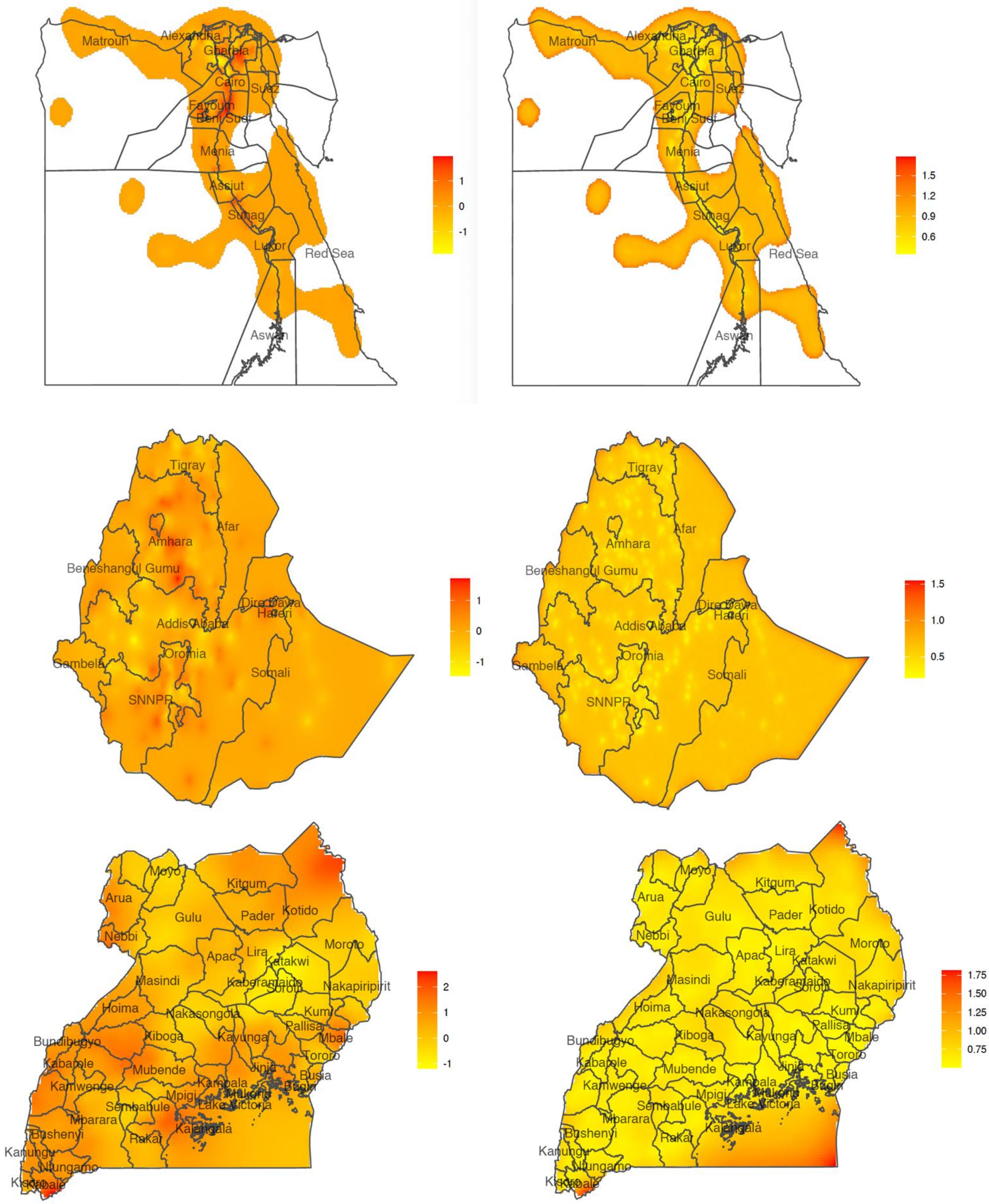
Figure 4. Effects of the average life exposure anomalies (temperature on the left and precipitation on the right) on stunting along with 95% credible intervals in Egypt (top), Ethiopia (middle) and Uganda (bottom)



4.3. Variation in Climate Effects

To further understand the climate change patterns on stunting, the probability of under five children being stunted is plotted across the range of temperature and precipitation anomalies, left and right panels of Figure 4, respectively, holding all categorical variables at the reference level and the other continuous variables at their means. Inspecting the estimation results, an increase in temperature anomalies in Egypt is clearly associated with an increase in the probability of stunting. Figure 4 also shows that a decline in the precipitation in Egypt to below the average historical level by 1 standard deviation is associated with an increase in the probability of stunting by almost 3%. In general, it is expected that precipitation deficits are associated with poor nutritional outcomes and leads to increased stunting. However, results also show that higher precipitation levels than average in Egypt slightly increases child stunting. This can possibly be attribute to the surge in waterborne sicknesses, which is in line with the findings of Cornwell and Inder (2015) in urban Indonesia. However, larger standard errors are associated with this increasing effect indicating higher uncertainty about such effect. We can also conclude that the average life-time precipitation exposure is a statistically significant predictor of stunting in Ethiopia in the sense that dry spells are associated with relatively higher likelihood of stunting. It is also evident that during spells of excess rainfall that the probability of stunting may increase or decrease due to the existence of two opposite forces. One is the increase in disease transmission that reduces child nutritional health. The second is the increase in crop production that improves child nutritional health through increased food availability. If the former effect outweighs the latter, it will result in an increase in the probability of child stunting during spells of high precipitation, whereas the probability of stunting will be reduced if the latter offsets the former. Those associations are robust across the studied Nile Basin countries, which is quite important given the detrimental vulnerability of the region to food insecurity and climate change (IPCC, 2014).

Figure 5. Posterior mean (left) and standard deviation (right) of the spatial random effects in Egypt (top), Ethiopia (Middle) and Uganda (Bottom)

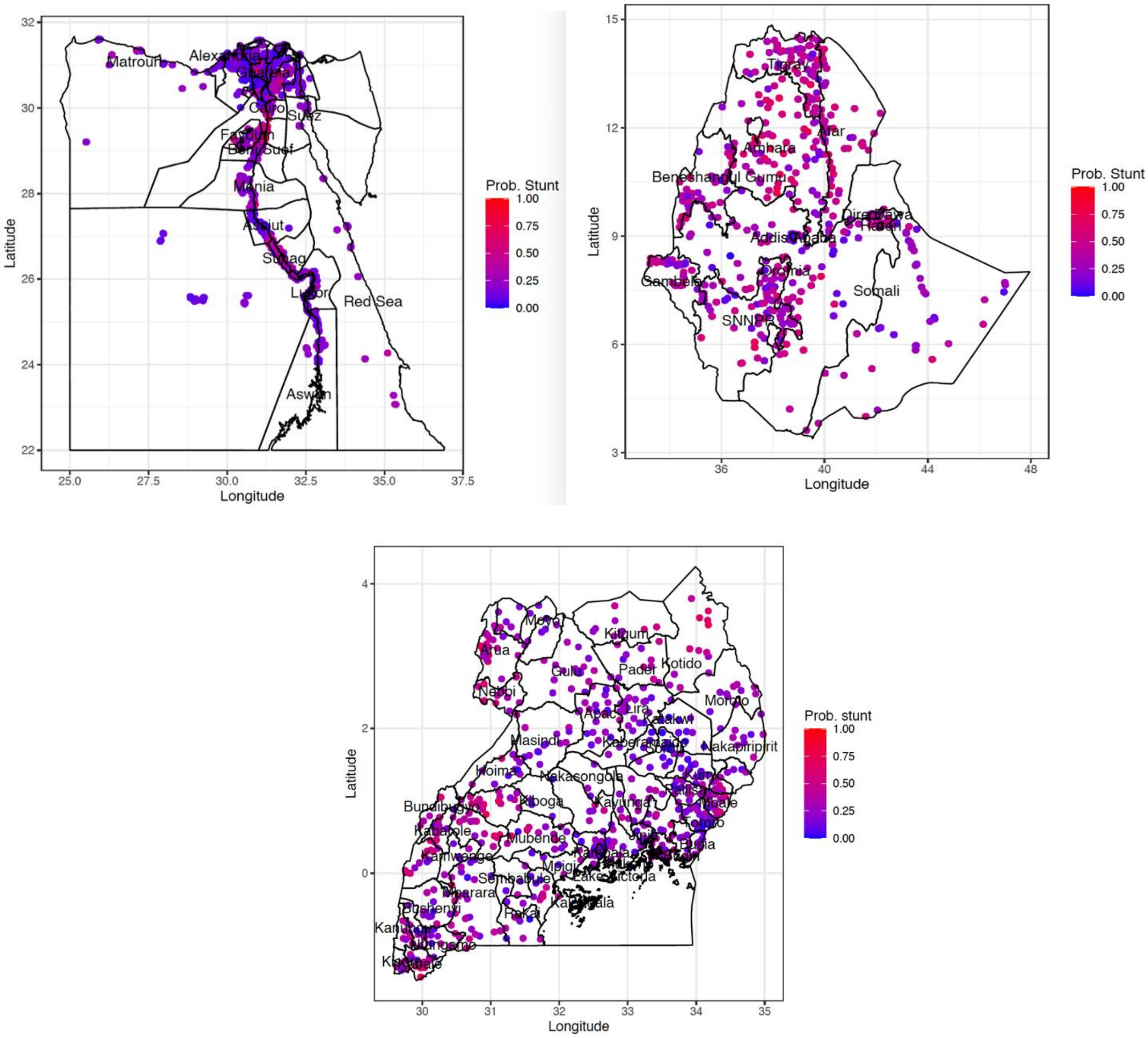


4.4. Geographical Patterns of Stunting and Significant Subnational Variations

The posterior mean of the spatial effects is shown in the left panels of Figure 5 with darker colors indicating higher spatial effects, whereas the right panels of the same figure show the associated standard errors which are clearly lower in densely sampled regions. The figure depicts spatial variations in the odds of stunting across the three countries. It is evident from Figure 5 that Lower Egypt (except the west of the Delta) exhibits higher risk of stunting among children aged 0-59 months relative to upper Egypt. Whereas the highest risks of stunting in Ethiopia are spotted in Amhara followed by the southern Ethiopian regions. In Uganda, it is most of the south-west part of the country that exhibits high risks of stunting among children aged 0-59 months.

Based on the preferred model specification that accounts for the spatial variations within each country, maps of the predicted probabilities of stunting at the observed clusters are produced in Figure 6. The results highlight that the highest probabilities of stunting are clustered in Egypt mainly in Fayoum, Sharqia and Suhag, which are densely populated governorates characterized by higher levels of poverty. Whereas for Ethiopia, the highest probabilities of stunting are likely to be observed in the region of Amhara which is a region that experiences more than usual natural and manmade distresses, including recurring droughts and famines, civil conflicts, and revolutions. These incidents seem to have significant effects on agricultural production and food insecurity, and hence child nutrition. In Uganda, it is the south-west region that suffers from higher risks of stunting relative to the rest of the country. This region of Uganda has proven to have a persistently high level of child stunting due to several risk factors mainly poor socio-economic ability of households, lack of good child health feeding practices, and poor hygiene practices (Bukusuba et al., 2017; and Vella et al., 1995). This further justifies why climate change variables have no significant effect in Uganda and calls for more targeted interventions into poverty alleviation with a nutrition focus.

Figure 6. Estimated probabilities of stunting at observed clusters in Egypt (top left), Ethiopia (top right) and Uganda (bottom)



5. Discussion and Conclusion

Given the global concern regarding climate change and its impacts on health, this paper attempts to fill a gap in the existing literature on nutritional vulnerability of children of age five and under in African developing countries, and more specifically in the Nile Basin countries. Understanding how climate impacts this particularly vulnerable group will significantly contribute to the decision-making process of policymakers in Egypt, Ethiopia and Uganda. This is achieved by answering key research questions such as, whether and how climate change impacts child nutrition in the Nile Basin countries as reflected in higher stunting rates. It is also necessary to identify which regions of the studied countries are particularly more vulnerable or most impacted by climate change. The choice of studied countries is not only driven by data availability, but also because they provide a sufficient diversity and coverage in the examination of the Nile Basin and its disparities.

Socioeconomic inequalities in health and healthcare occur everywhere. In the face of climate change, they are accentuated by poverty and under development. Most health disparities between and within countries can be mitigated through understanding the fundamental reasons of malnutrition and unhealthy behaviors. This paper investigates the underlying socioeconomic causes and the impact of climate change on under five morbidities. The effects of those conditions are revealed by disaggregating the prevailing under-five child malnutrition patterns across the Nile Basin countries. On the one hand, the paper draws attention to the relationship between climatic change and under five child malnutrition, utilizing a methodological structure that takes into consideration spatial and temporal confounders for three countries of the Nile Basin. The study contributes to the climate-nutrition literature by investigating the relationships between temperature and precipitation variability and child stunting across a diverse set of Nile Basin countries taking into consideration the socioeconomic factors of health such as education, urban-rural discrepancies, and wealth. Prevailing literature mostly supports that warmer and arid circumstances increase child stunting (Andalón et al. 2016; Davenport et al. 2018; Groppo and Kraehnert 2016; Randell et al. 2020; Thiede and Gray 2020; Thiede and Stube 2020). However, this paper underlines the complexity of this association through results that contradicts the above-mentioned assumption in some of the countries and results that are in line with it in others. On the one hand, Egypt's warmer weather seems to increase the probability of stunting, while periods of above average precipitation are detrimental to child nutrition. This could be due to increased localized flooding that reduces food accessibility and availability in addition to increased waterborne diseases. On the other hand, the results for Ethiopia show that the relationship between precipitation and stunting follows an inverted-U-shaped pattern which is consistent with the findings of Cooper et al. (2019) and Thiede and Stube (2020). This indicates that the impacts of changes in the climate on children malnutrition vary by region. The results in the paper highlight also the variations in stunting prevalence within the one country and across the different countries. It is thus evident that efforts to reduce the burden of infants and under-five children stunting should consider geographical heterogeneity and adaptable risk factors.

It is also worth noting that the public health community's attention has been attracted increasingly to the social determinants of health during the last two decades, which are elements other than medical care that can be impacted by social policies and shape health in profound ways. Social influences at the individual, family, neighborhood, and national levels have been shown to have a significant impact on children's health. Mother access to schooling is another important predictor of child nutrition. Improving child health in the Nile Basin countries necessitates developing the social environment conditions, mother education, and mother's access to employment. Structural adjustments to enhance access to education and work for women, as well as poverty reduction, are likely to be the most successful interventions. The strength of this paper lies in its significance for policymaking. The results of the model adopted in this study are expected to aid in cluster-level planning for child health. The mapping of the variation in child malnutrition associated with climate change and socioeconomic determinants of health can help with improving the allocation of limited resources to clusters with varying needs of healthcare and social policies.

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