Climate change and educational attainment in the global tropics

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Climate change may negatively impact education among children via exposure to extreme temperature and precipitation conditions. We link census data from 29 countries across the global tropics to high-resolution gridded climate data to understand how climatic conditions experienced in utero and during early childhood affect educational attainment at ages 12 to 16. We show that exposure to higher-than-average temperatures during the prenatal and early-life period is associated with fewer years of schooling in Southeast Asia. In this region, a child who experiences temperatures 2 SDs above average is predicted to attain 1.5 fewer years of schooling than one who experiences average temperatures. In addition, early-life rainfall is positively correlated with attainment in West and Central Africa as well as Southeast Asia, and negatively correlated with attainment in Central America and the Caribbean. While we expected that children from the most educated households would be buffered from these effects, we discover that they tend to experience the greatest educational penalties when exposed to hotter early-life conditions and, in some regions, to drier conditions. For example, among the most educated households in West and Central Africa, predicted schooling is 1.8 years lower for children who experience early-life rainfall 2 SDs below average versus 2 SDs above average, while the difference is just 0.8 years for children from the least educated households. These results suggest that development and educational gains in the tropics could be undermined by climate change, even for better-off households.

climate change | education | sustainable development

The historical and predicted effects of climate change include higher temperatures, more severe droughts and floods, and a greater frequency and intensity of extreme weather events such as hurricanes and heat waves (1–3). Exposure to adverse climatic conditions may constrain the ability of households to improve living standards via multiple channels, including through its effects on income, food security, and health (4–6). Indeed, the Intergovernmental Panel on Climate Change Fifth Assessment Report predicts with high confidence that climate change will jeopardize human health, food security, and livelihoods, particularly among the world's poor (7). Climate-induced health and income shocks could in turn negatively affect educational outcomes if, for example, children experience poorer health and nutrition in early life, thereby impairing cognitive and physical development; if households are unable to pay school fees; or if children must participate in income generation activities during school ages.

Formal education contributes to poverty reduction and economic development by fostering skills, intellectual ability, and employment opportunities. In addition, education can help reduce vulnerability to climate change and natural disasters by expanding the adaptive capacity of populations (8–13). However, a lack of access to education has long been a challenge in many low- and middle-income countries. In response, in 2000, the United Nations aimed one of its eight millennium development goals (MDGs) at attaining universal primary school education by 2015. The United Nations achieved substantial success over the course of implementing the MDGs; however, 57 million primary school-aged children worldwide remained out of school in 2015 (14). Further, children from the poorest households were five times less likely to complete primary school than those from the wealthiest households, and rural children were twice as likely to remain out of school as urban children (14). In 2016, the United Nations released a set of more ambitious sustainable development goals (SDGs), one of which aims to achieve universal primary and secondary attainment by 2030 (15).

If climate change undermines educational attainment, this may have a compounding effect on underdevelopment that over time magnifies the direct impacts of climate change. However, research on the relationship between climatic conditions and schooling outcomes remains limited. In this paper, we investigate how exposure to precipitation and temperature anomalies in early life is associated with educational attainment among children in 29 countries throughout the global tropics.

We focus on climatic conditions in utero and during early childhood, given the strong evidence that exposure to adverse environmental, political, and socioeconomic conditions during this period negatively impacts long-term human capital outcomes including educational attainment and earnings (16–22). We concentrate on the tropics because of the region's high levels of biophysical and social vulnerability to climate change. The tropics

Significance

This paper investigates the linkages between extreme temperature and precipitation in early life and educational attainment among children throughout the global tropics. We find that experiencing higher-than-average temperatures is associated with fewer years of schooling in Southeast Asia, and that early-life rainfall is positively associated with attainment in West and Central Africa and Southeast Asia and negatively associated with education in Central America and the Caribbean. While we expected that children from the most educated households would be buffered from these effects, we discover that they tend to experience the greatest educational penalties when exposed to hotter early-life conditions. These results suggest that climate change could undermine gains in socioeconomic development, particularly among the world's most vulnerable populations.

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are home to more than two-thirds of the world's poor, and adults in the region have an average of 2.5 fewer years of education than those in other regions (23). Biophysically, low-latitude regions are historically among the hottest, and further warming is predicted to threaten agricultural production and human health earlier in the tropics than in other parts of the world (24–26).

An emerging literature examines the relationship between climatic conditions experienced in utero and during early life and educational and cognitive outcomes in later childhood and adulthood. The studies, which primarily focus on single-country cases, have generally found that exposure to adverse climatic conditions leads to long-term negative human capital outcomes.

One set of studies centers on the amount of rainfall experienced in utero and during the first few years of life. In Burkina Faso, Vietnam, and Zimbabwe, exposure to negative rainfall shocks during this period is associated with adverse outcomes including poorer cognitive ability, lower school enrollment, reduced grade completion, and increased child labor (21, 27, 28). In India, drought exposure in utero through age 4 is negatively associated with having ever enrolled in school (29) and, in Indonesia, greater rainfall during the year of birth is positively associated with women's educational attainment in adulthood (30). In Malawi, in utero exposure to drought is associated with delayed school entry among male children (31). Further, in rural Ethiopia, greater rainfall during the main agricultural season in early childhood is positively associated with having completed at least 1 y of schooling as well as with attending school at the time of the survey (32).

Other studies have focused on high-rainfall shocks. In Ecuador, children exposed to El Niño floods in utero, particularly during the first trimester, scored lower on cognitive tests 5 to 7 y later (33). Similarly, in Mexico, children who experienced El Niño flooding during the first 2 y of life exhibited poorer language development and working memory when tested at ages 2 through 6.* Further, in 16 countries across Latin America, in utero exposure to natural disasters including floods and tropical cyclones was found to lead to an average of 0.3 fewer years of education (34). Taken together, these studies suggest that greater rainfall in early life generally has a positive effect on schooling, and that experiencing precipitation extremes (droughts, hurricanes, and floods) in utero and during the first few years of life negatively affects educational outcomes years, and even decades, in the future.

A smaller set of studies has examined how exposure to adverse temperatures in utero and during early life affects educational outcomes. In rural Ethiopia, experiencing milder temperatures (cooler springs and summers as well as warmer winters) during early childhood is positively associated with having completed at least 1 y of schooling (32). A study of six countries in sub-Saharan Africa found that exposure to high temperatures around the time of conception was positively associated with educational attainment and literacy (35). The authors argue that high temperatures lead to early fetal loss, which selects for the survival of healthier fetuses. In contrast, multiple studies have found that exposure to hot temperatures in utero correlates with preterm birth and lower birthweight (36–40), which are known to negatively impact future human capital outcomes, including education (41, 42).

Many of the above studies conclude that climatic effects on agricultural production and income likely mediate the relationship between early-life climate and educational, cognitive, and labor outcomes. Pregnant mothers, infants, and young children exposed to unfavorable climatic conditions are more likely to experience poor health and food insecurity during critical periods of fetal and child development. Another pathway between climate and education is through direct heat exposure. Extreme heat in utero can impact fetal development, leading to adverse birth outcomes including low birthweight and preterm birth (36, 40), which are associated with impaired physical and cognitive development (41). A third potential pathway is through infectious diseases. Climatic conditions play an important role in the transmission of vector-borne and waterborne diseases such as malaria and cholera (5, 43), and exposure to diseases in utero and during early life have been found to negatively impact cognitive development and educational outcomes (44, 45). Lastly, prenatal exposure to stress caused by natural disasters has been shown to impact children's cognitive ability, particularly among poor households (46). Taken together, these studies support arguments that the physical, cognitive, and socioemotional effects of shocks in early childhood act as key determinants of future life outcomes (16) and that undernutrition and poor health in early life negatively impact cognitive function, educational attainment, and school performance over the long term (17, 18, 20, 21).

We build on this emerging literature in several ways. First, most prior studies on climate and education have examined single-country cases, which offer valuable insights but are not generalizable beyond the country of interest. We expand the scope to countries across the global tropics to understand this relationship more broadly and determine how it varies over space as well as between populations. Second, while most prior studies have focused solely on rainfall, we examine temperature as well. Changes in both temperature and precipitation due to climate change are expected to affect agricultural productivity as well as human health (5, 47, 48), and therefore examining rainfall alone does not provide a comprehensive picture of climate change's impacts. Third, we examine how impacts vary by household head education. Formal education has been found to foster greater adaptive capacity to climate change, as education better equips households to perceive and respond to risks, decreases poverty, and expands access to resources and information (8–12). We examine whether and to what extent household head education mitigates the impact of adverse precipitation and temperature conditions on child schooling outcomes. We predict that household head education will have a protective effect, buffering children from the most educated households from the negative effects of adverse climatic conditions.

Results

Our analysis examines the relationships between temperature and precipitation anomalies experienced during early life (the year before birth through age 5) and educational attainment among children aged 12 to 16 in 29 countries throughout the global tropics (see Fig. 1 for a map of the study provinces). There is substantial variation in annual temperature and precipitation both within and between the five study regions (see *SI Appendix*, Table S2 for a description of historical climate data for the regions during the period 1949 to 2012 as well as early-life climate anomalies experienced by sample children). East and Southern Africa (ESA) are relatively cool and dry due to their high-altitude areas, while West and Central Africa (WCA) are hot, with precipitation conditions varying from monsoonal to desert. Central America and the Caribbean (CAC) tend to be warm and wet and are subject to seasonal hurricanes, while climatic conditions in South America (SAM) vary greatly, from cold and dry in the Andean highlands to hot and wet in the Amazon. Southeast Asia (SEA) is primarily hot and humid with ample rainfall.

We estimate a set of ordinary least squares (OLS) models predicting years of educational attainment based on early-life climate anomalies. The models are stratified by the five world regions mentioned above. Fig. 2 displays predicted years of schooling based on early-life temperature z score. The z score is an indicator of how different the temperature was in a child's province of birth across his or her early life compared with all

*Aguilar A, Vicarelli M (2012) El Niño and Mexican children: Medium term effects of early-life weather shocks on cognitive and health outcomes (Harvard University, Cambridge, MA).

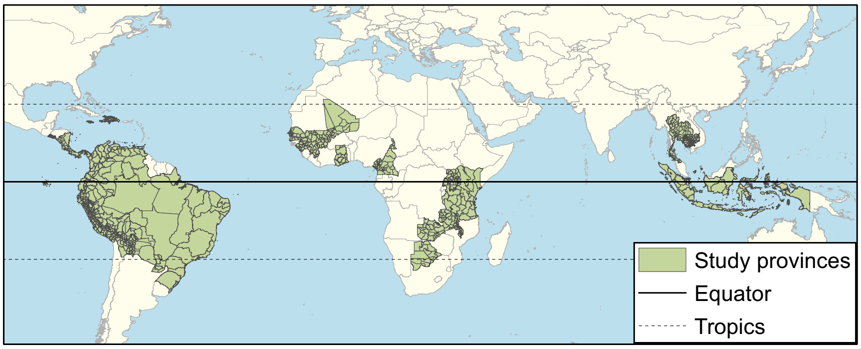

Fig. 1. Map of study provinces.

equivalent periods between 1949 and 2012. A z score of 2 therefore represents an early-life temperature 2 SDs hotter than the average 7-y period in that province. For each region, the graph on the left presents results for the full sample, while the graph on the right presents results stratified by the household head's educational attainment.

We find that hotter-than-normal temperatures in early childhood are negatively associated with educational attainment in SEA, and that cooler temperatures are associated with the highest educational attainment in ESA. In SEA, a child who experiences early-life temperatures 2 SDs above average is predicted to attain 1.5 fewer years of schooling than one who experiences average temperatures and, in ESA, a z score of −2 compared with 0 increases predicted education by 2.6 y.

We next examine predicted years of schooling stratified by educational attainment of the household head. Contrary to our expectations, we find that children from households in which the head has at least a secondary school education are most negatively impacted by high temperatures, and this relationship is strongest in SEA and WCA, the two hottest regions. In SEA, among children from households in which the head has a secondary or greater education, those who experience early-life temperatures 2 SDs above the mean are predicted to attain 2.9 fewer years of schooling than those who experience temperatures 2 SDs below the mean. In contrast, for children from households in which the head has less than a primary education, the difference is 0.7 y. In WCA, the decline in predicted education among children from households in which the head has a secondary or greater education is 1.6 y, while those from the least educated households experience small benefits from temperatures that are both cooler and warmer than average.

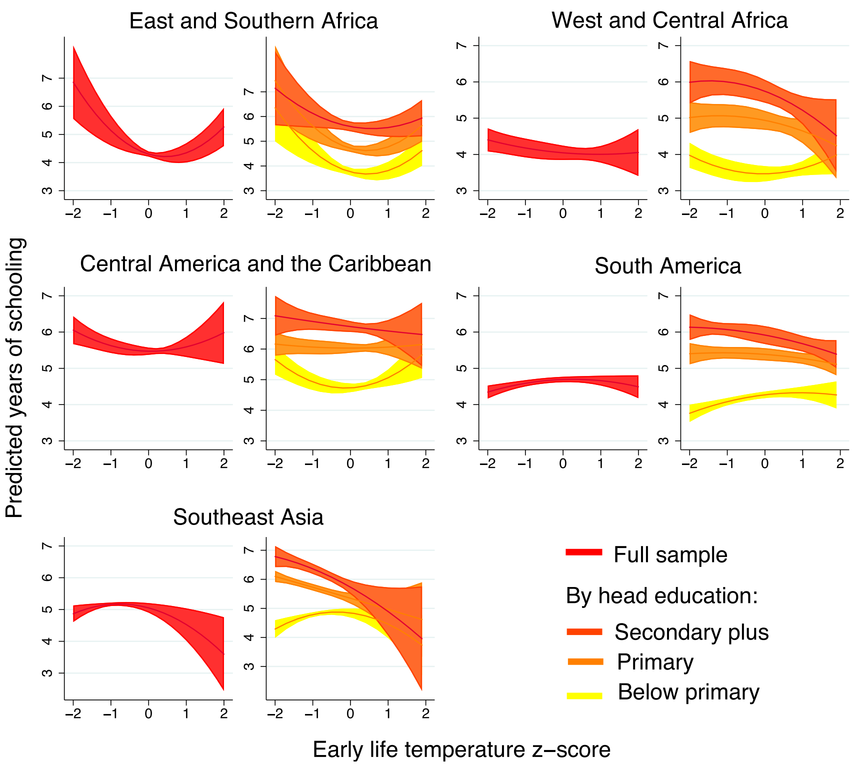

Fig. 2. Predicted years of schooling among children aged 12 to 16 based on early-life temperature z score, including cluster-robust 95% confidence intervals. Note: Models also include controls for the child's age, sex, and relationship to household head, province fixed effects, country-specific linear time trends, and two-way clustering at the birth province and country–birth year levels.

Similar findings emerge in ESA and CAC, as children from the most educated households experience lower predicted education with hotter temperatures, while children from the least educated households appear to benefit from both cooler and warmer temperatures. In ESA, predicted education among children from the most educated households is 1.1 y lower for those who experienced conditions 2 SDs above average compared with those who experienced conditions 2 SDs below average. In contrast, among those from the least educated households, predicted education is 2.6 y higher for those who experienced temperatures 2 SDs below average compared with average temperatures, and 1 y higher for those who experienced temperatures 2 SDs above average compared with average temperatures. Lastly, in SAM, children from households in which the head has at least a primary school education have fewer predicted years of schooling with hotter temperatures, while those from the least educated households appear to benefit from hotter-than-average temperatures during early childhood.

Fig. 3 displays predicted years of schooling based on early-life rainfall z score. Low rainfall is negatively associated with educational attainment in WCA, and this relationship is strongest among children from households in which the head has at least a primary school education. In WCA, predicted schooling is 1.8 y lower for children who experience early-life rainfall 2 SDs below average versus 2 SDs above average among the most educated households, 1.4 y lower for children from households in which the head has a primary education, and 0.8 y lower for children from the least educated households. In SEA, children from households in which the head has at least a primary school education experience educational benefits from greater early-life rainfall, while there is little effect among children from the least educated households. Lastly, early-life rainfall is negatively correlated with educational attainment in CAC among children from the least educated households. A child who experiences rainfall 2 SDs above average is predicted to attain 0.7 fewer years of schooling than one who experiences average rainfall in households in which the head has less than a primary education, while the decrease is just 0.2 y among children from households in which the head has at least a secondary education.

Finally, we also examine the effects of childhood climate anomalies stratified by household location (rural/urban) and occupation of the head (agricultural/nonagricultural) at the time of census (*SI Appendix*, Fig. S4, Table S9 and Fig. S5, Table S10, respectively). These results should be interpreted with caution, because for some households these values will have changed since the time of climate exposure and thus they are potentially endogenous to climate. However, it is worth noting that, consistent with the stratification by education of the household head above, these results reveal surprising forms of vulnerability. Urban households appear to be most vulnerable to climate anomalies in WCA, CAC, SAM, and SEA, possibly reflecting their differential exposure to food prices, infectious diseases, and/or urban heat islands. Indeed, a study in CAC found that high heat was associated with greater losses in nonagricultural production than in agriculture, likely stemming from reduced productivity of workers given heat stress (49). In WCA and CAC, high rainfall negatively impacts agricultural households more so than nonagricultural households, which may be due to impacts of hurricanes or flooding on agricultural production and/or exposure to tropical diseases. Taken together, these results suggest that development and educational gains in the tropics are fragile and could be undermined by climate change, even for better-off households.

Discussion and Conclusions

In this paper, we reveal that climatic conditions experienced in utero and during early childhood are associated with educational

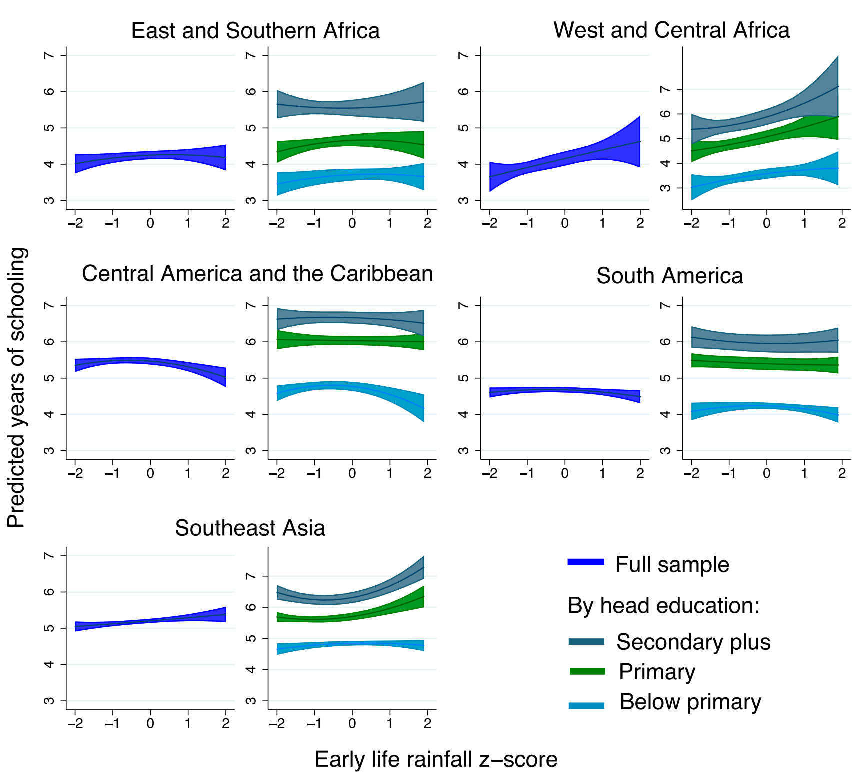

Fig. 3. Predicted years of schooling among children aged 12 to 16 based on early-life rainfall z score, including cluster-robust 95% confidence intervals. Note: Models also include controls for the child's age, sex, and relationship to household head, province fixed effects, country-specific linear time trends, and two-way clustering at the birth province and country–birth year levels.

attainment in later childhood and adolescence. Exposure to higher-than-average temperatures during the prenatal and early-life period is correlated with fewer years of schooling in Southeast Asia, a historically hot and humid region. A combination of high heat and humidity is known to be particularly dangerous to human health (50, 51). Indeed, supplementary analyses (*SI Appendix*, Fig. S13 and Table S18) indicate that high heat only has a negative relationship with educational attainment in provinces that are historically warm and wet. In addition, we found that early-life rainfall is positively associated with attainment in West and Central Africa as well as Southeast Asia (the hottest regions), and negatively associated with attainment in Central America and the Caribbean (a region that is prone to hurricanes).

Our work expands upon prior research which has found that both rainfall and temperature conditions experienced in utero and during early life have important implications for long-term educational outcomes (21, 27–30, 32–34). While much of the prior work focuses solely on rainfall, we discovered that temperature plays a large role in shaping educational attainment. A few potential mechanisms may be driving the link between heat and educational attainment. Extreme heat affects agricultural production (47, 48), infectious disease transmission (5, 43), and fetal development (36, 40). Exposure to excessive heat during the prenatal and early-life period may therefore impact child health and nutrition, hindering physical and cognitive development, and in turn negatively affecting educational outcomes in later childhood.

Given evidence that education decreases vulnerability to climate change (8–13) and that greater education in low- and middle-income countries is associated with higher incomes (52), we expected that children from the most educated households would be least affected by climatic conditions. However, we found evidence of the contrary, as children from households in which the head has at least a secondary education tend to experience the greatest educational penalties when exposed to early-life temperatures that are substantially hotter than normal. Among children who experienced early-life temperatures that were typical of long-term averages, we see a clear educational gradient, with a child's predicted attainment increasing with household head education. At hot temperatures, however, we see a convergence in educational attainment—children from households in which the head has at least a secondary education experience sharp declines, while those from households in which the head has less than a primary school education are less affected, or in some cases even benefit.

Children from the least educated households have a lower schooling trajectory to begin with, and likely face many additional barriers to attending school (e.g., poverty, lack of access to nearby schools, child labor). In addition, adverse temperatures may lead to increased food prices, which could benefit agricultural households and therefore lead to higher attainment among rural children, though the evidence on this is mixed (53). Our findings suggest that children from the most educated households have the most to lose in a warming world as their advantages are eroded. These findings correspond to studies of economic losses due to natural disasters, which find that wealthier households lose more in assets and income than the poorest households because they had more to begin with (54). Similarly, this study echoes Scheidel (55), who argues that wars and state failure can act as "the great leveler." According to Scheidel, the wealthiest in society have the most to lose during periods of violence or political unrest, which diminishes their advantages vis-à-vis more socioeconomically disadvantaged individuals and in turn decreases social inequality.

With regard to rainfall, in West and Central Africa, children from households in which the head has at least a secondary school education tend to suffer most from abnormally dry conditions. Similar to temperature, we believe that the barriers to school attendance among children from the least educated households outweigh the health benefits of additional rainfall in early life. In contrast, in Central America and the Caribbean, children from households in which the head has less than a primary education are most negatively impacted by higher-than-average early-life rainfall. This region is prone to hurricanes, which cause flooding, landslides, infrastructure damage, and crop loss, and tend to most severely affect socioeconomically disadvantaged households in terms of the percentage of assets and income lost (54). Indeed, a supplementary analysis (*SI Appendix*, Fig. S12) indicates higher-than-typical early-life rainfall is negatively correlated with educational attainment only among children from the least educated households living within hurricane-prone countries.

As the effects of climate change intensify, children in the tropics will face additional barriers to education. Achieving the SDG of universal primary and secondary school completion will necessitate the effective development and implementation of policies that reduce vulnerability to extreme temperature and precipitation, particularly during prenatal and early-childhood periods. Ensuring food security and income stability in the face of adverse climatic conditions (for example, through the expansion of crop insurance or social protection programs), as well as limiting heat exposure among pregnant women, will be critical. Additional research is needed to better understand the mechanisms underlying the relationship between climate and educational attainment in different regions to design effective policies that increase access to education in a warmer, more variable world.

Methods

For our analysis, we link social data from multiple censuses from the Integrated Public Use Microdata Series, International (IPUMS-I) (56) to temperature and precipitation from the Climatic Research Unit Time-Series (CRU TS, v. 4.00) through the University of East Anglia (57). Our final sample is composed of data from 85 censuses conducted between 1969 and 2012 in countries across sub-Saharan Africa, Latin America and the Caribbean, and Southeast Asia (see *SI Appendix*, Table S1 for a list of countries and survey years). For our analysis, we restrict the sample to children born in 1950 or later who were aged 12 to 16 y at the time of the census. Using the CRU data, we then construct a set of climate variables at the province–year scale, which we link to individuals using their birthplace province.

We measure two attributes of climate change in the analysis: temperature and precipitation anomalies during early life, defined as the year before birth until age 5. Our measures are mean annual temperature (°C) and total annual rainfall (mm) over this period, which we transform into *z* scores relative to all other 7-y periods of the same duration from 1949 to 2012 for that province. Our outcome variable is the highest grade/level of formal schooling completed, measured in years. We estimate a set of OLS models stratified by world region (East and Southern Africa, West and Central Africa, Central America and the Caribbean, South America, and Southeast Asia). [The range of predicted values of education in our main specification is −1.77 to 11.16 y. Only 0.3% of predicted values fall outside the realistic range (fewer than 0 y of education).] Control variables include the child's age, sex, relationship to the household head (child of head or other), and household head's education (below primary completed, primary completed, or secondary or more completed). To test whether household head education mitigates the effects of climatic conditions on children's educational outcomes, we estimate an additional set of models in which household head education is interacted with the climate variables (see *SI Appendix*, Table S5 for results).

We also include province fixed effects and country-specific linear time trends, and we use two-way clustering: We cluster at the province level to account for nonindependence among individuals living in the same province and also at the country–birth year level to account for nonindependence among individuals born in the same country in the same year. In addition, we use sampling weights to account for the number of individuals represented by each observation in the dataset. The analytic sample contains 13,831,770 observations, while the weighted data, which account for the IPUMS sampling weights, are representative of ∼246 million individuals.

We performed a number of sensitivity analyses and estimated a set of supplementary models to further examine the linkages between climatic conditions and education. We describe our methods in greater detail and present additional results in *SI Appendix*.

Data Availability. The census data that support the findings of this study are available from IPUMS-I, version 6.5 (56) (https://www.ipums.org/doi/D020.

V6.5.shtml). The climate data that support the findings of this study are available from the gridded CRU TS (57) (doi.org/10.5285/58A8802721C94-C66AE45C3BAA4D814D0).

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