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ABSTRACT

The Impact of Changing Climate on Children's Nutritional Status in Bangladesh*

This paper studies the impact of climate change on the nutritional status of very young children between the ages of 0 – 3 years by using weather data from the last half century merged with rich information on child, mother and household characteristics in rural coastal Bangladesh. We evaluate the health consequences of rising temperature and relative humidity and varying rainfall jointly. Leveraging a saturated fixed-effects model that controls for annual trends and location-specific seasonality, and that allows the impacts of temperature to vary non-parametrically while rainfall and humidity have flexible non-linear forms, we find that extreme heat and humidity in the month of birth exert significant negative effects on children's nutritional status as measured by mid upper arm circumference. The impact of humidity in particular persists when child, mother and household controls are included. We find that exposure to changing climate *in utero* and in the month of conception also matters. Possible explanations for our findings include consequences of varying heat, humidity, and rainfall on the extent of pasture, rain-fed and irrigated lands, on the propensity of household out-migration, and on mother's age at first marriage. We employ alternate models and undertake falsification tests to underline the robustness of the estimates. Our results indicate that climate change has real consequences for the health of very young populations who are in vulnerable areas.

JEL Classification: Q54, I15, O15, Q56, J13

Keywords: climate change, temperature, humidity, rainfall, Bangladesh, children, mid upper arm circumference, non-parametric, non-linear

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1. Introduction

Climate change is especially salient in Bangladesh, a low-lying country. While rising sea levels have resulted in land loss in Bangladesh, land may also be "lost" if it is deemed infertile for production. Infertility of land results when increased temperatures cause depressions in atmospheric pressure, triggering the inflow of seawater into fresh water streams and rivers. Shallow ocean basins that characterize much of Bangladesh are especially vulnerable. Rising sea levels move brine water further inland, contaminating agricultural land. In addition to immediate impacts such as reducing harvests and the quality of the crops, consistent exposure to salt changes the nutrient mix of top soils, rendering fields barren. Although researchers have considered the implications of climate change on coastal communities in this country, most studies have focused on rising temperatures alone. Previous literature has not considered the correlation - and possible joint impact – of other weather measures such as rainfall and humidity in detail. We address this gap in our research by studying the simultaneous consequences of changing temperatures, rainfall, and humidity on the nutritional status of young children, a topic that, to the best of our knowledge, has not been analyzed closely before.

A sizable proportion of rural households in Bangladesh is involved in agriculture, and land is an important livelihood asset. Ahmed et al. (2012) notes that in terms of production, up to 43 % of rural women devote their time to aquaculture and agriculture, which are spheres likely to be affected by weather variability. If income from cultivating land and from fisheries is at risk, potential reductions in earnings may translate into nutritional deficiencies, particularly for vulnerable individuals. In particular, such deficits are likely to have serious health consequences for those who are very young.[1] Utilizing weather data from half a century in rural coastal Bangladesh, we investigate the consequences of rising temperature, and changing patterns in precipitation and relative humidity on children's nutritional status as measured by mid upper arm circumference (MUAC), a commonly used indicator of wasting (Hossain et al. 2017, Sultana et al. 2018, Haque et al. 2021, Hossain et al. 2021).

We find that there is convincing time-series evidence that climate has changed in coastal Bangladesh. Results using non-parametric techniques for modeling data on temperature, rainfall and humidity show that average monthly temperature, both in levels and in deviations from the long run means, has been trending upwards since the early 1970s. Similarly, monthly relative humidity has risen in the fifty-year time span from 1970 – 2020. Although patterns in rainfall are less consistent, the variability of monthly rainfall has increased particularly at higher precipitation levels. Using a saturated fixed-effects model that flexibly controls for annual variations and location-specific seasonality, our empirical approach leverages random fluctuations in weather parameters while conditioning on child, mother and household characteristics to identify causal impacts on child health.

In our preferred specification and the full sample of rural children aged 0 – 3 years, we find that relatively high temperatures in the month and year of birth have detrimental effects on child MUAC measures. Compared to children born in the comfortable monthly temperatures of 20 – 21 ^{o}C, those who happen to be born in the next higher bin of 22 – 23 ^{o}C have MUAC measures that are a little over 1 millimeter (mm) smaller when measured at the time of the survey. This represents a 0.7 % decline from mean MUAC. Humidity, especially when allowed

[1] Declines in income may have consequences for women's agency, time-use, dietary quality, and assets (Malapit et al. 2018, Quisumbing et al. 2018, Sraboni and Quisumbing 2018, Quisumbing et al. 2021, van den Bold et al. 2020). Changes in these dimensions often affect child health outcomes.

to vary non-linearly, has a positive impact on MUAC up to a certain threshold. When we include child, mother and household characteristics, the temperature impacts are no longer measured with precision while the effects of humidity persist. Among these characteristics, mother's age and years of schooling are found to have beneficial effects for children's nutritional status. Land owned by the household, a proxy for household wealth, is also found to have strong positive effects on children's MUAC.

We next analyze consequences of exposure in the month and year of birth on different age-groups post-birth. In general, the non-linear effects of humidity are evident up to the first 1000 days while at very young ages (six months or less), there is some evidence that relatively higher temperatures are beneficial for child MUAC. We then shift the window of time to investigate whether impacts of changing climate are evident for exposure in the month of conception of the child. The month of conception is a time when mothers are often unware of their pregnancies, and thus we are relatively more confident that protective behaviors may not have been adopted. In this case, we find that relatively high temperatures have strong negative impacts on children's MUAC measures that remain significant even after we include child, mother and household controls. We also investigate consequences of exposure *in utero* and find that in general, the harmful impacts of relatively extreme temperatures result from exposure in the first and second trimesters. Rainfall, on the other hand, is beneficial in the first and second trimesters, while humidity exerts concave effects in the second and third trimesters.

In terms of mechanisms explaining these results, we find that relatively high temperatures increase the propensity of population displacement (household out-migration), reduce the area of rain-fed land, and increase the area of irrigated land owned by households. Rising temperature also raises soil oxygen availability, which is consistent with the literature on the impact of temperature on soil respiration. Rainfall is found to have some positive consequences in increasing the area of pasturelands. Interestingly, higher relative temperatures increase mother's age at first marriage; our lack of detailed data do not allow us to study further why this might be the case. We hypothesize however that this may be because extreme heat reduces agricultural assets and thus, household wealth, in a part of the world where transfers from bride's families to groom's families are commonplace at the time of marriage. We find no evidence that climate change affects the incidence of miscarriage in our sample of mothers, supporting our claim that the sample of children we study is representative. We undertake a series of specification checks and present falsification tests to demonstrate the robustness of our results.

We contribute to the literature in three ways. First, given evidence in our data that weather parameters are correlated, we study climate change in a developing country context that jointly evaluates the impacts of varying temperature, rainfall and humidity over time. Considering these parameters in isolation may render the estimated coefficients biased. Second, we evaluate implications of climate change on an outcome for very young children – MUAC – that is very responsive to short-term stresses as captured in monthly climate shocks (Hoddinott et al. 2020, Pinchoff et al. 2021). MUAC is also easy to measure accurately even in young populations, reducing the possibility of measurement errors in the outcome variable. Finally, we use weather data spanning half a century in multiple alternate specifications to analyze consequences of changing climate on our outcome of interest.

Section 2 provides evidence of changing climate in the region of Bangladesh we study and section 3 provides details on our empirical methodology. Section 4 describes the data and summary statistics while section 5 discusses the results. Section 6 investigates potential mechanisms and section 7 provides results of alternate specifications and robustness checks. Section 8 concludes.

2. Evidence of Changing Climate

We use data from the International Center for Diarrheal Disease Research, Bangladesh (ICDDR,B) health monitoring station in Chakaria upazilla (sub-district) located in Chittagong division. Figure 1 is a map of Bangladesh with the centroid of Chakaria highlighted in the southeast corner slightly towards the interior of the country. ICDDR,B has been involved in community initiated health care projects in the Chakaria region since the early 1990s. However, in order to understand the efficacy of ICDDR,B's interventions including those on health education on water, sanitation, impacts on diarrhea, safe delivery practices, and treatment of malaria, a health station was established in a subset of villages in the Chakaria region that has been involved in monitoring conditions since 1999. Additional details on this location and data we use in this study are discussed below.

We use weather variables obtained from the Bangladesh Meteorological Department's monitoring station in Cox's Bazaar, which is the closest station to Chakaria (at a distance of about 40 kilometers or 25 miles). The second point on the coastline in Figure 1 is the weather station at Cox's Bazaar. We have monthly information from 1970 to 2020 from this weather monitor on average temperature in degrees Centigrade, average rainfall in millimeters, and average relative humidity in percent.[2] Figure 2 shows non-parametric (bin) forms for these variables where Panel A denotes patterns in average monthly temperature, and Panels B and C depict patterns for monthly rainfall and monthly humidity, respectively. The y-axis in each case

[2] Relative humidity is defined as a ratio where the numerator is the amount of water vapor in the air and the denominator is the maximum water vapor that the air can hold at a certain temperature (Zhang et al. 2017). We refer to "relative humidity" as "humidity" in the paper.

indicates the total number of months over the fifty years that the weather variables fell in these ranges. The framework of Figure 2 follows techniques developed in Barreca (2012) and Graff Zivin and Neidell (2014). Focusing on Panel A, there is evidence that as compared to the 1970s, there is an increase in the heights of bins with relatively high temperatures as decades progress. For instance, between 1970 and 1979, there were 32 months when temperature was in the 28-29 ºC range. Thirty years later (between 2000 and 2009), there were 54 months when average temperature was in this 28-29 ºC range. By the 2010s, there were 57 months in this range. This is also clear when we look at the maximum values of temperature in these data. There was one month with above 30 ºC temperature between 1970 and 1979. Between 2010 and 2020, this number had increased to 5 months.

Panel B focuses on rainfall. Unlike the variations evident in temperature, rainfall patterns in this region of Bangladesh appear to be relatively stable over the fifty years we analyze (the consistency of rainfall patterns are similar to those noted in Dell et al. (2012)). There is a slight increase in the number of months with no rainfall (from 38 to 41) from 1970-1979 to 2010-2020, but the months with the highest and second highest levels of rainfall have increased only from 5 to 7 across decades. Patterns in Panel C for humidity resonate a little more with the variations evident for temperature. The number of months with oppressively high levels of humidity that exceed 76 % increased from 80 months in 1970-1979 to 98 months in the most recent decade. Hence, for temperature and humidity at least, we see measurable changes in this coastal region over time.

Figure 3 plots the kernel densities for the weather variables for the first and the last decade of the fifty-year time span we consider. Consistent with Zhang et al. (2017) and trends in Figure 2, climate change shifts the distribution of temperature to the right as seen in Panel A of

Figure 3. Panel B indicates that higher levels of precipitation are more evident in the 2010-2020 decade as compared to the earliest decade. Hence, the frequency of higher levels of temperature and higher levels of rainfall have increased over time. Panel C indicates that climate change has altered the distribution of humidity as well. In particular, the bimodal distribution of humidity in the 1970s with peaks around 75 % and 85 % has experienced a right shift to peaks closer to 80 % and 90 % fifty years later.[3] Hence, this region now experiences relatively higher levels of humidity. Taken together, the patterns in Figure 3 highlight that there have been measurable changes in temperature and humidity in particular over the last half century of weather information we study.

We end this section by nothing that these weather variables are significantly correlated. The pair-wise correlation coefficient between temperature and rainfall is 0.5, which is significant at the 99 % level. Similarly, the pair-wise correlation coefficient between temperature and humidity is 0.7, which is also significant at the 99 % level. This underlines the importance of considering all three weather measures concurrently in the analysis.

3. Empirical Methodology

3.1. Preferred specification

Our main specification estimates models of the following form:

$$y_{ihv} = \sum_{B} \beta^{B} Temp_{mt}^{B} + \gamma Rain_{mt} + \delta Humid_{mt} + \theta X_{ihv} + \sigma_m + \alpha_t + \mu_v + (\sigma_m * \mu_v) + \varepsilon_{ihv} \qquad (1)$$

where i denotes a child, h denotes a household, v is village, and m and t are month and year of birth, respectively. y_{ihv} is the mid upper arm circumference (MUAC) for child i in household h

[3] These bimodal patterns in the humidity kernel densities are similar to those noted in Zhang et al. (2017) for China.

in village v at the time of the survey. This measure is available for children born from 2011 to 2020. β^B are the coefficients on the monthly temperature bins ($Temp_{mt}^B$) in a non-parametric form, where similar to Zhang et al. (2017), we include dummy variables for each 1 ºC interval. The β coefficients are interpreted relative to the excluded bin (20 – 21 ºC or 68 – 70 ºF, which is considered "comfortable").[4] Rainfall in the month and year of birth and its quadratic are included in $Rain_{mt}$. We estimate the impacts of humidity in $Humid_{mt}$ in both its linear and quadratic form similar to Zhang et al. (2017).

Equation (1) also controls for child, mother and household characteristics in X_{ihv}. Child characteristics include age and gender. Mother characteristics include age, years of schooling, age at first marriage, and whether she has had a miscarriage.[5] Household characteristics include amount of land owned in decimals (100 decimals equals one acre), and whether the household migrated from the area. In our main estimates, we add these sequentially to understand how they moderate the influence of temperature, rainfall and humidity. Similar to Barreca (2012) and Geruso and Spears (2018), Equation (1) includes disaggregated region (in our case, village) fixed-effects μ_v, month of birth fixed-effects σ_m, and their interactions. The interactions control for village-specific (local) seasonality that could, in their absence, lead to the endogeneity of weather and the composition of births with possible resulting implications on the dependent variable y_{ihv}. α_t are year of birth fixed-effects as in Zhang et al. (2017), and ε_{ihv} is the error term. We cannot include year of birth fixed-effects interacted with month of birth fixed-effects

[4] We follow the most recent literature in casting temperature in its non-parametric form. Temperature impacts have also been allowed to vary non-linearly as in Burke et al. (2015). We estimated models in which temperature was modeled non-linearly but report results from the non-parametric specification to be consistent with most recent work. As acknowledged in Geruso and Spears (2018), the literature on the exact form of "…climate damage functions and integrated assessment models to determine optimal climate policy…" is continually evolving.

[5] We also considered other variables such as pre-term births and stillbirths. There were too many missing values in these variables for them to be included in all models consistently.

as our weather variables are measured at the month and year level. In this empirical framework, the impacts of temperature, rainfall and humidity may be interpreted as "presumably random" monthly deviations from their long-run averages (Deschenes and Greenstone 2007).[6] That is, the identifying assumption is that conditional on normal weather and location specific seasonality, the actual profile of weather realizations is random.

3.2. Alternate specifications

We consider two alternate specifications in order to ascertain the robustness of our results. First, we allow humidity also to vary non-parametrically as in Barreca (2012). This leads to Equation (2) of the following form:

$$y_{ihv} = \sum_{B} \beta^{B} Temp^{B}_{mt} + \gamma Rain_{mt} + \sum_{B} \delta^{B}\, Humid^{B}_{mt} + \theta X_{ihv} + \sigma_m + \alpha_t + \mu_v + (\sigma_m * \mu_v) + \epsilon_{ihv} \qquad (2)$$

The interpretation of the variables remain similar to those in Equation (1) but now the δ coefficients are interpreted relative to the excluded humidity bin (humidity less than 65% which is the lowest value in our data, usually 30-50% humidity levels are considered to be "comfortable").[7] Consistent with Barreca (2012), Zhang et al. (2017) and Geruso and Spears (2018), and because Figures 2 and 3 do not indicate sizable measurable shifts in the non-parametric or kernel densities over the years we consider, precipitation is modeled parametrically (non-linear quadratic form).

Second, we construct weather shocks as deviations relative to historical mean values adjusted by historical standard deviation. As noted in Ibanez et al. (2021), Dell et al. (2014), and

[6] As Deschenes and Greenstone (2007) also notes, the use of a saturated fixed-effects model may amplify the effect of measurement error (if it exists), which may consequently attenuate the estimated coefficients.

[7] We also considered interaction of the highest temperature bin with humidity measured linearly as in Barreca (2012) but the results for these parameters were insignificant.

Feng et al. (2010), these may be interpreted as random draws from the respective underlying weather distributions. We define a weather shock between 2011 and 2020 (the year of birth of children in our data) as the standardized value of weather equal to or exceeding two standard deviations (SD) above its historical average (1970 – 2007). Hence, a temperature shock occurred in a month if the temperature realization in that month (relative to historical mean and historical standard deviation) was equal to or greater than 2 SDs. Similarly for rainfall and humidity. We incorporate these measures in Equation (1) in two steps. We begin by replacing only the non-parametric form of temperature with this shock equivalent given the focus on temperature in the climate change literature (Aragon et al. 2021, Jessoe et al. 2016, Carleton and Hsiang 2016). This leads to:

$$y_{ihv} = \beta TempShock_{mt} + \gamma Rain_{mt} + \delta Humid_{mt} + \theta X_{ihv} + \sigma_m + \alpha_t + \mu_v + (\sigma_m * \mu_v) + \vartheta_{ihv} \quad (3)$$

We then investigate shocks to all three measures of weather we consider in a related specification of the following format:

$$y_{ihv} = \beta TempShock_{mt} + \gamma RainShock_{mt} + \delta HumidShock_{mt} + \theta X_{ihv} + \sigma_m + \alpha_t + \mu_v + (\sigma_m * \mu_v) + \omega_{ihv} \quad (4)$$

We also investigate the impact of smaller shocks that condition on being larger than 1 SD but report results only for shocks greater than or equal to 2 SDs to be consistent with Ibanez et al. (2021). Results from these alternate models are discussed below.

4. Data and Summary Statistics

Data for this study are from the Chakaria Health and Demographic Surveillance System (HDSS) which, since 2011, has collected comprehensive information on a variety of indicators for 49 randomly chosen villages in the Chakaria in conjunction with the International Center for

Diarrheal Disease Research, Bangladesh (ICDDR, B). As noted above, Chakaria is ICDDR, B's health monitoring station in the southeast of the country near Cox's Bazaar (Figure 1). The original site has existed for close to twenty years, surveying about 20,000 households (about 118,000 residents) every quarter. More information may be obtained from the Chakaria HDSS Annual Report (various years). We focus on the malnutrition module that collected information on children's MUAC measure for 19,357 children (below the age of 3 years) of 12,398 mothers from 13,197 households. These children are born between 2011 and early 2020.

The closest weather station to the households in our survey is situated in Cox's Bazaar. Since our sample is from the sub-district of Chakaria, there is little variation in the distance of each household in the sample from the weather station to exploit (most households are at the same average distance). We have information on average temperature in degrees Centigrade (^{o}C), on average rainfall in millimeters (mm), and on average humidity in percent (%) at the monthly level from 1970 to 2020. We construct the non-parametric and standardized forms of the weather variables and merge them with the child sample by month and year of birth. In subsequent analysis, we shift time windows to consider impacts of exposure in the month of conception and by trimesters *in utero*. For purposes of the summary statistics discussion, we focus on the sample constructed by merging information at the month and year of birth levels only.

We merge four additional data sets to the child health and weather sample. The first includes incidence of miscarriage suffered by mothers in the past (merged with the main sample on the basis of mother's ID), and the second includes information on households that were surveyed in 2011 but then out-migrated from the region in the 2011-2020 time window (merged with the main sample on the basis of household ID). Both are from Chakaria HDSS sources.

We also include satellite-sourced information on changes from 1990 to 2017 in pasture area in square kilometers (kms), in total rain-fed area in square kms, and in total irrigated area in square kms from the Historical Database of the Global Environment (HYDE 3.2) data source (Goldewijk et al. 2017). We merge these variables with the Chakaria HDSS data using the GIS location codes of households in the sample to understand whether they explain the impacts of changing climate on child MUAC. We supplement these variables with satellite data on soil oxygen availability and soil excess salts obtained from FAO's Harmonized World Soil Database (FAO 2012).

Other characteristics that were initially included in the main sample include change in area (in hectares) of the Sundarbans (to measure land lost due to either rise in the sea level or excessive salinity from rising ocean waters) and causes of mortality and morbidity (pneumonia, tuberculosis, diarrheal diseases, anemia, diabetes, stroke and asthma). These were available only at the annual level and thus their impacts could not be separately identified given lack of variation and the structure of our empirical models that condition on year fixed-effects.

Table 1 provides the descriptive statistics of the sample. Panel A (children's and mother's statistics) reports that the mean MUAC is 138.7 millimeters. The threshold for being well nourished in this age group is 135 millimeters, and so the average child in this sample is just barely above this benchmark. In estimates not reported, 25 % of children in our sample is at risk for acute malnutrition, and 6.4 % suffer moderate acute malnutrition. About 0.6 % of children may be classified as experiencing severe acute malnutrition. Other estimates in Panel A show that 51 % of the sample is male, and 12 % are infants. The average age in days of children in the sample is 557 (1.5 years). Average year of birth of mothers in the sample is 1989 (average age is 31 years). Age at first marriage of mothers is 18 years. The mean level of mother's schooling is about 5 years, which indicates that most mothers in the sample have not completed primary school. Approximately 11 % of mothers report having had at least one miscarriage in the past.

Panel B (household sample) shows that average land ownership among these households is low at 0.3 decimals, about 9 percent of households migrated from the area in the years of the survey, and pasture area and total rain-fed areas have decreased between 1990 and 2017. Correspondingly, total irrigated area has increased in this span of time. Soil quality measures range from 0 (low) to 7 (high) and indicate that oxygen availability is on the lower end of this spectrum as is the measure of soil excess salts.

Panel C (children's sample) notes the summary statics for the weather variables in our data in the month and year of birth of the child. Considering the temperature bins, most children are born in months of the year when temperature ranges between 28 – 29 ºC (82 – 84 ºF) on average, and temperature shocks are evident on average for around 5.3 % of the months from 1970 to 2020. The mean of average monthly rainfall in this region (total monthly rainfall divided by number of days in a month) is around 10 mm, and approximately 6.6 months have experienced a rainfall shock as described above. The final weather related measures involve humidity where the constructed bins indicate that the largest proportion of months experience relatively high humidity levels of 76 – 80 %, also reflected in the mean value of average humidity (78 %).

5. Results for Impacts on MUAC

5.1. Exposure in month and year of birth

Table 2 reports results for impacts of temperature, rainfall and humidity in month and year of birth on children's MUAC. The first three columns (Model 1) correspond to Equation (1) where humidity is measured only in its linear form. Model 2 encompasses columns (4) through (6) where the impact of humidity is allowed to vary non-linearly with a quadratic model, as in Zhang et al. (2017). Columns (1) and (4) condition on only the saturated fixed-effects in Equation (1), while columns (2) and (5) add the child and mother characteristics to the fixed-effects controls in column (1). Columns (3) and (6) include household characteristics as well. We report only the weather related variables in Table 2. The full set of results for all variables included in the model are shown in Appendix Table 1 and discussed briefly below.

Estimates in column (1) indicate that as compared to children born in the comfortable monthly temperatures of 20 – 21 ºC, those who happen to be born in the next higher bin of 22 – 23 ºC have MUAC measures that are a little over 1 mm smaller when measured at the time of the survey. Since the mean MUAC in the sample is 138.7 mm, this represents a 0.7 % decline. The only other climate related variable in column (1) that has an impact is linear humidity where higher levels also have a negative impact on MUAC.

Columns (2) and (3) add the child, mother and household variable sequentially and while the relative negative impact of the 22 – 23 ºC temperature bin is still evident, these are not measured with significance anymore. Similarly, humidity still has a retarding impact on child health as embodied in MUAC, but is no longer measured with precision.

Focusing on columns (4) – (6) in Table 2, again, relatively higher temperature in the 22 – 23 ºC leads to declines in children's MUAC but now the linear measure of humidity has a positive impact while its square terms has a negative impact. Hence, humidity has a positive impact on child health, but there is an optimal level beyond which these impacts decline. These signs are consistent with the non-linear effects of humidity in Zhang et al. (2017). Although we do not have information on crops in these data, improvement in crop yield with rising humidity (as documented in Zhang et al. 2017) is a channel that may explain the beneficial effect on child

MUAC. As before, adding child, mother and household characteristics absorbs the significance of the 22 – 23 ºC temperature bin. However, the humidity variables continue to be significant in column (6).

We briefly discuss the impacts of the child, mother and household characteristics in the full model of Equation (1) reported in Appendix Table 1. Male children have relatively higher MUAC measures than female children do, while infants have lower MUAC measures as compared to older children in the 0-3 years age group. Older mothers have children with better health, as expected, and mother's years of schooling have positive effects on her children's MUAC, also as expected. Households that own more land (and so potentially richer) have children with relatively higher MUAC values. The sign and significance of the household out-migration indicator suggests that population displacement has a negative effect on child MUAC measures. A possibility here is that the relatively richer households (with better child health) are more likely to leave the area and thus the average level of MUAC among children who remain and are measured at the time of the survey is comparatively lower. The significance of this variable underlines the importance of controlling for displacement of this nature as we do here.

5.2. Impacts on different age groups post-birth

We disaggregate children by age post-birth in order to analyze whether exposure in the month and year of birth has differential impacts over time. Results are reported in Table 3 where column (1) and (5) focus on children who are six months old or younger, and columns (2) and (6) focus on children who are one year old or younger. There is some indication that relatively higher temperatures are beneficial for the youngest age group but we are less confident of these results given the substantially reduced sample size. Relative temperature impacts are absent when we extend the window to those who are a year old or younger while humidity has impacts only in Model 2 that allows its more flexible form. While temperature and humidity have the expected signs in Model 1 for those who are 18 months or younger (column (3)) and those in the first 1000 days of life (column (4)), there are few results that are statistically significant. This is true for the corresponding columns under Model 2 as well (columns (7) and (8)) with only the quadratic term for humidity being significant in column (7). We conclude that overall, disaggregation by ages reduces sample sizes substantially enough such that it is difficult to obtain statistical precision in the weather variables.

5.3. Exposure in month of conception

We next consider exposure in the month of conception. Focusing on this time-period is particularly helpful since it is often the time when a mother is unaware that she is pregnant, thus minimizing the effect of any adaptive behaviors that might render the impact of weather endogenous. We begin by focusing on estimates in column (2) of Table 3, which shows that relative to the "comfortable" temperature range, exposure to higher temperatures significantly reduces children's MUAC. In general, exposure to progressively higher temperatures in the month of conception has increasing negative impacts with exposure to the highest 30 – 31 ^{o}C temperature bin leading to almost a 3 mm decline in child MUAC (a 2.2 % decline relative to the mean). Humidity in its linear form is not significant in the columns of Model 1. Similarly, coefficients in column (4) in Model 2 also underline the harmful consequences on children's health of exposure to high temperatures in the month of conception. Again, humidity is not significant in the more flexible form of Model 2.

It is useful to compare the results in Table 2 that focuses on month of birth and those in Table 4 that considers exposure in the month of conception. The stronger impacts of temperature in Table 4 suggest that these manifest in children's future health mainly by affecting mothers health very early in the gestational cycle. Exposure to relatively high temperatures in the month of birth still has detrimental impacts on children's MUAC post-birth, but humidity now plays a more important role perhaps by affecting nutritional status of both mothers and children through its beneficial impacts on crop yields and productivity. As we note above, we lack data in the Chakaria HDSS to test this explicitly. However, we provide evidence that higher temperatures reduce rain-fed areas and increase irrigated areas over time below.

5.4. Exposure by trimester

The final window of time we consider is exposure *in utero*. We adopt the most flexible form that conditions on all three trimesters simultaneously and report results in Table 5.[8] Focusing on the more flexible specification of Model 2 in column (2), coefficients indicate that the largest harmful impacts of relatively high temperatures result from exposure in the first trimester mostly, with some evidence that exposure in the second trimester matters as well, especially at the highest temperature ranges. Rainfall is beneficial in mainly the first and second trimesters, while humidity has similar effects to those documented in the results sections above in the second and third trimesters.

The first trimester is when the fetus develops rapidly both neurologically (brain and spinal cord form) and physically (heart develops and begins to beat, initial structures of eyes, ears and arms form). These progress into the second trimester; the fetus begins to gain weight near the end of the second trimester and through the third trimester. The results in Table 5 indicate some differential impacts of weather during these time-spans with temperature exerting negative effects mainly during the early phase of neurological development, whereas rainfall and humidity mattering more later when weight gain occurs. A channel through which later trimester

[8] Evaluating effects trimester-by-trimester risks missing the possible cumulative impacts of exposure to weather extremes over time.

impacts may occur include influences on mother's health and nutritional status, thus supporting the Fetal Origins hypothesis attributed to Barker (2007) that nutritional deprivation prenatally can have strong effects.[9]

6. Mechanisms

6.1. Impacts of weather on migration, changes in pasture, rain-fed, and irrigated areas, and soil oxygen availability and soil excess salts

In order to understand possible mechanisms underlying the effects of changing weather on child's health, we analyze impacts on household indicators including whether the household out-migrated, changes between 2017 and 1990 in the extent of pastures, rain-fed and irrigated areas, and the health of soil in the region as measured by oxygen availability and the presence of excess salts. These results are reported in Table 6 where column (1) shows that higher relative temperatures lead to increased out-migration from the area. In particular, relative to the excluded category of 20 – 21 ºC, monthly temperatures in the three successively higher temperature bins are associated with increased propensity of households to leave the area.

Column (2) indicates that rainfall has some non-linear influence in increasing the area of pastures between 1990 and 2017 (these are the earliest start and end points of time for the available HYDE 3.2 data from these localized regions). In terms of rain-fed areas, temperature has uniform negative effects with the highest bin of 30-31 ºC measured with significance. The coefficient in this cell indicates that relative to the "comfortable" benchmark, monthly temperatures in this bin lead to a decline in rain-fed areas by about one square kilometer. Correspondingly, results in column (4) that measure changes in irrigated areas indicate that rising relative temperatures cause increases in the extent of such areas by almost the same amount.

[9] Edwards (2017) synthesizes recent work on the Barker (2007) hypothesis and its relation to nutritional deprivation prenatally and in early-life.

Finally, there is some evidence that higher relative temperatures increase the oxygen availability of soils (perhaps by its impact on overall soil respiration as in Bond-Lamberty and Thomson (2010)), but there is no measurable impact of weather on the extent of excess salts in column (6).[10] The results in Table 6 underline that temperature in particular may influence child health post-birth by altering agricultural landscapes that could affect household nutritional intake.

6.2. Impacts of weather on mother's age at first marriage and incidence of miscarriage

As is well understood, child health is importantly influenced by mother's characteristics. We focus on the measures that are available to us in this realm and study the consequences of changing climate on mother's age at first marriage and the incidence of miscarriage. Considering results in column (2) of Table 7 that includes all controls, there is evidence that relatively higher temperatures increase age at first marriage while increasing rainfall reduces it up to a certain level (the coefficient on quadratic rain is significant). These patterns may reflect impact of changing weather on household (agricultural) wealth with subsequent implications on marriage in a society where dowry payments by brides' families have become increasingly more prevalent (Ambrus et al. 2010).[11] Results in column (4) show that there are no measurable impacts of changing weather on the miscarriages reported by mothers.[12] This gives us additional confidence that the sample of children we study is not selected along this dimension. Even with selection of this nature, we would have a conservative bias in our results. This is because if

[10] Using data for 2010 from the Gridded livestock of the World (GLW3) database, we find evidence that higher humidity reduces the number of livestock (buffaloes, chicken, ducks and pigs) assets per square km. Temperature and rainfall have mostly insignificant effects. These results are available on request.

[11] Young and Hassan (2016) note that although illegal since 1980, up to 80 % of Bangladeshi marriages involve dowry "agreements."

[12] We also considered impacts on miscarriage of weather in the month of conception, three months prior to conception, and six months prior to conception. There is some weak evidence that rainfall in the month of conception reduces the incidence of miscarriage; these effects are no longer evident once we consider the earlier months. Temperature and humidity have no measurable effects across these time spans. These temperature results are in contrast to evidence in Sun et al. (2020) where exposure to moderately high temperatures (20-26 degrees Centigrade) in the two months prior to hospitalization is found to increase the risk of miscarriage.

climate change increased the risk of miscarriage, then the sample of births is likely to be positively selected, as the strongest fetuses would survive to term. Hence, our coefficients would underestimate the (negative) impacts of changing weather on children's health.

7. Alternate Specifications and Falsification Tests

We report the results of the alternate empirical frameworks in Equations (2), (3) and (4) in Table 8. In this table, Model 3 corresponds to Equation (2) which now includes non-parametric measures for humidity in the month and year of birth of the child. Focusing on column (1) that includes only the fixed-effects, negative impacts of relatively high temperature is still evident but relative excessive humidity also exerts harmful effects on children's MUAC. The significance of both temperature and humidity measured non-parametrically (with rainfall measured parametrically) is similar to results in Barreca (2012). However, coefficients in column (2) indicate that these impacts are no longer significant when child, mother and household characteristics are included.

Results in columns (3) and (4) correspond to Model 4, which is Equation (3). Here rainfall and humidity are measured in their quadratic forms while the temperature variable is in its shock form denoting a standardized monthly level that is 2 SDs above the historical mean. Results indicate the expected negative impact of such temperature shocks on child MUAC; however, the coefficients are insignificant (in the 50-year time span we consider, there are relatively few months with temperature shocks of this size). On the other hand, humidity continues to exert similar significant effects as reported in Table 2 for Equation (1).

We end the discussion of estimates in Table 8 by noting that the last two columns report results for Model 5 (Equation (4)). While the temperature and humidity shocks have the expected detrimental impacts on child MUAC in column (6), these are both measured with error.

A rainfall shock of this size and nature however has large positive and significant consequences on children's health as measured by MUAC.

We undertake falsification tests to check the robustness of the results. In order to do this, we consider the impact of weather three months before the month of conception and in a separate set of runs, six months before the month of conception. If the results in our preferred specification in Table 2 are due to omitted variables that are simultaneously correlated with the outcome and the weather measures, or if the model is mis-specified, then temperature, rainfall and humidity will have significant effects on children's MUAC even before conception. Table 9 reports the results of these falsification tests for Models 1 and 2 that include all controls. The lack of significance in this table provides re-assurance that threats to validity from omitted variables are absent in our preferred specification in Table 2.

8. Conclusions and Policy Implications

This study undertakes a careful analysis of the effects of climate change on the nutritional status of young children in rural coastal Bangladesh, which, to the best of our knowledge, has not been undertaken before. We find convincing evidence that children's health (as measured by mid upper arm circumference) is at risk from rising temperatures and humidity, and from variable rainfall in the month of birth. Male children are less impacted, and mother's years of schooling in particular protects children's nutritional well-being. There is some evidence that exposure *in utero* matters, as does exposure in the month of conception, and at different windows of time post-birth. Some channels that explain these findings include the detrimental impact of extreme heat on population displacement, total rain-fed areas and total irrigated areas. We find little evidence in our data that climate change in the last fifty years has contributed to mother's reproductive failure as measured by miscarriages. Various specification and robustness checks underline the validity of our estimates. The data from this study is from the Chakaria sub-district of southeast Bangladesh supplemented with satellite information on agricultural land use in this region. In future work, we aim to implement a full-scale study of the comprehensive impacts of climate change on children and women throughout Bangladesh where GIS weather data from land monitors on temperature, precipitation, humidity and land cover are supplemented with data from ocean monitors on temperature, salinity, pH and wind velocity.

The results of our study offer clear thinking on how to alleviate some of the impacts of changing climate on populations who are unprotected. Evidence indicates that particular attention needs to be paid to the agricultural resources of households, damage to which may have long-lasting implications on the extent of cultivable lands, changes to crop choice and input mixes, and may result in declining agricultural productivity, which further threatens rural livelihoods. Focusing on protecting the health of vulnerable groups such as young children is a direct implication of our work. Creative thought that guides designs on policies, solutions, and possible adaptations, may help circumvent some of the negative consequences on those who are especially susceptible. Since environmental insults to child health have long-run consequences (Currie and Vogl 2013), this topic deserves serious consideration in current discourses on the deleterious effects of climate change.

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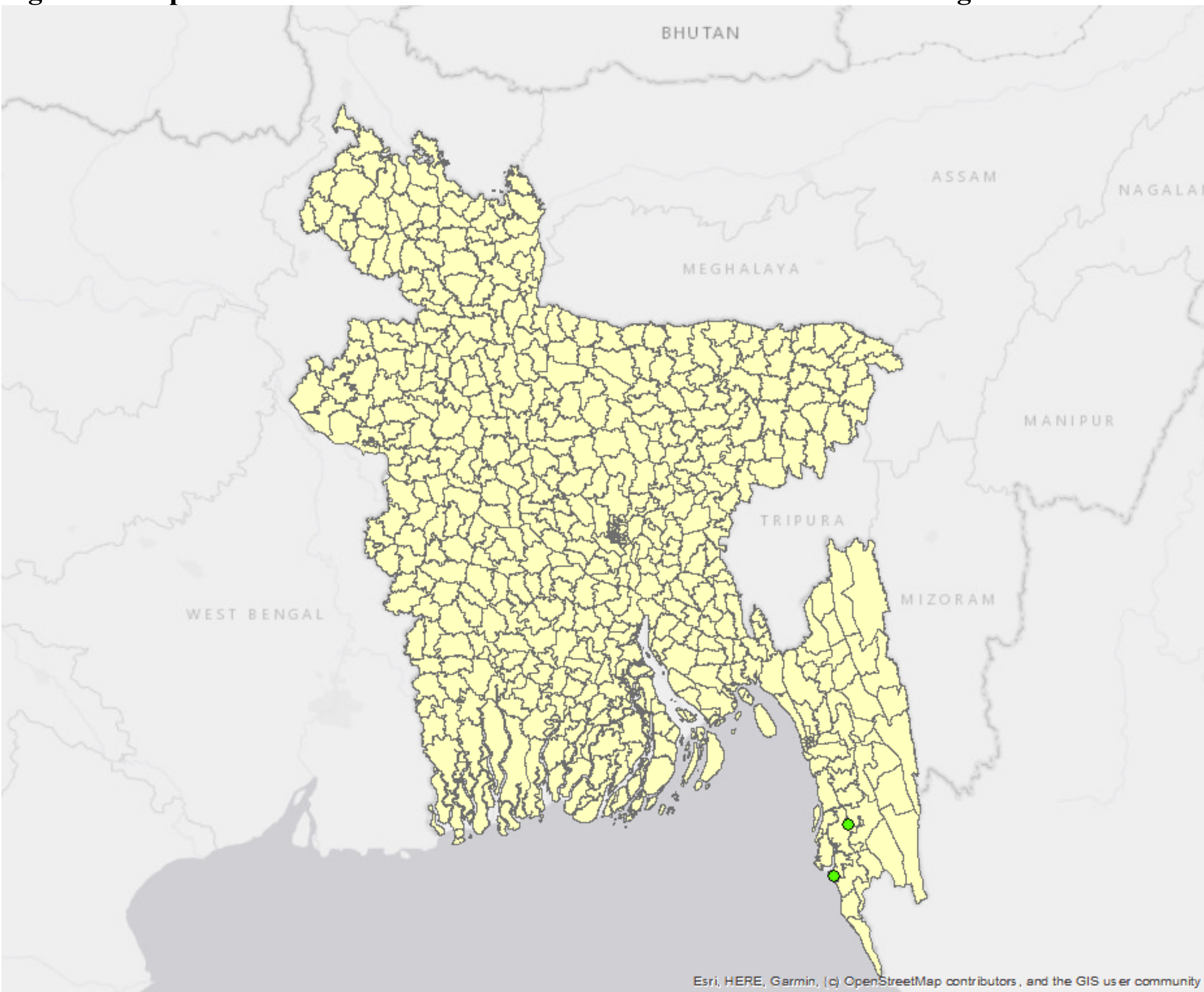
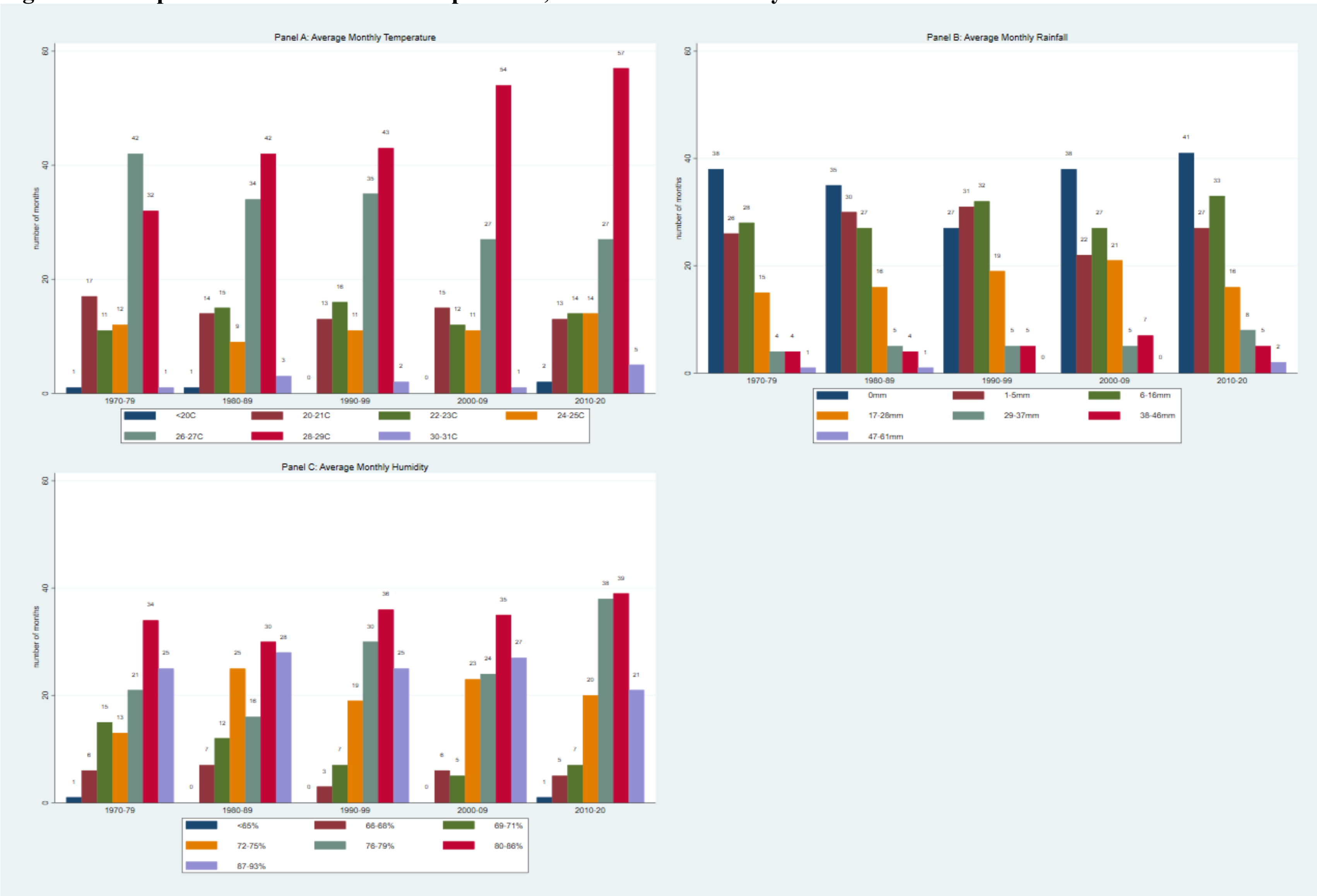
Figure 1: Map of Chakaria and the weather station in Cox's Bazaar in Bangladesh



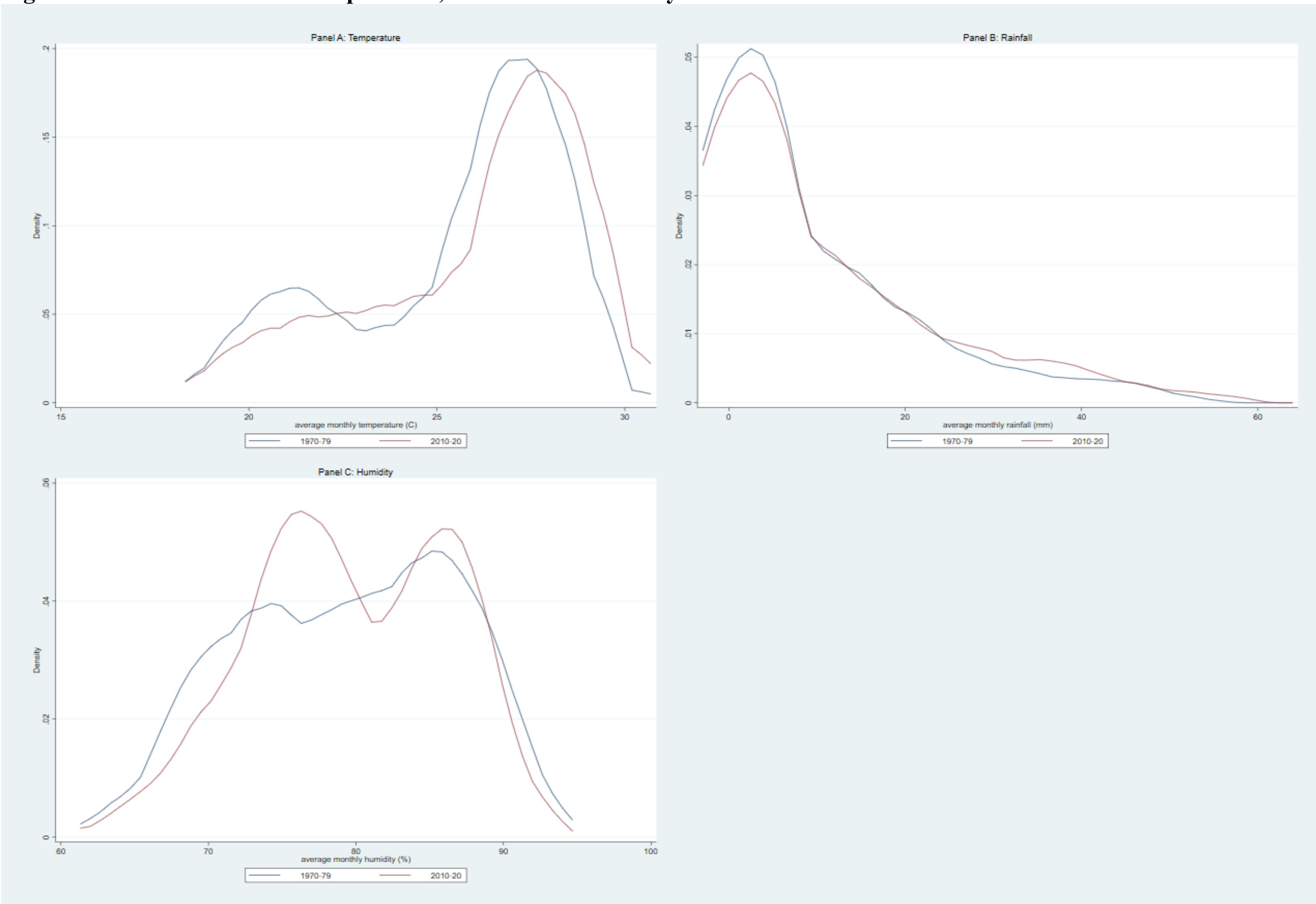
Notes: Authors' calculations. Boundaries denote upazillas (sub-districts) in Bangladesh.

Figure 2: Non-parametric measures of temperature, rainfall and humidity 1970-2020



Notes: Author's calculations using meteorological data from the Cox's Bazaar weather station.

Figure 3: Kernel densities of temperature, rainfall and humidity 1970-2020



Notes: Author's calculations using meteorological data from the Cox's Bazaar weather station.

Table 1: Summary statistics for the sample

Variable	Mean	Standard Deviation	Observations
Panel A: Child and mother related			
Outcome: Mid upper arm circumference (MUAC)	138.687	9.796	19,357
Male	0.507	0.500	19,357
Infant	0.116	0.320	19,357
Age in days	557.128	307.491	19,357
Month of birth	6.513	3.487	19,357
Year of birth	2015.232	2.688	19,357
Mother's Year of birth	1989.632	6.469	12,392
Mother's Age at first marriage	18.116	2.994	12,198
Mother's Years of schooling	4.828	3.712	12,385
Whether mother has had a miscarriage	0.109	0.311	8,210
Panel B: Household related			
Land owned in decimals	0.267	1.262	12,407
Whether migrated from the area	0.087	0.282	12,408
Change in pasture area (km^2) between 1990 and 2017	-0.039	0.094	10,614
Change in total rain-fed area (km^2) between 1990 and 2017	-54.892	10.704	10,614
Change in total irrigated area (km^2) between 1990 and 2017	46.825	9.187	10,614
Soil oxygen availability	1.465	0.722	10,614
Soil excess salts	0.864	0.343	10,614
Panel C: Weather related			
< 20 ^{o}C	0.019	0.137	19,357
20 – 21 ^{o}C	0.110	0.312	19,357
22 – 23 ^{o}C	0.097	0.295	19,357
24 – 25 ^{o}C	0.111	0.314	19,357
26 – 27 ^{o}C	0.210	0.408	19,357
28 – 29 ^{o}C	0.420	0.494	19,357
30 – 31 ^{o}C	0.033	0.179	19,357
Temperature >= 2SD above historical mean (1970 – 2007)	0.053	0.224	19,357
Rainfall (mm)	10.234	12.930	19,357
Rainfall^2 (mm)	271.907	539.278	19,357
Rainfall >= 2SD above historical mean (1970 – 2007)	0.066	0.248	19,357
< 65 %	0.010	0.099	19,357
65 – 70 %	0.072	0.259	19,357
71 – 75 %	0.160	0.367	19,357
76 – 80 %	0.309	0.462	19,357
81 – 85 %	0.170	0.375	19,357
86 – 90 %	0.271	0.444	19,357
91 – 95 %	0.008	0.091	19,357
Humidity (%)	79.797	6.522	19,357
Humidity^2 (%)	6410.035	1031.227	19,357
Humidity >= 2SD above historical mean (1970 – 2007)	0.008	0.088	19,357

Notes: Weather is average temperature, average rainfall and average humidity. Sample in Panels A and D includes all children. Sample in Panel B includes mothers and sample in Panel C includes households.

Table 2: Impact of temperature, rainfall and humidity in month and year of birth on children's MUAC

	Model 1			Model 2		
Variable	(1)	(2)	(3)	(4)	(5)	(6)
< 20 ºC	0.145	0.197	0.132	0.054	0.122	0.054
	(0.700)	(0.602)	(0.606)	(0.721)	(0.615)	(0.619)
22 – 23 ºC	-1.012**	-0.547	-0.559	-0.998**	-0.514	-0.526
	(0.474)	(0.422)	(0.430)	(0.474)	(0.423)	(0.431)
24 – 25 ºC	0.361	0.638	0.637	0.228	0.503	0.500
	(0.753)	(0.752)	(0.744)	(0.756)	(0.765)	(0.757)
26 – 27 ºC	0.257	0.076	0.102	0.161	-0.030	-0.004
	(0.851)	(0.978)	(0.978)	(0.845)	(0.985)	(0.984)
28 – 29 ºC	0.432	0.291	0.313	0.121	-0.083	-0.066
	(0.818)	(0.999)	(1.000)	(0.791)	(1.023)	(1.017)
30 – 31 ºC	-0.661	-0.261	-0.199	-1.038	-0.722	-0.668
	(0.941)	(1.114)	(1.119)	(0.907)	(1.116)	(1.114)
Rainfall	-0.005	0.010	0.012	0.016	0.033	0.034
	(0.036)	(0.035)	(0.034)	(0.038)	(0.038)	(0.037)
$Rainfall^2$	0.000	0.000	0.000	0.000	0.000	0.000
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Humidity	-0.073**	-0.056	-0.055	0.957**	1.019*	1.038*
	(0.031)	(0.036)	(0.036)	(0.468)	(0.576)	(0.568)
$Humidity^2$				-0.007**	-0.007*	-0.007*
				(0.003)	(0.004)	(0.004)
Observations	19,354	13,813	13,813	19,354	13,813	13,813
R-squared	0.234	0.257	0.260	0.234	0.258	0.260
Year, village, month FEs, village FEs x month FEs	✓	✓	✓	✓	✓	✓
Child and mother characteristics	×	✓	✓	×	✓	✓
Household characteristics	×	×	✓	×	×	✓

Notes: The excluded category for temperature is 20 – 21 ºC (68 – 70 ºF), which is considered "comfortable." Models include a constant term. Sample includes children. Child characteristics include age and gender. Mother characteristics include age, years of schooling, age at first marriage, and whether has had a miscarriage. Household characteristics include amount of land owned in decimals, and whether the household migrated from the area. Models report robust standard errors clustered at the village level. *** Denotes significance at the 1% level, ** at the 5% level and * at the 10% level.

Table 3: Impact of temperature, rainfall and humidity in month and year of birth on children's MUAC by age groups

	Model 1				Model 2			
Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
< 20 °C	3.254*	1.084	0.999	0.723	3.245	0.945	0.893	0.655
	(1.809)	(1.137)	(0.819)	(0.690)	(2.118)	(1.150)	(0.815)	(0.699)
22 – 23 °C	6.770**	0.166	-0.209	-0.287	6.757**	0.109	-0.194	-0.265
	(2.918)	(1.451)	(0.598)	(0.489)	(3.062)	(1.444)	(0.602)	(0.491)
24 – 25 °C	4.741	1.203	1.216	1.074	4.711	0.651	0.990	0.948
	(4.935)	(1.566)	(0.902)	(0.807)	(5.568)	(1.554)	(0.919)	(0.807)
26 – 27 °C	8.281*	1.095	0.783	0.683	8.255	0.573	0.586	0.579
	(4.628)	(1.708)	(1.120)	(1.035)	(5.074)	(1.671)	(1.128)	(1.033)
28 – 29 °C	8.972*	1.314	1.088	0.882	8.947*	0.354	0.612	0.575
	(4.735)	(1.946)	(1.162)	(1.089)	(5.110)	(1.873)	(1.149)	(1.081)
30 – 31 °C	4.609	-1.402	0.132	0.497	4.583	-2.473	-0.442	0.121
	(5.909)	(2.144)	(1.353)	(1.245)	(6.438)	(2.071)	(1.294)	(1.196)
Rainfall	-0.123	-0.051	-0.034	0.015	-0.119	-0.016	-0.007	0.033
	(0.279)	(0.089)	(0.052)	(0.037)	(0.330)	(0.092)	(0.057)	(0.041)
Rainfall^2	-0.002	0.001	0.001	-0.000	-0.002	0.001	0.001	-0.000
	(0.005)	(0.002)	(0.001)	(0.001)	(0.006)	(0.002)	(0.001)	(0.001)
Humidity	0.012	-0.064	-0.023	-0.065	0.088	2.177*	1.296	0.784
	(0.310)	(0.069)	(0.047)	(0.039)	(4.427)	(1.259)	(0.784)	(0.622)
Humidity^2					-0.001	-0.015*	-0.009*	-0.006
					(0.030)	(0.008)	(0.005)	(0.004)
Observations	1,170	4,122	8,945	12,408	1,170	4,122	8,945	12,408
R-squared	0.535	0.356	0.287	0.268	0.535	0.356	0.287	0.268
Year, village, month FEs, village FEs x month FEs	✓	✓	✓	✓	✓	✓	✓	✓
Child and mother characteristics	✓	✓	✓	✓	✓	✓	✓	✓
Household characteristics	✓	✓	✓	✓	✓	✓	✓	✓

Notes: The excluded category for temperature is 20 – 21 °C (68 – 70 °F), which is considered "comfortable." Models include a constant term. Sample includes children. Child, mother and household characteristics are the same as in Table 2. Models report robust standard errors clustered at the village level. Columns (1) and (5) consider children less than or equal to six months old, columns (2) and (6) consider children less than or equal to a year old, columns (3) and (7) are children less than or equal to two years old, and columns (4) and (8) consider children in the first 1000 days of life. *** Denotes significance at the 1% level, ** at the 5% level and * at the 10% level.

Table 4: Impact of temperature, rainfall and humidity in month of conception on children's MUAC

	Model 1		Model 2	
Variable	(1)	(2)	(3)	(4)
< 20 ºC	-0.191	-1.106*	-0.176	-1.120*
	(0.607)	(0.606)	(0.602)	(0.600)
22 – 23 ºC	-2.506***	-1.833***	-2.511***	-1.828***
	(0.392)	(0.418)	(0.392)	(0.418)
24 – 25 ºC	-3.053***	-1.684**	-3.040***	-1.703**
	(0.655)	(0.665)	(0.657)	(0.670)
26 – 27 ºC	-3.293***	-2.272**	-3.290***	-2.278**
	(0.776)	(0.934)	(0.777)	(0.934)
28 – 29 ºC	-3.414***	-2.308**	-3.380***	-2.356**
	(0.835)	(0.989)	(0.853)	(0.995)
30 – 31 ºC	-3.706***	-2.624**	-3.670***	-2.677**
	(0.978)	(1.104)	(0.993)	(1.107)
Rainfall	-0.028	-0.006	-0.031	-0.003
	(0.051)	(0.052)	(0.050)	(0.052)
Rainfall^2	0.000	0.000	0.000	0.000
	(0.001)	(0.001)	(0.001)	(0.001)
Humidity	0.048	0.027	-0.109	0.210
	(0.042)	(0.051)	(0.485)	(0.479)
Humidity^2			0.001	-0.001
			(0.003)	(0.003)
Observations	19,353	13,812	19,353	13,812
R-squared	0.242	0.263	0.242	0.263
Year, village, month FEs, village FEs x month FEs	✓	✓	✓	✓
Child and mother characteristics	×	✓	×	✓
Household characteristics	×	✓	×	✓

Notes: The excluded category for temperature is 20 – 21 ºC (68 – 70 ºF), which is considered "comfortable." Models include a constant term. Sample includes children. Child characteristics include age and gender. Mother characteristics include age, years of schooling, age at first marriage, and whether has had a miscarriage. Household characteristics include amount of land owned in decimals, and whether the household migrated from the area. Models report robust standard errors clustered at the village level. *** Denotes significance at the 1% level, ** at the 5% level and * at the 10% level.

Table 5: *In utero* impacts of temperature, rainfall and humidity on children's MUAC

Variable	Model 1 (1)	Model 2 (2)
First trimester: < 20 ºC	-2.918*	-3.165*
	(1.513)	(1.617)
Second trimester: < 20 ºC	-1.591	-2.698
	(2.036)	(2.080)
Third trimester: < 20 ºC	-4.427**	-5.947***
	(1.661)	(1.706)
First trimester: 22 – 23 ºC	-2.863	-2.860
	(2.087)	(2.280)
Second trimester: 22 – 23 ºC	-2.115	-3.339
	(2.037)	(2.125)
Third trimester: 22 – 23 ºC	-0.915	-1.543
	(1.835)	(1.779)
First trimester: 24 – 25 ºC	-3.629	-4.896
	(2.792)	(3.113)
Second trimester: 24 – 25 ºC	-1.923	-6.376**
	(2.479)	(2.747)
Third trimester: 24 – 25 ºC	1.337	-1.869
	(2.315)	(2.430)
First trimester: 26 – 27 ºC	-4.938	-7.807*
	(3.714)	(4.085)
Second trimester: 26 – 27 ºC	-1.966	-7.576**
	(3.301)	(3.572)
Third trimester: 26 – 27 ºC	1.101	-3.024
	(2.652)	(2.981)
First trimester: 28 – 29 ºC	-5.472	-8.219**
	(3.661)	(3.986)
Second trimester: 28 – 29 ºC	-1.393	-6.457*
	(3.492)	(3.650)
Third trimester: 28 – 29 ºC	2.167	-1.800
	(2.950)	(3.136)
First trimester: 30 – 31 ºC	-5.667	-7.353*
	(4.086)	(4.268)
Second trimester: 30 – 31 ºC	-0.519	-4.738
	(3.878)	(3.899)
Third trimester: 30 – 31 ºC	2.081	-2.138
	(3.479)	(3.616)
First trimester: Rainfall	-0.318***	-0.364***
	(0.115)	(0.117)
Second trimester: Rainfall	-0.260**	-0.230
	(0.116)	(0.139)
Third trimester: Rainfall	0.172	0.275*

	(0.147)	(0.144)
First trimester: Rainfall^2	0.005***	0.006***
	(0.002)	(0.002)
Second trimester: Rainfall^2	0.005**	0.006***
	(0.002)	(0.002)
Third trimester: Rainfall^2	-0.002	-0.002
	(0.002)	(0.002)
First trimester: Humidity	0.202	-0.053
	(0.124)	(1.137)
Second trimester: Humidity	0.123	2.636*
	(0.149)	(1.423)
Third trimester: Humidity	-0.184	3.272**
	(0.120)	(1.263)
First Trimester: Humidity^2		0.002
		(0.008)
Second Trimester: Humidity^2		-0.017*
		(0.009)
Third Trimester: Humidity^2		-0.024***
		(0.008)
Observations	13,812	13,812
R-squared	0.265	0.266
Year, village, month FEs, village FEs x month FEs	✓	✓
Child and mother characteristics	✓	✓
Household characteristics	✓	✓

Notes: The excluded category for temperature across trimesters is 20 – 21 ºC (68 – 70 ºF), which is considered "comfortable." Models include a constant term. Sample includes children. Child characteristics include age and gender. Mother characteristics include age, years of schooling, age at first marriage, and whether has had a miscarriage. Household characteristics include amount of land owned in decimals, and whether the household migrated from the area. Models report robust standard errors clustered at the village level. *** Denotes significance at the 1% level, ** at the 5% level and * at the 10% level.

Table 6: Impact of temperature, rainfall and humidity in month and year of birth on mechanisms

Variable	HH out migration (1)	Change in pasture area (2)	Change in rain-fed area (3)	Change in irrigated area (4)	Soil oxygen availability (5)	Soil excess salts (6)
< 20 ºC	-0.023	-0.000	-0.114	0.131	-0.006	-0.001
	(0.017)	(0.001)	(0.211)	(0.215)	(0.006)	(0.002)
22 – 23 ºC	0.008	0.001	-0.167	0.166	0.001	0.000
	(0.021)	(0.000)	(0.169)	(0.168)	(0.008)	(0.002)
24 – 25 ºC	0.043*	0.004	-0.333	0.311	-0.000	0.002
	(0.025)	(0.003)	(0.272)	(0.243)	(0.008)	(0.003)
26 – 27 ºC	0.071**	0.002	-0.547	0.558	0.016	0.007
	(0.030)	(0.003)	(0.366)	(0.367)	(0.012)	(0.006)
28 – 29 ºC	0.065*	0.004	-0.694	0.685	0.018*	0.007
	(0.034)	(0.004)	(0.448)	(0.446)	(0.011)	(0.005)
30 – 31 ºC	0.045	0.002	-0.995*	0.999*	0.029*	0.007
	(0.036)	(0.003)	(0.552)	(0.570)	(0.015)	(0.006)
Rainfall	0.002	-0.000	-0.009	0.010	0.001	0.000
	(0.002)	(0.000)	(0.012)	(0.012)	(0.001)	(0.000)
$Rainfall^2$	-0.000	0.000*	-0.000	0.000	-0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Humidity	0.035	-0.002	0.047	-0.027	-0.001	0.000
	(0.026)	(0.001)	(0.139)	(0.143)	(0.003)	(0.001)
$Humidity^2$	-0.000	0.000	-0.000	0.000	0.000	-0.000
	(0.000)	(0.000)	(0.001)	(0.001)	(0.000)	(0.000)
Observations	12,400	10,604	10,604	10,604	10,604	10,604
R-squared	0.088	0.956	0.917	0.883	0.983	0.988
Year, village, month FEs, village FEs x month FEs	✓	✓	✓	✓	✓	✓
Household characteristics	✓	✓	✓	✓	✓	✓

Notes: The excluded category for temperature is 20 – 21 ºC (68 – 70 ºF), which is considered "comfortable." Models include a constant term. Sample includes households. Household characteristics include land owned in decimals, and whether the household out-migrated (latter is excluded in column (1)). Models report robust standard errors clustered at the village level. Area measured in square kilometers, change is measured as (2017 – 1990). Soil oxygen availability and soil excess salts are measured in 2012. *** Denotes significance at the 1% level, ** at the 5% level and * at the 10% level.

Table 7: Impact of temperature, rainfall and humidity on mother's outcomes

Variable	Age at first marriage (1)	(2)	Miscarriage (3)	(4)
< 20 ºC	-0.126	-0.111	-0.046	-0.048
	(0.217)	(0.214)	(0.038)	(0.038)
22 – 23 ºC	0.623***	0.564***	-0.011	-0.012
	(0.190)	(0.186)	(0.026)	(0.026)
24 – 25 ºC	0.864**	0.782**	-0.034	-0.036
	(0.335)	(0.321)	(0.038)	(0.039)
26 – 27 ºC	0.532	0.567	-0.062	-0.067
	(0.407)	(0.395)	(0.048)	(0.049)
28 – 29 ºC	0.427	0.533	-0.017	-0.022
	(0.425)	(0.409)	(0.051)	(0.051)
30 – 31 ºC	0.339	0.443	0.013	0.006
	(0.455)	(0.421)	(0.055)	(0.055)
Rainfall	-0.035*	-0.038**	0.000	0.000
	(0.018)	(0.015)	(0.003)	(0.003)
Rainfall^2	0.000	0.000*	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Humidity	0.031	-0.059	-0.017	-0.021
	(0.229)	(0.217)	(0.028)	(0.028)
Humidity^2	-0.000	0.000	0.000	0.000
	(0.002)	(0.001)	(0.000)	(0.000)
Observations	12,186	12,175	8,191	8,104
R-squared	0.081	0.152	0.093	0.095
Year, village, month FEs, village FEs x month FEs	✓	✓	✓	✓
Mother characteristics	×	✓	×	✓
Household characteristics	×	✓	×	✓

Notes: The excluded category for temperature is 20 – 21 ºC (68 – 70 ºF), which is considered "comfortable." Models include a constant term. Sample includes mothers. Mother characteristics include age and years of schooling in column (2), also includes mothers' years of schooling in column (4). Household characteristics include amount of land owned in decimals, and whether the household migrated from the area. Models report robust standard errors clustered at the village level. *** Denotes significance at the 1% level, ** at the 5% level and * at the 10% level.

Table 8: Impact of temperature, rainfall and humidity in month and year of birth on children's MUAC in alternate specifications

	Model 3		Model 4		Model 5	
Variable	(1)	(2)	(3)	(4)	(5)	(6)
Temperature measures						
< 20 ºC	0.089	0.139				
	(0.742)	(0.629)				
22 – 23 ºC	-0.888*	-0.469				
	(0.471)	(0.418)				
24 – 25 ºC	0.445	0.578				
	(0.739)	(0.714)				
26 – 27 ºC	0.552	0.175				
	(0.852)	(0.946)				
28 – 29 ºC	0.926	0.535				
	(0.841)	(0.991)				
30 – 31 ºC	-0.073	0.161				
	(1.012)	(1.156)				
Temperature >= 2SD above historical mean			-0.281	-0.284	-0.278	-0.285
			(0.230)	(0.296)	(0.224)	(0.280)
Rainfall measures						
Rainfall	0.066	0.068	0.028	0.048		
	(0.041)	(0.048)	(0.042)	(0.038)		
Rainfall^2	-0.001	-0.001	0.000	-0.000		
	(0.001)	(0.001)	(0.001)	(0.001)		
Rainfall >= 2SD above historical mean					0.412	0.668***
					(0.258)	(0.246)
Humidity measures						
65 – 70 %	-0.218	0.602				
	(0.659)	(0.626)				
71 – 75 %	-0.615	0.256				
	(0.726)	(0.738)				
76 – 80 %	-0.645	0.039				
	(0.652)	(0.681)				

81 – 85 %	-1.646**	-0.528				
	(0.796)	(0.802)				
86 – 90 %	-2.694***	-1.328				
	(0.927)	(0.946)				
91 – 95 %	-1.784	-0.239				
	(1.328)	(1.433)				
Humidity			1.137***	1.197**		
			(0.418)	(0.515)		
Humidity^2			-0.008***	-0.008**		
			(0.003)	(0.003)		
Humidity >= 2SD above historical mean					-1.900*	-1.378
					(1.060)	(0.973)
Observations	19,354	13,813	19,354	13,813	19,354	13,813
R-squared	0.234	0.260	0.233	0.260	0.233	0.259
Year, village, month FEs, village FEs x month FEs	✓	✓	✓	✓	✓	✓
Child and mother characteristics	✗	✓	✗	✓	✗	✓
Household characteristics	✗	✓	✗	✓	✗	✓

Notes: The excluded category for temperature is 20 – 21 ºC (68 – 70 ºF), which is considered "comfortable." The excluded category for humidity is < 65 % (30-50 % is considered "comfortable"). Historical means include data from 1970 to 2007. Models include a constant term. Sample includes children. Child characteristics include age and gender. Mother characteristics include age, years of schooling, age at first marriage, and whether has had a miscarriage. Household characteristics include amount of land owned in decimals, and whether the household migrated from the area. Models report robust standard errors clustered at the village level. *** Denotes significance at the 1% level, ** at the 5% level and * at the 10% level.

Table 9: Impact of temperature, rainfall and humidity in three and six months before conception on children's MUAC (falsification)

	Three months before conception		Six months before conception	
Variable	(1)	(2)	(3)	(4)
< 20 ºC	0.420	0.366	0.202	0.222
	(0.578)	(0.577)	(0.670)	(0.660)
22 – 23 ºC	-0.466	-0.488	0.179	0.188
	(0.516)	(0.514)	(0.486)	(0.481)
24 – 25 ºC	-0.659	-0.799	0.949	1.000
	(0.794)	(0.768)	(0.866)	(0.890)
26 – 27 ºC	-0.222	-0.342	0.918	0.969
	(1.018)	(0.995)	(0.949)	(0.992)
28 – 29 ºC	0.025	-0.229	0.852	0.939
	(1.104)	(1.067)	(0.898)	(1.000)
30 – 31 ºC	-1.023	-1.285	1.029	1.115
	(1.170)	(1.146)	(0.943)	(1.046)
Rainfall	-0.047	-0.040	0.044	0.042
	(0.041)	(0.042)	(0.039)	(0.040)
Rainfall^2	0.001	0.001	-0.000	-0.000
	(0.001)	(0.001)	(0.001)	(0.001)
Humidity	0.057	0.587	-0.057	-0.215
	(0.037)	(0.468)	(0.043)	(0.525)
Humidity^2		-0.004		0.001
		(0.003)		(0.004)
Observations	13,812	13,812	13,812	13,812
R-squared	0.262	0.262	0.263	0.263
Year, village, month FEs, village FEs x month FEs	✓	✓	✓	✓
Child and mother characteristics	✓	✓	✓	✓
Household characteristics	✓	✓	✓	✓

Notes: The excluded category for temperature is 20 – 21 ºC (68 – 70 ºF), which is considered "comfortable." Models include a constant term. Sample includes children. Child characteristics include age and gender. Mother characteristics include age, years of schooling, age at first marriage, and whether has had a miscarriage. Household characteristics include amount of land owned in decimals, and whether the household migrated from the area. Models report robust standard errors clustered at the village level. *** Denotes significance at the 1% level, ** at the 5% level and * at the 10% level.

APPENDIX

Appendix Table 1: Impact of temperature, rainfall and humidity in month and year of birth on children's MUAC (full set of results)

	Model 1			Model 2		
Variable	(1)	(2)	(3)	(4)	(5)	(6)
< 20 ºC	0.145	0.197	0.132	0.054	0.122	0.054
	(0.700)	(0.602)	(0.606)	(0.721)	(0.615)	(0.619)
22 – 23 ºC	-1.012**	-0.547	-0.559	-0.998**	-0.514	-0.526
	(0.474)	(0.422)	(0.430)	(0.474)	(0.423)	(0.431)
24 – 25 ºC	0.361	0.638	0.637	0.228	0.503	0.500
	(0.753)	(0.752)	(0.744)	(0.756)	(0.765)	(0.757)
26 – 27 ºC	0.257	0.076	0.102	0.161	-0.030	-0.004
	(0.851)	(0.978)	(0.978)	(0.845)	(0.985)	(0.984)
28 – 29 ºC	0.432	0.291	0.313	0.121	-0.083	-0.066
	(0.818)	(0.999)	(1.000)	(0.791)	(1.023)	(1.017)
30 – 31 ºC	-0.661	-0.261	-0.199	-1.038	-0.722	-0.668
	(0.941)	(1.114)	(1.119)	(0.907)	(1.116)	(1.114)
Rainfall	-0.005	0.010	0.012	0.016	0.033	0.034
	(0.036)	(0.035)	(0.034)	(0.038)	(0.038)	(0.037)
$Rainfall^2$	0.000	0.000	0.000	0.000	0.000	0.000
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Humidity	-0.073**	-0.056	-0.055	0.957**	1.019*	1.038*
	(0.031)	(0.036)	(0.036)	(0.468)	(0.576)	(0.568)
$Humidity^2$				-0.007**	-0.007*	-0.007*
				(0.003)	(0.004)	(0.004)
Male		2.771***	2.765***		2.770***	2.763***
		(0.133)	(0.134)		(0.133)	(0.134)
Infant		-3.810***	-3.827***		-3.789***	-3.806***
		(0.316)	(0.323)		(0.317)	(0.324)
Mother's year of birth		0.077***	0.077***		0.077***	0.078***
		(0.017)	(0.017)		(0.017)	(0.017)
Mother's age at first marriage		0.044	0.039		0.045	0.039

		(0.032)	(0.033)		(0.033)	(0.033)
Mother's years of schooling		0.156***	0.140***		0.156***	0.139***
		(0.026)	(0.027)		(0.026)	(0.027)
Whether mother has had a miscarriage		-0.333	-0.305		-0.334	-0.306
		(0.271)	(0.270)		(0.271)	(0.270)
Land owned by household in decimals			0.427***			0.426***
			(0.086)			(0.086)
Whether household migrated from the area			-0.682*			-0.693*
			(0.355)			(0.354)
Observations	19,354	13,813	13,813	19,354	13,813	13,813
R-squared	0.234	0.257	0.260	0.234	0.258	0.260
Year, village, month FEs, village FEs x month FEs	✓	✓	✓	✓	✓	✓
Child and mother characteristics	×	✓	✓	×	✓	✓
Household characteristics	×	×	✓	×	×	✓

Notes: The excluded category for temperature is 20 – 21 ºC (68 – 70 ºF), which is considered "comfortable." Models include a constant term. Sample includes children. Child characteristics include age and gender. Mother characteristics include age, years of schooling, age at first marriage, and whether has had a miscarriage. Household characteristics include amount of land owned in decimals, and whether the household migrated from the area. Models report robust standard errors clustered at the village level. *** Denotes significance at the 1% level, ** at the 5% level and * at the 10% level.