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MAPPING THE CUMULATIVE EFFECTS OF CLIMATE CHANGE ON CHILDREN'S EDUCATION IN TEN AFRICAN COUNTRIES

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ABSTRACT

Climate change significantly impacts education in Sub-Saharan Africa, causing disruptions in access to education, teaching, and learning. These disruptions may cause reductions in educational attainment and exacerbate educational inequalities. This paper investigates the impact of climate anomalies on primary education in ten Sub-Saharan African countries using the latest phase of the Demographic and Health Surveys (DHS) and temperature and precipitation data from the Climatic Research Unit-time series (CRU-TS). Our findings show that cumulative exposure to climate anomalies, especially in early childhood, has a significant negative effect on primary school completion and that the effect varies depending on socioeconomic status. Children of better-educated mothers are less affected by climate anomalies, even in economically disadvantaged households. These results emphasize the need to monitor the human capital implications of climate change, especially for young children, and to continue improving education for women to prevent a cycle of educational disadvantage exacerbated by climate hazards.

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1. Introduction

Climate change is an increasing concern to the global community, and the impact of climate change can have far-reaching consequences for future generations. Sub-Saharan Africa is exceptionally vulnerable to the effects of climate change due to its predominantly low socio-economic levels, poor infrastructure, and high dependency on agriculture. African countries have already experienced changes in temperature, increased droughts, floods, and coastal erosion, along with changes to the natural environment including glacier melting, species extinction, and desertification. These impacts are projected to worsen as global temperatures continue to rise, disproportionately affecting the poorest and most vulnerable members of African society.

One of the areas which requires immediate attention is education. Climate change has caused an increase in extreme weather events, leading to adverse impacts on people's livelihoods and access to education. In particular, the majority of those most vulnerable to climate change in the region are girls and women, as well as other marginalised populations. Certain regions may have to cope with out-of-school children due to displacement from conflict, drought, and poverty. In addition, severe weather events can damage educational infrastructure, such as schools and universities, which can also disrupt the educational process. Poor environmental conditions can also impede learning, resulting in lower educational achievement. Furthermore, climate change has been linked to a rise in child labour, as people increasingly find it difficult to secure enough income due to the adverse changes in their environment. This can lead to children dropping out of school, as they are required to work in order to help their families survive. Additionally, water scarcity and food insecurity due to climate change can reduce students' ability to concentrate and learn, resulting in lower educational attainment.

The objective of this report is to evaluate how climate change has affected SDG 4 related indicators in Sub-Saharan Africa, such as early childhood education, school attendance, attainment, and the differential impact on girls versus boys. By utilising the geocoded and education information at the individual, household, and cluster-level from the Demographic and Health Survey (DHS) and rich historical climate data, we take a step forward compared to previous studies in investigating the cumulative effects of extreme temperature and changing precipitation on children's primary school completion rate in 10 African countries. In addition, we examine the potential mitigating effects of mother's education and household wealth between the link of climate change and children's education. Overall, we find that cumulative exposure to climate abnormalities, specifically relating to extremes in precipitation and temperature (either high or low) has a significant negative effect on the primary school completion rate, adjusting for family socioeconomic status, community characteristics, and inter-country variation. In addition, this effect is more detrimental in early childhood compared to late childhood. However, we show that the effect varies significantly depending on children's socioeconomic status. Even in economically disadvantaged families, children born to more educated mothers have higher primary school completion rates than children with less educated mothers. Better education for women potentially serves to mitigate the vicious circle of poverty and educational disadvantages that may be exacerbated by intensifying climate hazards.

2. Literature Review

2.1. Prior studies on the relationship between climate change and children's education

Consistent evidence indicates that exposure to extreme climate events and natural disaster has significant detrimental effects on children's education outcomes (González et al. 2021). In rural Maharashtra, a state of India, droughts have been found to reduce children's maths scores by 4.14% and reading scores by 2.67% (Joshi 2019). The impact of climate shocks can also be long lasting. In Argentina, natural disasters reduced 0.03 years of schooling on average for those who experienced them within their first year of life compared to those who did not (González et al. 2021). Global climate change suggests that extreme climate shocks may become more frequent and less predictable (Cai et al. 2014). The effects of climate change on children's education are expected to worsen.

In recent years, increasing efforts have been made to disentangle the mechanisms in explaining the impact of climate shocks on children's education. The existing literature indicates four interrelated pathways. First, climate change can have a direct impact on children's education through its effects on educational personnel and infrastructure. Natural disasters, in particular, can destroy schools and related educational infrastructure and supplies. In 2022, heavy rainfall in South Korea damaged 78 schools in Seoul alone and resulted in large-scale school closings nationwide (link: https://koreajoongangdaily.joins.com/2022/08/16/national/socialAffairs/korea-rain-flood/20220816155035417.html). An extreme heatwave in India and Europe forced many schools to change their schedule and close earlier. Great natural disasters in previous years have led to massive destruction in schools, roads, and transportation and high casualties of both teachers and students. For instance, the Indian Ocean tsunami destroyed 750 schools in Indonesia, 51 in Sri Lanka, 44 in Maldives, 30 in Thailand and damaged thousands more (link: https://www.britannica.com/event/Indian-Ocean-tsunami-of-2004). In the 2008 earthquake in China, an estimated 10,000 children died in their schools (link: https://www.nytimes.com/2008/05/28/world/asia/28quake.html).

Second, climate change can reduce family disposable income, either through shocks that result in damage to crops and thus losses in agricultural income or by reducing adult productivity in general and hence losses in other earnings. For instance, scholars have demonstrated in multiple settings that droughts during the prenatal period and infancy have negative effects on children's school attendance as such weather shocks decrease family income. However, children who experience higher rainfall in utero to age 5 are more likely to be enrolled in school and to be on track in school (Shah and Steinberg 2017). Applying child fixed-effects models to longitudinal data, Nguyen and Pham (2018) found that being exposed to floods decreases the number of completed grades of children aged 12 and 15 years in Ethiopia, India, and Vietnam by around 3.4, 3.8, and 1.8 percent, respectively. They found that the climate shocks also significantly decreased the household economic level. This implies that the negative impact of floods was most likely operated through a pathway of economic loss and subsequent reduction in educational investment.

Reduced household income may result in the impairment of children's nutritional status, and hence affect their cognitive development (Shah and Steinberg 2017). Parents may also cut off their investment in children's education during difficult economic times. In addition, child labour may increase during such difficult periods to compensate for household needs (Hanna and Oliva 2016). For instance, Santos (2007) reports that children in families most hit by El Salvador's 2001 earthquake were three times as likely to work following the shock. Similarly, a study on rural Central Mexico finds that children's work participation increased after droughts (de Janvry et al. 2006).

However, a competing hypothesis suggests that households suffering from climate shocks may increase educational investment in children. First, the climate shocks may reduce outside opportunities for young children in the labour market and leave them for no choice but remain in school. In addition, parents may view education as a coping strategy against droughts for future gain. For example, one research study found that small farm households in Iran suffering from severe droughts spend more money on education (Khalili et al. 2020). Furthermore, the school attendance rates of young children in Iran also increased among households hit by severe droughts. However, the utility of education investment has an upper limit. Khalili et al. find that droughts cause a drop in family expenditure on university education, particularly for girls, because the cost of university education is relatively expensive.

Nevertheless, the impact of rainfall can be both positive and negative. One study in Indonesia has shown that women with 20% higher rainfall in their year of birth attain 0.22 more years of schooling (Maccini and Yang 2009). These patterns reflect a positive impact of rainfall on agricultural production and food availability. Taken together, the mixed results seen in previous literature imply that the way that climate-induced income loss affects children's education depends on both the local and household's economic situation.

Third, health declines caused by climate change —in utero, in early childhood, or during the school years—may threaten children's education. The association between poor health and low educational performance is well known (Currie and Stabile 2006; Miguel and Kremer 2003). Climate change will likely increase the optimal conditions for infectious and parasitic diseases through more heavy rainfall, flooding, and rising water temperature, directly impacting children's health (Hanna and Oliva 2016). Higher risks of exposure to infectious diseases can lower children's nutritional intake and disrupt healthy anthropometric development, thus impeding cognitive development and learning (Khalid Ijaz and Rubino 2012). Heat also affects children's learning and other cognitive performances. For example, high temperature reduces high-stakes test performance by 5.83 percent of a standard deviation in China and by 13 percent of a standard deviation in the U.S. and leads to persistent impacts on high school graduation and entrance to college (Park 2020; Zivin et al. 2020).

The impact of climate shocks on children's health can be long-lasting. A growing body of research has found that the intrauterine and early childhood environments can have an impact on later life outcomes. Increasing extreme climate events can pose challenges to SDG 2 on early-life nutrition and further impact early childhood education under SDG 4. For example, children in Ecuador who were exposed to severe El Niño floods in utero were shorter in height and scored lower on cognitive tests five or seven years later (Rosales-Rueda 2018). In Argentina, natural disasters reduced 0.03 years of schooling on average for those who experienced them within their first year of life compared to those who did not (González et al. 2021). Evidence from rural India indicates that children who were exposed to droughts as younger children had lower attendance rates and performed poorly on cognitive tests later in life. The negative impacts of droughts on younger children relate to the previous findings that malnutrition in utero and during infancy have detrimental effects on human capital accumulation. Children who were exposed to droughts at school age, on the other hand, were less affected and even performed better on maths tests and had greater attendance rates. This is because the opportunities outside the school declined during the drought periods, so that the relative benefits of remaining in school increased (Shah and Steinberg 2017). In addition, rising temperatures and air pollution have been associated with increased preterm birth and low birth weight (Chen et al. 2018; Keivabu and Cozzani 2022; Liu et al. 2021), which are strong predictors of later health status and school outcomes (Islam 2015; Petrou, Sach and Davidson 2001). Another recent study indicates that climate extremes have a direct impact on children's developmental outcomes, even ruling out agricultural productivity as an exclusive mechanism. In the Kyrgyzstan, cold winters, drought, and excessive rainfall have increased the probability of stunting in children under 20 months (Freudenreich et al. 2022)

Lastly, displacement or climate migration can result from either acute climate disasters or chronic environmental deterioration and has posed challenges to accessing education among relocated children (UNICEF(UK) 2021). Estimates suggest that in Sub-Saharan Africa, Southeast Asia, and Latin America over 143 million people could migrate internally due to the impacts of climate change by 2050 (World Bank 2018). Thus, the disruption to children's education could be sizable.

2.2. Heterogeneous effects of climate change

It is also worth noting that children exposed to the same climate hazards may not react in the same way. Extensive research has documented that the magnitude of the climate effect depends on children's socioeconomic status. Children from households with higher socioeconomic status are less likely to suffer from an income shock. Those who come from lower-income households are more likely to live in areas that are more vulnerable to extreme weather, such as floods, hurricanes, tornadoes, and wildfires. These unique situations can lead to a disruption of transportation, power outages, and more, making it more difficult for students to access school and other educational resources. Additionally, these communities may not have the resources or infrastructure to adequately prepare for these extreme weather events. However, families with higher socioeconomic status often have greater access to resources that can help to mitigate the negative effects of extreme weather on education. For example, higher-income families may be able to relocate during natural disasters or purchase emergency alert systems to be notified when extreme weather is headed their way. They may also have greater access to educational resources when schools are closed or evacuated due to extreme weather. Furthermore, higher-income families may be able to purchase specialised educational materials, such as books or internet access, that can provide some continuity of learning during extreme weather events.

Increasing evidence also shows that the mother's level of education has protective effects against the negative impact of climate hazards (Basu et al. 2018; Son et al. 2019). For example, using a sample of 4 million newborns born in Spain between 1990 and 2016, Keivabu and Cozzani (2022) found that while the incidence of negative birth outcomes increased for children exposed to extreme heat during early gestation, low SES mothers were more likely to deliver infants with poor birth outcomes after being exposed to high temperatures. Liu et al. (2022) conducted an analysis of birth records from Guangzhou, China during a period of high pollution and discovered that the adverse impact of PM10, a type of air pollutant, exposure on birth weight was more significant for mothers with lower education levels.

Notwithstanding the growing body of research examining the protective effect of maternal education, the underlying mechanisms driving this phenomenon remain speculative and in need of further exploration. With more education, mothers are better equipped to provide their children with the resources they need in times of adversity. Educated mothers can be more proactive in finding solutions and have the educational skills to make effective decisions. This includes understanding the risks associated with extreme weather and recognizing the warning signs. They can also seek out information from reliable sources, such as humanitarian and relief organisations, to understand what resources are available and how to access them. Educated mothers also have the ability to act as advocates for their families, providing guidance and support to their children and helping them cope with the psychological aspects of extreme weather. Educated mothers also have the knowledge to prepare their homes and communities with resources or strategies to mitigate or limit the severity of potential hazards associated with extreme weather. Similarly, evidence from rural India shows that the father's level of education can also mitigate the negative effects of droughts (Joshi 2018).

2.3. Research gap

We identify two main research gaps in the previous literature. First, although an increasing number of studies tackle the effect of climate change on children's educational outcomes, there is little cross-national comparison on this issue. Despite a broad consensus on the detrimental effects of climate change on children's education, the magnitude of the effects varies across different nations, regions, communities, and individuals. This variation reflects the different response strategies to climate change across individuals, families, local communities, and nation states. From a comparative perspective, we can identify strategies that are better adapted to the impacts of climate change and factors that have a protective effect on children's education.

Second, most of the studies focus on the impact of a one-time shock on children's education. The dominant method investigates the effect of natural disasters on children's education using natural disasters as an exogenous variable. Because natural disaster occurrences are not directly connected to characteristics of persons who are exposed to disasters, this approach has the advantage of isolating climate side effects from other confounding factors. Yet less is known about the cumulative impact of climate change on children's education. It is particularly relevant in the contexts we examine in this paper because the intensity and duration of extreme weather events have increased during the past decades. In this study, we address these gaps by adopting a cross-national comparison framework to study the cumulative effects of climate change.

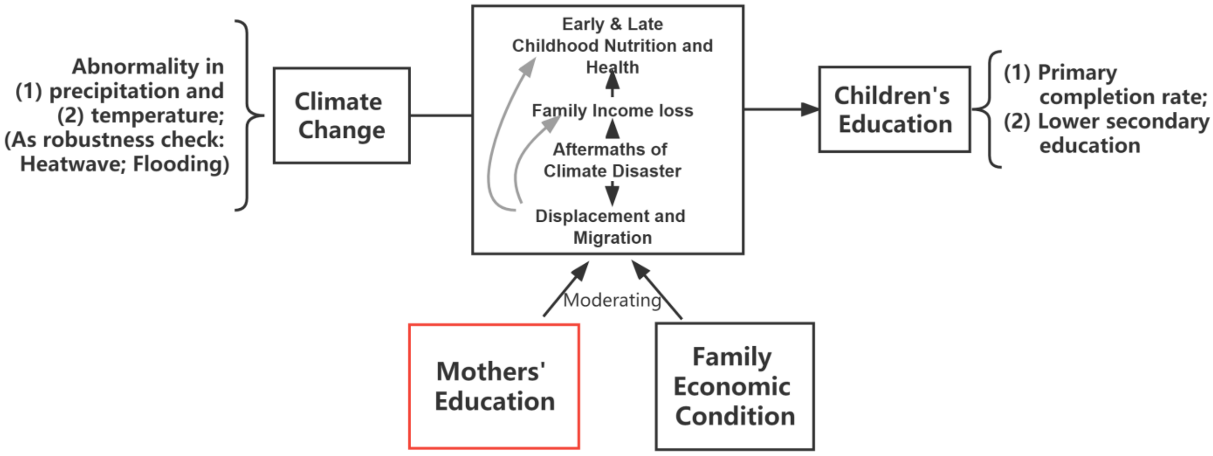


Figure 1. Mechanisms through which climate change affects child's education

3. The Study Contexts

3.1. The association between climate index and education outcomes

Although the climate change challenges vary from country to country, low- and middle-income countries suffer to varying degrees from droughts and floods caused by rising temperatures. These risk factors could directly affect children's education attainment and destroy the infrastructure needed for education. In addition, the resulting infectious diseases and famine brought about by these climate shocks can affect children's access to education by affecting children's health and overall well-being. The negative impacts of climate shocks can be either mitigated or exacerbated depending on children's family backgrounds. Children who reside in rural regions, who are at the bottom of the socioeconomic scale, and/or who are marginalised in some other way are anticipated to be the most adversely harmed.

Benin: Benin is one of the most vulnerable country to climate change effects. Rising temperatures and changing rainfall patterns are having an impact on agricultural production and increasing the intensity and frequency of droughts. This is affecting farmers' capacity to grow food, which is a major concern because agriculture is an important sector of the economy and a vital source of income for many people in the country.

Burundi: Burundi has suffered greatly as a result of climate change. Weather patterns are changing, and the torrential rains, fierce winds, and dry periods have grown more difficult to predict as well as more intense. Floodwaters have destroyed homes and livelihoods in communities across the country. Landslides are a continual concern in the mountains. Flooding and other natural disasters raise the chance of students dropping out of school.

Cameroon: Cameroon is a country in central Africa that has been hit by climate change, in addition to a continuing civil conflict. According to a climate survey from European Investment Bank, 86% of Cameroonians believe that climate change is already affecting their lives, and 59% say environmental damage has harmed their source of income (link: https://www.eib.org/en/press/all/2022-556-86-of-cameroonian-respondents-say-climate-change-is-already-affecting-their-everyday-life#:~:text=The%20survey%20results%20confirm%20that,such%20as%20floods%20or%20hurricanes). The Sahel region in the north of the country is particularly vulnerable to natural disasters such as floods. Food insecurity is widespread.

Gambia: Gambia is one of the world's lowest-lying countries. Wetlands and swamps cover around 20% of the country, and floods occur in flood-prone areas every year following heavy rain. A study predicts that a 1 metre increase in sea level would sink 10% of the land in Banjul, the capital city of Gambia (link: http://www.columbia.edu/~msj42/pdfs/ClimateChangeDevelopmentGambia_small.pdf).

Guinea: Guinea is already prone to floods during the rainy season, and climate change may worsen the problem by changing rainfall patterns. Approximately 6% of Guinea's population lives in low-lying regions that are vulnerable to sea level rise; in fact, sea level increase is already visible in coastal locations. Sea level rise damages agriculture, water supplies, coastal infrastructure, and mangrove ecosystems through increasing salinization of water sources and coastal floods. Coastal flooding may also contribute to disease transmission, particularly in metropolitan areas, and distributing pathogens from wastewater and sewage. Rising temperatures and changes in regional rainfall may continue to produce floods as well as the possibility for drought and the extension of dry spells in some places.

Liberia: Liberia is subject to climate variability and change, which is predicted to manifest in higher temperatures, more extreme weather events such as heavy rains and rising sea levels. Agricultural production, which is already hampered by land degradation and extreme weather events, is made even more vulnerable by climate change due to its reliance on climate-sensitive staple crops such as rice and to the increasing prevalence of pests and disease. As sea temperatures rise and coastal habitats deteriorate, saltwater and freshwater fisheries, a vital economic and nutritional resource, are expected to suffer. Coastal zones, which house the majority of the population, infrastructure, and economic activity, are vulnerable to floods and erosion caused by sea level rise, which will result in the salinization of coastal agricultural land.

Mali: Mali's mean annual temperatures have risen since the 1960s and are anticipated to rise by 1.2°C to 3.6°C by 2060, especially in the southwest, centre, and north. The average annual rainfall varies from north to south, although it generally fell throughout the 1900s. Droughts of unprecedented severity have occurred in recent years. Future precipitation is expected to be more variable, disrupting seasonal rainfall patterns and raising the danger of drought and flooding.

Mauritania: Located in the Sahel region, Mauritania has a hot and arid climate, and desertification is widespread. Mauritania is 75% desert or semi-arid. The bulk of Mauritania receives very little rainfall throughout the year. Climate change is anticipated to increase the frequency and severity of natural disasters by increasing temperatures, extending heat waves, and increasing rainfall unpredictability.

Nigeria: Climate change is worsening Nigeria's concerns in its natural and socioeconomic systems. Extreme weather patterns - more severe, longer dry seasons and shorter, more intense rainy seasons - are increasing the local populations' problems. Desertification, along with extensive farming and overgrazing, has rendered significant areas of northern Nigeria unproductive. Unpredictable and severe rains in southern Nigeria have resulted in agricultural losses and community migration. In the face of a rapidly rising population, environmental resources are being drained throughout the country, posing a severe threat to food security.

Rwanda: Rwanda is a landlocked country with a temperate climate and abundant rainfall. Higher temperatures, heavier rainfall, and a longer dry season are all projected as a result of climate change. Different regions will face different problems as a result of this: erosion will occur in western mountainous regions, the north-central and south will endure significant flooding, and the east and southeast will suffer from drought and desertification. Some of the effects of climate change, such as lower lake and river flow levels and forest degradation, are expected to occur nation-wide.

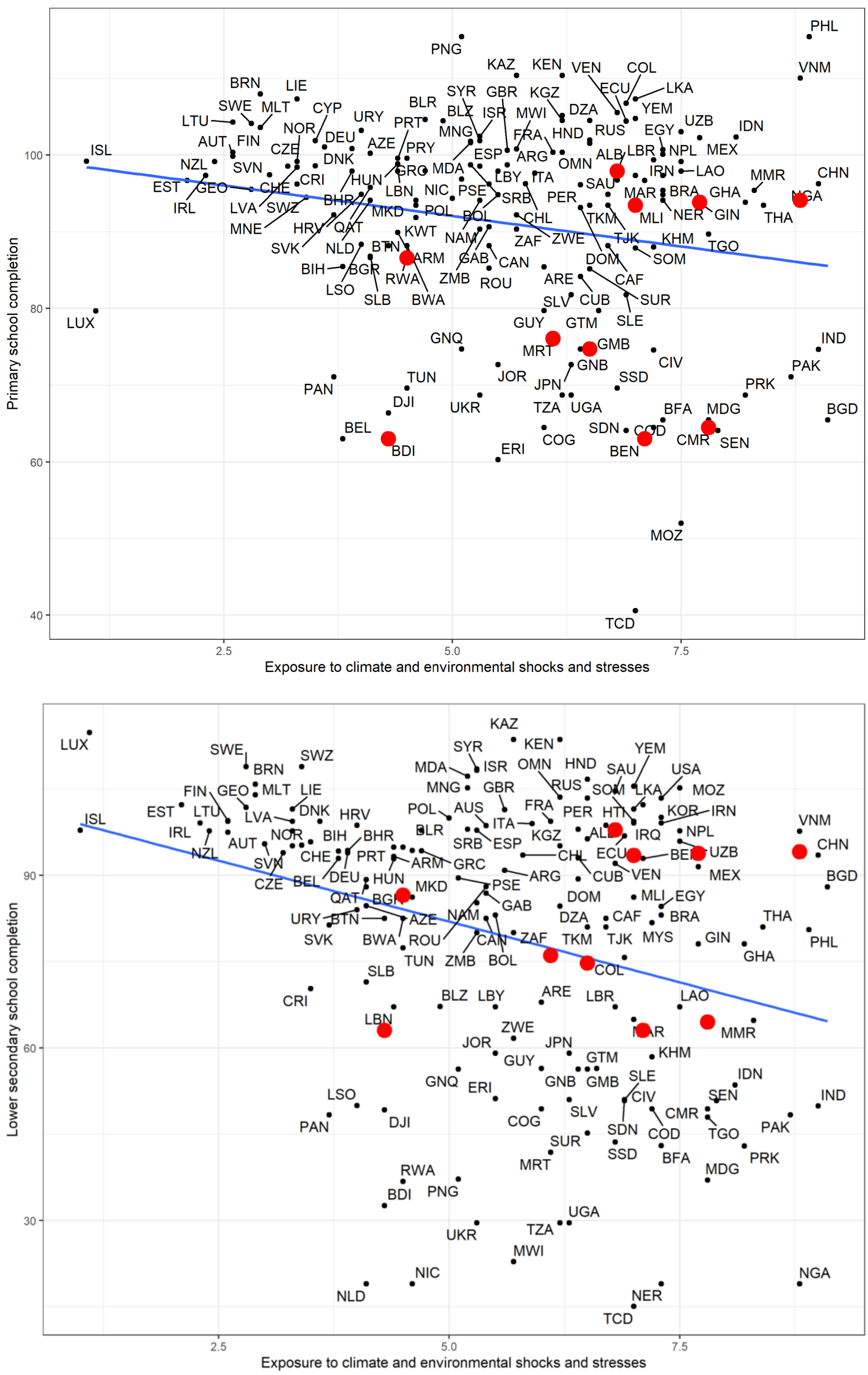


Figure 2. The association between climate index and educational outcomes*

* The climate index measures climate and environmental hazards, shocks and stresses. It captures a range of climate and environmental hazards, shocks and stresses that are currently monitored and recorded. It is important to note that these are current hazards, shocks and stresses, and not future projections. Figure 11 and Table 5 in the UNICEF report (2021) document the methodology (https://www.unicef.org/reports/climate-crisis-child-rights-crisis). Educational outcomes come from UNESCO with 2018 as the reference year.

4. Data and Methods

4.1. Research questions

We address two research questions in this study: (1) Will children's cumulative exposures to environmental hazards during early childhood or later in life have an impact on their educational attainment in low- and middle-income countries? (2) To what extent will the mother's education mitigate the impact of environmental hazards?

4.2. Data and Method

Children in low- and middle-income countries are more vulnerable to climate change. DHS is widely used to study the relationship between environmental hazards and children’s outcomes in developing countries. DHS contains abundant information about individual, household, and community characteristics as controls, as well as geocode information for linkage to climate and environmental data. In comparison, other cross-national surveys such as MICS and YoungLives do not provide detailed geocoded information.

4.3. Outcome variables

We use the educational attainment and years of education provided by DHS to construct our dependent variables. Three main variables in use are whether or not the respondent has completed primary school and lower and upper secondary school. For countries in Sub-Saharan Africa, completion of primary school shows large variation and can reflect actual educational attainment. For countries in Asia and Latin America, where the overall primary school completion rate is high, completion of lower and upper secondary education better captures the variation in educational attainment. The World Inequality Database on Education (WIDE) has created a good example for constructing educational-related outcome variables. We largely follow their description with minor modifications to the targeted age range.

4.4. Cumulative exposure to climate hazards

Monthly precipitation and temperature data starting from the year 2000 were obtained from the Climatic Research Unit-time series (CRU-TS) database. This dataset offers detailed monthly information on temperature and rainfall, at a high frequency and a 50-km resolution, on a 0.5 × 0.5 degree grid. We use the child's birthday and location of the sampling cluster to link these climate variables. Temperature and precipitation anomalies are the independent variables used to measure climate variability. We superimposed the gridded temperature and precipitation datasets on the buffers around the DHS clusters. Because the temperature and precipitation raster grids are smaller than the buffers, an algorithm was used to calculate the mean of the values of all grids that fell within the buffers' boundaries. Grids that only partially overlaped with the buffers were weighted based on the area overlapped. For each cluster, a 20-year calendar of daily maximum temperature (collapsed into monthly average) and monthly precipitation was created.

Temperature and precipitation anomalies have previously been operationalized using short-term deviation from the long-term mean (Andalón et al 2016; Dos Santos and Henry 2008; Eissler et al. 2019; Sellers and Gray 2019). Consistent with well-established measures in the literature, we calculated z-scores to measure deviations from the 20-year (2000-2020) mean of daily maximum temperatures and precipitation around DHS clusters from the year the individual was born. A year with a z-score greater than 2 or less than -2 is characterized by anomalously high or low precipitation/temperature. We divided this annual measurement into months and matched the exact month of birth for each individual without assuming that children born in the same year have the same length of exposure. Cumulative exposure to climate hazard was calculated by summing up all the months experiencing abnormal precipitation and temperature from birth to the month of the DHS survey. To assess whether the timing of exposure matters, we also divided the total duration of exposure into two periods, early childhood and later in life.

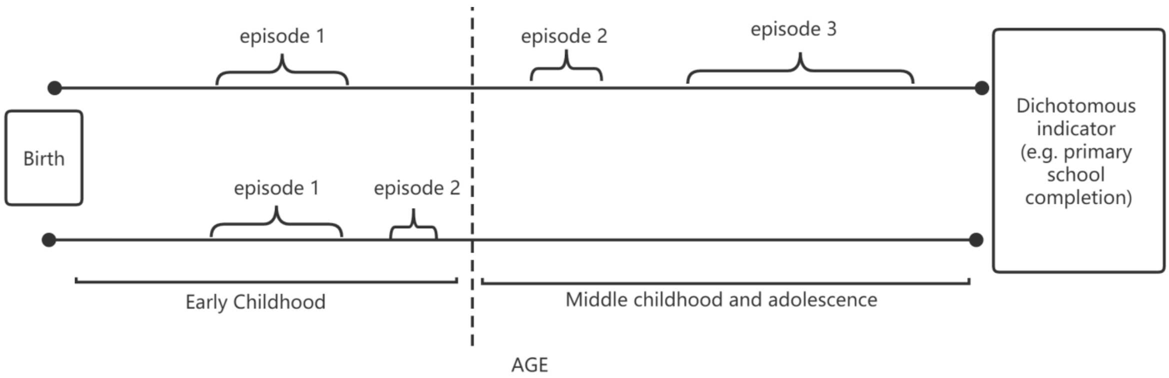


Figure 3. Cumulative exposure by period and educational outcomes

4.5. Estimation of the effect modifications

We interacted mothers' education and family wealth index with climate anomaly measures, respectively, to estimate effect modifications—potentially mitigating effects—associated with mothers' education and family SES, after adjusting for a set of control variables mentioned above.

4.6. Control variables

To identify the impact of environmental hazards on children's educational attainments, we included a set of control variables related to socioeconomic characteristics of children's mothers, households, and the surrounding livelihood zone. Alternatively, we also used the nightlight composite as a proxy for local socioeconomic status with the assumption that more developed areas have brighter night lights than less developed areas.

5. Results on Climate Hazards and Education

The descriptive statistics of variables by country are shown in Table 1. Nigeria accounts for more than one-fourth of the sample, with over 7,000 adolescents. It also outperforms the majority of the other countries in this ten-country sample in terms of primary school completion and has the second-highest proportion of mothers with primary school education or above. Cameroon has the highest rate of children's primary school completion (72%), and the second highest rate in terms of

Table 1. Descriptive statistics of sample sizes, education outcome, climate data, and key socioeconomic status measures by country

Country	Survey year	Analytic sample: Youth aged 14-17	Primary completion rate		Mother's education (Primary school and above)		Abnormally High Precipitation (month)		Abnormally Low Precipitation (month)		Abnormally High Temperature (month)		Abnormally Low Temperature (month)		Socioeconomic condition (Nightlight composite)	
			Mean	Std	Mean	Std	Mean	Std	Mean	Std	Mean	Std	Mean	Std	Mean	Std
Benin	2017-2018	2,327	0.51	0.50	0.21	0.41	18.75	13.15	12.53	7.34	45.06	13.48	75.89	23.65	0.96	2.39
Burundi	2016-2017	3,087	0.45	0.50	0.43	0.50	32.18	14.23	29.64	6.20	43.77	12.92	70.32	22.80	0.12	0.50
Cameroon	2018	1,904	0.72	0.45	0.68	0.47	21.38	10.62	15.60	5.87	49.56	11.95	83.80	19.40	2.32	5.36
Gambia	2019-2020	1,688	0.56	0.50	0.28	0.45	25.82	11.53	7.03	18.79	15.46	5.04	5.13	10.34	1.61	3.57
Guinea	2018	1,611	0.35	0.48	0.13	0.34	42.13	12.41	31.06	7.23	51.43	11.22	88.73	15.62	0.89	2.29
Liberia	2019-2020	1,105	0.27	0.45	0.42	0.49	42.23	11.89	30.63	6.56	50.77	12.07	88.86	13.95	0.24	0.88
Mali	2018	2,007	0.45	0.50	0.19	0.40	24.65	11.64	16.47	5.74	50.45	11.98	90.05	14.74	2.13	4.55

Mauritania	2019-2021	2,494	0.44	0.50	0.43	0.49	23.30	14.81	22.76	9.35	26.46	20.41	38.85	36.68	1.79	3.97
Nigeria	2018	7,077	0.70	0.46	0.53	0.50	21.64	15.15	21.45	11.02	25.37	20.81	37.71	36.15	1.81	4.52
Rwanda	2017-2018	2,059	0.60	0.49	0.81	0.40	36.06	13.66	30.73	6.59	47.64	12.29	78.49	20.67	0.31	1.47

mothers' education attainment, with 68% of mothers holding a primary school diploma or higher. In contrast, Liberia has the lowest primary completion rate among children, and Guinea has the lowest rate among mothers.

In terms of precipitation abnormalities, Guinea and Liberia appear to be the two countries with the highest abnormally high precipitation over the past 20 years, as each has the highest mean cumulative exposure to excessive precipitation at approximately 42 months (more than 3.5 years). Somewhat paradoxically, children from these two countries are also exposed to unusually low precipitation for more than 30 months on average. Rwanda is the third largest country in terms of the length of excessive precipitation exposure, as well as the second largest country in terms of low precipitation exposure (mean: 30.73 months). Benin, on the other hand, has less abnormality in precipitation on average, with 1.5 years of cumulatively more precipitation and just over a year of abnormally low precipitation.

In terms of temperature abnormalities, eight of these ten nations, including Benin, Burundi, Cameroon, Guinea, Liberia, Mauritania, Mali, and Rwanda, have experienced abnormally high temperatures for more than 40 months (cumulatively more than 3 years). Guinea has the most cumulative months with abnormally high temperatures, with approximately 51 months. Moving on to exposure to abnormally low temperatures, it is important to note that the average from 2001 to 2020 is used as a reference because it more accurately reflects children's ability to adapt to the environment in which they were born, and this is not necessarily a good indicator of global warming. If we use the mean temperature of the preceding 20 years (i.e. 1981–2000), as the World Meteorological Organization (WMO) does (WMO 2021), the cumulative high abnormity may be greater than the current statistics, while the cumulative low abnormity may be shorter. Based on the current reference point, Mali, Liberia, and Guinea were exposed to approximately 90 months (7.5 years) of cumulative low temperature anomalies. The nightlight composite, measuring the degree of nighttime luminosity, is a proxy for economic development and urbanisation of the area surrounding the cluster. Cameroon and Mali have the two highest average nightlight composite levels out of the ten nations, despite considerable within-country variation.

Table 2 shows the main results from the logistic regressions on children's primary school completion using a combined sample of 10 countries. Each subtable of Table 2 displays the key coefficient of interest, extreme high and low precipitation or temperature, from a set of 12 logistic models.

The three exposure measures (overall, early childhood, and mid/late childhood) are not modelled at the same time but are respectively modelled with different sets of controls, as indicated by the bottom panel of each subtable. To summarise, the coefficients for exposure to any climate anomalies are given in subtables 2-1 to 2-4, and all of them significantly and negatively predict the primary school completion rate, indicating that the models are robust to additional layers of control and, substantively, that exposure to enduring climate anomalies did negatively affect children's primary school completion. In addition, within each type of exposure, anomalies occurring in early childhood have the greatest magnitude of negative effects.

Table 2 Log odds ratio from logistic regression models showing associations between different types of exposure by children and primary school completion

Table 2-1 Abnormally High Precipitation

	Model 1	Model 2	Model 3	Model 4
	with Exposure 1, 2, and 3, respectively			
Abnormally High Precipitation (month)				
Exposure 1. childhood overall	-0.016***	-0.007***	-0.004***	-0.003**
	(0.001)	(0.001)	(0.001)	(0.001)
Exposure 2. Early childhood (0-5 years old)	-0.046***	-0.019***	-0.010**	-0.007*
	(0.003)	(0.003)	(0.003)	(0.003)
Exposure 3. Mid/late childhood (> 5 years old)	-0.024***	-0.011***	-0.006***	-0.004**
	(0.001)	(0.001)	(0.001)	(0.002)
Individual level controls	Yes	Yes	Yes	Yes
Country dummy variables	No	Yes	Yes	Yes
Cluster level controls	No	No	Yes	Yes
Household level controls	No	No	No	Yes

Table 2-2 Abnormally Low Precipitation

	Model 1	Model 2	Model 3	Model 4
	with Exposure 1, 2, and 3, respectively			
Abnormally Low Precipitation (month)				
Exposure 1. childhood overall	-0.027***	-0.024***	-0.017***	-0.011***
	(0.001)	(0.002)	(0.002)	(0.002)
Exposure 2. Early childhood (0-5 years old)	-0.078***	-0.071***	-0.054***	-0.035***
	(0.004)	(0.005)	(0.005)	(0.006)
Exposure 3. Mid/late childhood (> 5 years old)	-0.039***	-0.035***	-0.023***	-0.014***
	(0.002)	(0.002)	(0.003)	(0.003)
Individual level controls	Yes	Yes	Yes	Yes
Country dummy variables	No	Yes	Yes	Yes
Cluster level controls	No	No	Yes	Yes
Household level controls	No	No	No	Yes

Table 2-3 Abnormally High Temperature

	Model 1	Model 2	Model 3	Model 4
	with Exposure 1, 2, and 3, respectively			
Abnormally High Temperature (month)				
Exposure 1. childhood overall	-0.016***	-0.012***	-0.007***	-0.005***
	(0.001)	(0.001)	(0.001)	(0.001)
Exposure 2. Early childhood (0-5 years old)	-0.049***	-0.038***	-0.024***	-0.016***
	(0.002)	(0.003)	(0.003)	(0.003)
Exposure 3. Mid/late childhood (> 5 years old)	-0.023***	-0.018***	-0.010***	-0.007***
	(0.001)	(0.001)	(0.001)	(0.001)
Individual level controls	Yes	Yes	Yes	Yes
Country dummy variables	No	Yes	Yes	Yes
Cluster level controls	No	No	Yes	Yes
Household level controls	No	No	No	Yes

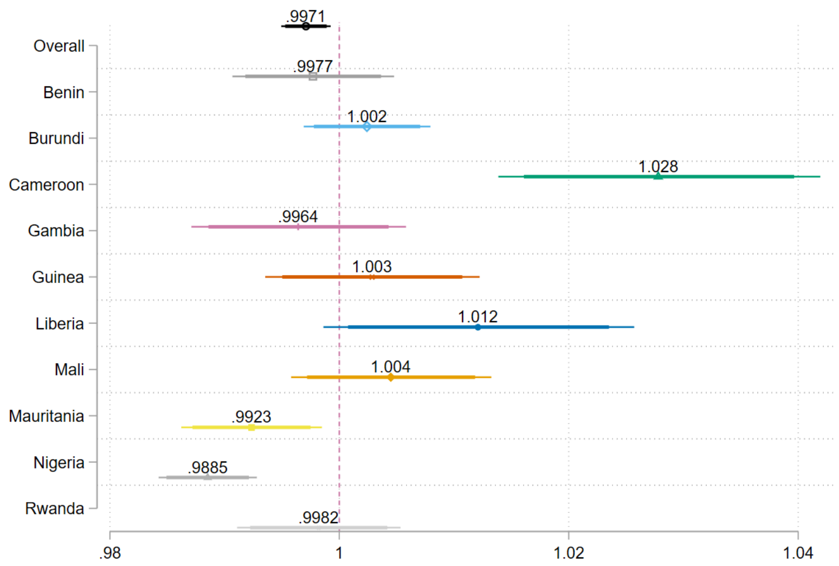
Table 2-4 Abnormally Low Temperature

	Model 1	Model 2	Model 3	Model 4
	with Exposure 1, 2, and 3, respectively			
Abnormally Low Temperature (month)				
Exposure 1. childhood overall	-0.009***	-0.007***	-0.005***	-0.003***
	0.000	(0.001)	(0.001)	(0.001)
Exposure 2. Early childhood (0-5 years old)	-0.031***	-0.025***	-0.017***	-0.011***
	(0.001)	(0.002)	(0.002)	(0.002)
Exposure 3. Mid/late childhood (> 5 years old)	-0.013***	-0.010***	-0.006***	-0.004***
	(0.001)	(0.001)	(0.001)	(0.001)
Individual level controls	Yes	Yes	Yes	Yes
Country dummy variables	No	Yes	Yes	Yes
Cluster level controls	No	No	Yes	Yes
Household level controls	No	No	No	Yes

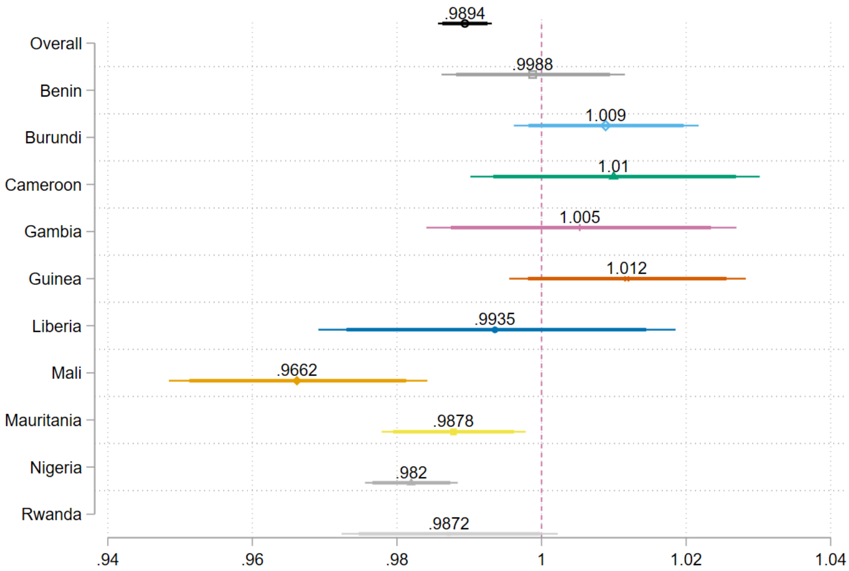
† p < 0.1, * p<0.05; ** p<0.01; *** p<0.001. Standard error in the parentheses.

Tables 2-1 through 2-4 provide the log odds ratio from logistic regression models demonstrating associations between primary school completion and cumulative exposure to abnormally high or low precipitation and high or low temperature, respectively. Focusing on early childhood exposures in Model 4's in Table 2-1 with full control over individual-level, country dummy, cluster-level, and household-level variables, one additional month of anomalously high precipitation during early childhood (i.e. the first 5 years in life) is associated with a 0.8% (1-e^(−0.008)) decrease in the probability of completing primary school. This is non-trivial because it shows that the probability of finishing primary school goes down by 2.4% for every extra three months (approximately one season) of exposure to an anomaly like this. Similarly, each additional three months of early childhood exposure to low precipitation is associated with a 10.3% decline. The results presented in Tables 2-3 and 2-4 indicate that exposure to extremely high or low temperatures in early childhood for a season (again, approximately three months) reduces the likelihood of completing primary school by 4.8% and 3.3% respectively.

Figures 4 and 5 present the odds ratios of the overall childhood climate hazards on completion of primary school for each country separately. The top whisker indicates the overall association (values are the exponentiated coefficients of Exposure 1 for model 4 in Table 2). In Figures 4-1 and 4-2, more than half of these ten nations have odds ratios below 1, indicating that abnormally high or low precipitation has a negative impact on primary school completion. An additional half-year of cumulative excessive precipitation decreases primary school completion by 1.7%, while an extra half-year of cumulative low precipitation decreases it by 6.4%. With the exception of Cameroon and Liberia, children in all other countries were either significantly and negatively affected by unusually heavy precipitation or were experiencing no effect. In Figures 5-1 and 5-2, similarly, a cumulative half-year of abnormally high temperatures decreases the likelihood of finishing primary school by 2.9%, while low precipitation decreases it by 1.9%. With the exception of Mali and Rwanda, children in all other nations were either adversely impacted by cumulatively high temperatures or showed no significant effects. By contrast, Burundi and Gambia differed from other nations in that abnormally low temperatures were associated with higher primary school completion rates.

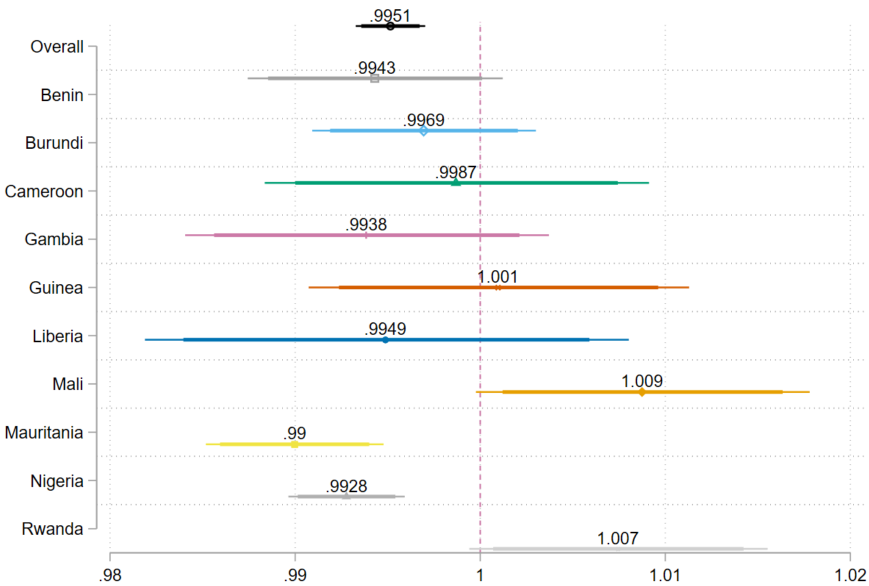


4-1. High precipitation

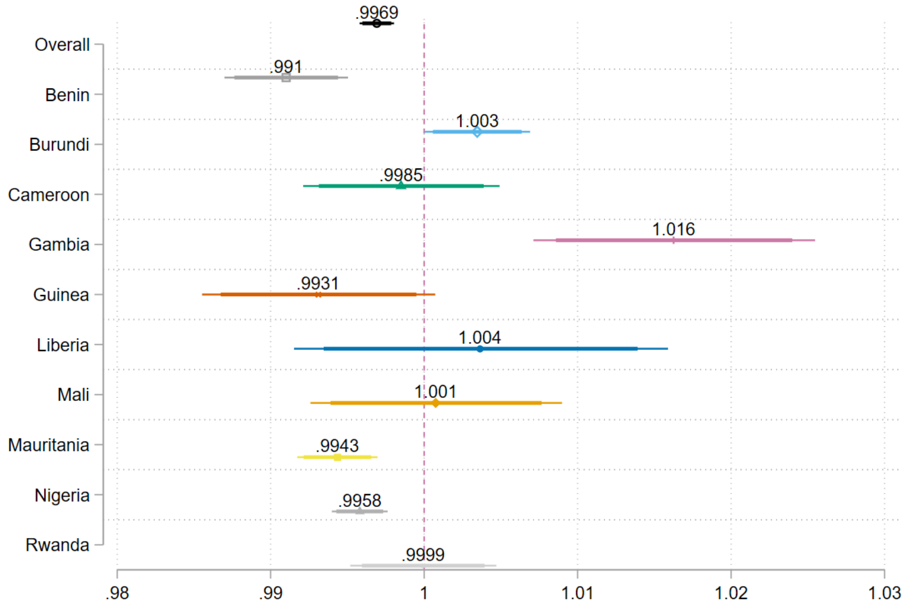


4-2. Low precipitation

Figure 4. Odds ratios from logistic regressions between cumulative abnormal precipitation exposure (month), for all countries combined (the first whisker on the top) and by country (the whiskers below the "overall"). Data are from DHS files. Thinner whiskers represent 95% confidence intervals with thicker whiskers within them for 90% confidence intervals. N = 25,283.



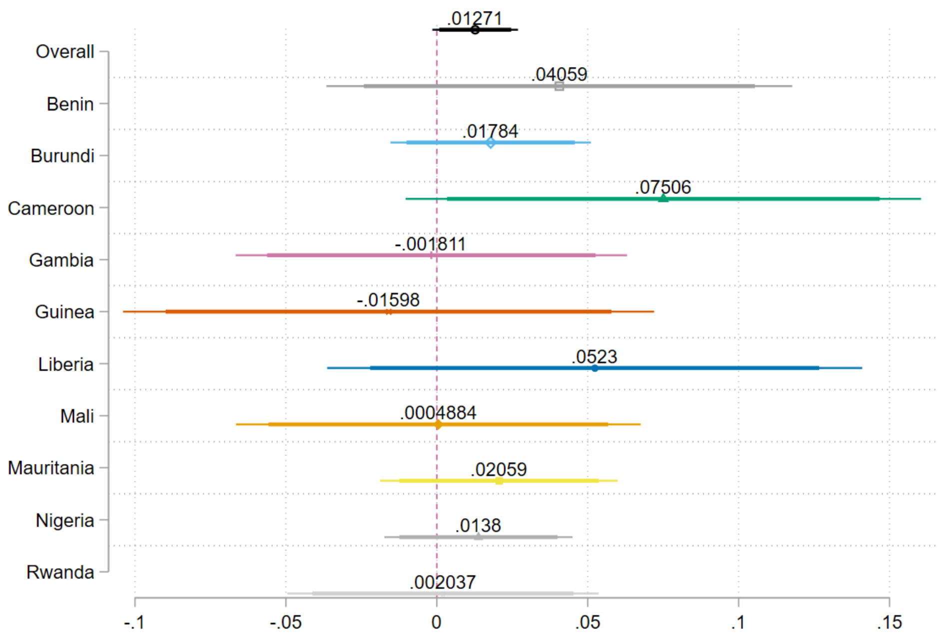
5-1. High temperature



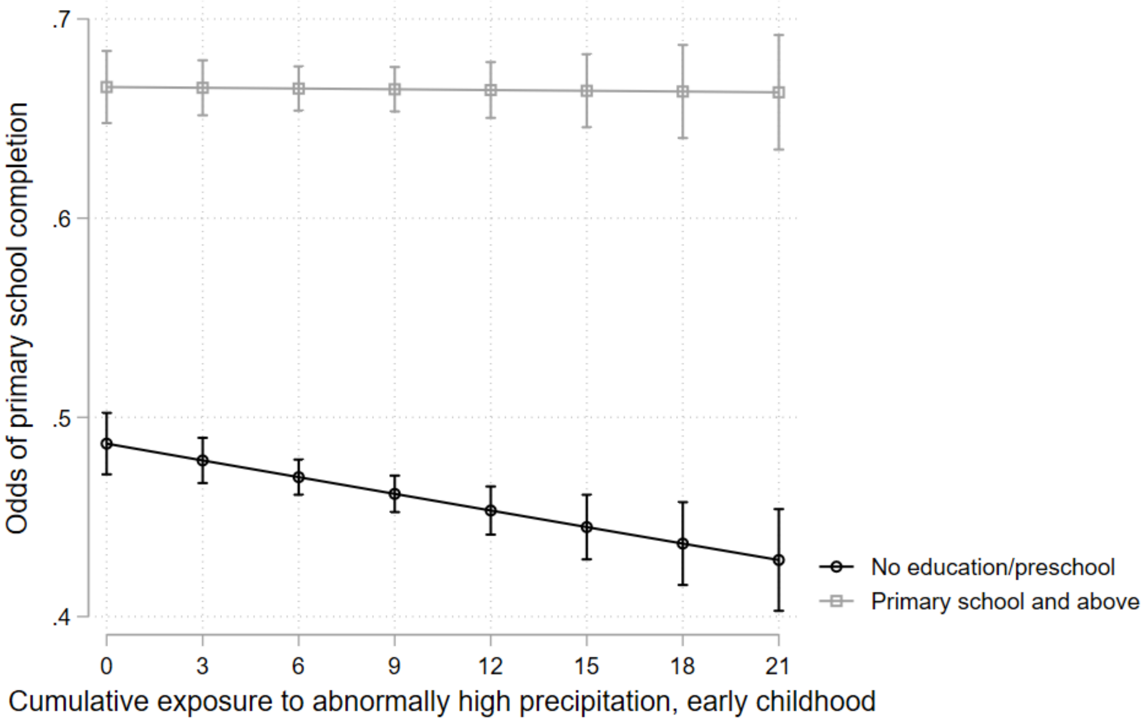
5-2. Low temperature

Figure 5. Odds ratios from logistic regressions between cumulative abnormal temperature exposure (month), for all countries combined (the first whisker on the top) and by country (the whiskers below the "overall"). Data are from DHS files. Thinner whiskers represent 95% confidence intervals with thicker whiskers within them for 90% confidence intervals. N = 25,283.

Our findings have demonstrated that even when controlling for family socioeconomic status and mothers' level of education, climate anomaly exposure still significantly harms children's educational attainment, particularly for children who were exposed to such hazards during early childhood; however, the models have not examined whether negative effects of climate hazards have manifested differently depending on mothers' education. Figure 6 answers this question by plotting the interactive effect of mothers' education and excessive precipitation in early childhood on children's predicted probability of finishing primary school. Figure 6-1 depicts the coefficients for the interaction between mothers' education and climate anomaly exposure for the ten countries combined (the upper whisker) and for each country individually (the other whiskers). For children born to mothers without a primary school degree, one more month of exposure to excessive precipitation anomalies is associated with a 1.4% decrease (1-e^(0.0138)) in the probability of completing primary school, but among those born to better-educated mothers, it is only associated with a decrease of 0.17% (1-e^(-0.0138+0.0121)) in the likelihood of completing primary school ($p < 0.1$). This is nearly ten times less harm compared to their counterparts with less-educated mothers, and such a difference is non-trivial as the exposure to climate anomalies accumulates. Figure 6-2 shows how the mitigating effects of the mother's education makes a difference in widening the educational gap between children born to better-educated mothers and less-educated ones. Despite the noticeable gap in the likelihood of completing primary school between the two groups, the chances of completing primary school further diverge and the gap between children born to better-educated mothers and less-educated mothers widens as exposure to excessive precipitation accumulates.



6-1



6-2

Figure 6. Predicted values of probability of primary school completion with the interaction of mother's education×cumulative abnormally high precipitation exposure during early childhood (upper panel) and later in childhood (lower panel), all six countries combined. Whiskers represent 95% confidence intervals. Models with the interaction between the mother's education and other climate hazard exposures are also estimated and available upon request, but those interactions are statistically insignificant.

This indicates that cumulative exposure to abnormally high precipitation in early childhood is especially harmful to children born to less-educated mothers. Exposure to other types of climate anomalies during early childhood or later in life demonstrates similar trends but with less effect magnitude. The country-specific results shown in Figure 6-1 suggest that the mitigating effects of having a better-educated mother are positive yet non-significant for most countries, in part due to relatively small sample sizes and substantial variation. It is also possible that the group of better-educated mothers includes mothers from both wealthy and poor households, thereby diluting the mitigating effect of education. For example, children in wealthier households are more likely to have the resources to cope with climate anomalies, regardless of the mothers' education.

To further distinguish the effect of household economic conditions and the mothers' education, we constructed a variable indicating whether a mother has a primary school degree or above, and at the same time, resides in a low-income household. Table 2 shows models with interactions between climate anomaly exposure and having better-educated mothers in poor households in the 10-country combined sample. After comparing the magnitude of these mitigating effects by interacting this newly constructed variable with various types of climate anomalies and by timing of exposure, Table 2 and Figure 7 highlight the most notable mitigating effects across all models (other models can be found in the appendix). Overall, one additional month of climate anomaly exposure decreases the odds of completing primary school by 6.0% (1-e^(- 0.061)) but with better-educated mothers, the negative effect drops to 1.8% (1-e^(-0.061+0.043)). In terms of exposure to abnormally high temperatures in mid/late childhood, one additional month of anomaly exposure decreases the probability of completing primary school by 0.2% (1-e^(-0.007+0.005)) for households with limited economic resources but a better educated mother, but by 0.7% (1-e^(-0.007)) for other households.

Figure 7 depicts the overall and country-specific interaction effects. The first whisker with positive log odds ratios in both graphs shows the same information as described in the previous paragraph. The other whiskers give the country-specific mitigating effects. For exposure to abnormally low precipitation during early childhood (on the left), most counties have positive but non-significant point estimates of such mitigating effects except for Benin and Nigeria. Similarly, for exposure to abnormally high temperatures (on the right), the education of mothers, even in poor households, has a positive mitigating effect in almost all countries, though such positive effects are only statistically significant in Cameroon and Nigeria. Overall, these results suggest that having a better educated mother in a low-income household mitigates the harm of both abnormal precipitation and temperature. In a resource-limited family, having a better-educated mother significantly buffers early childhood exposure to abnormally low precipitation (which may cause episodes of drought), while this matters more when it comes to high temperatures in mid/late childhood, which may be partially explained by the negative effects of heat waves on learning during the early school years (Park 2020).

Table 2. Models with interactions between exposure to abnormally high or low precipitation and having better-educated mothers in poor households

	DV: Primary school completion	
	Cumulative exposure to **low precipitation in early childhood**	Cumulative exposure to **high temperature in later childhood**
Climate anomaly exposure	-0.061***	-0.007***
	(0.005)	(0.001)
Better-educated mother in poor households (bottom 2 quintiles)	-0.072	-0.129
	(0.259)	(0.274)
Cumulative exposure × Better-educated mother in poor households		
Primary school and above	**0.043****	**0.005***
	(0.016)	**(0.002)**
Individual level controls	√	√
Country dummy variables	√	√
Cluster level controls	√	√
Household level controls	√	√

† p < 0.1, * p<0.05; ** p<0.01; *** p<0.001. Standard error in the parentheses.

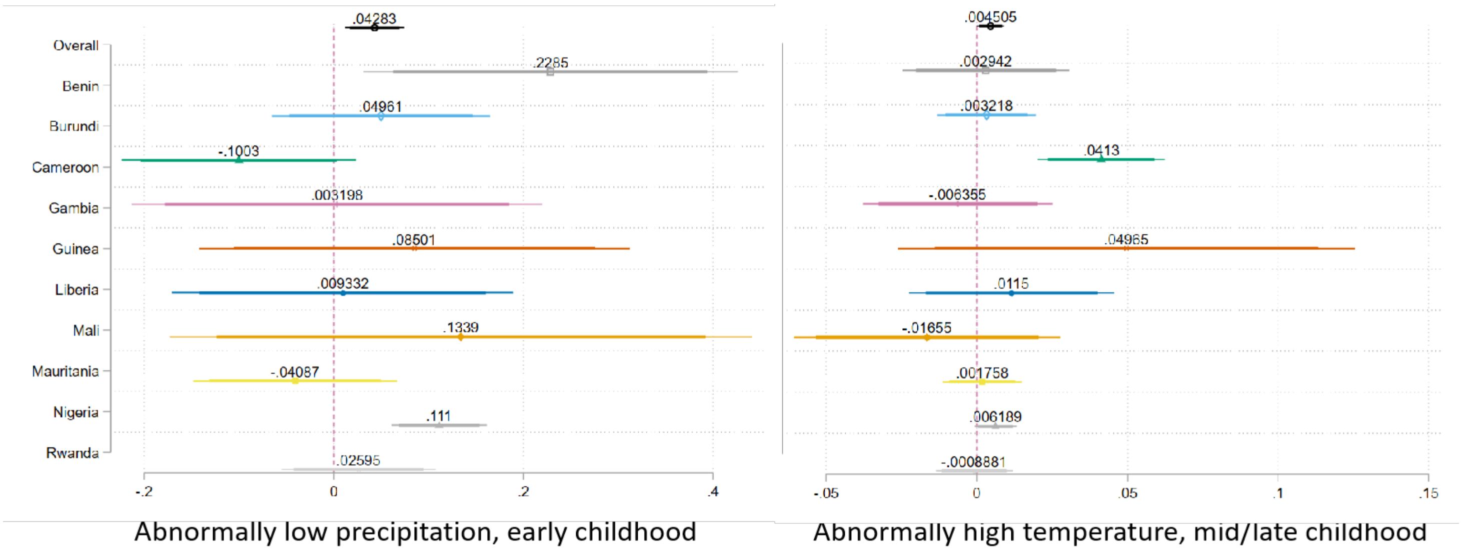


Figure 7. Mitigating effects among all the interaction terms by country

Figure 7. Log odd ratio showing the interaction effect between climate hazard exposure and having better-educated mothers in poor households on children's primary school completion. Data are from DHS files. Thinner whiskers represent 95% confidence intervals with thicker whiskers within them for 90% confidence intervals. N = 25,283.

6. Discussion and Conclusions

This study examines the effect of cumulative exposure to extreme precipitation and temperature on children's education attainment in 10 African countries. Combining survey and meteorological data, we document a significant negative effect of cumulative exposure to extreme weather on children's primary school completion rate. This negative effect cannot be explained by family socioeconomic factors, communities characteristics, and inter-country variation. Furthermore, we identify that the negative effects were stronger in children's early childhood compared to the mid- and late- childhood. Despite the overall negative effect of the climate hazards on children's education, we find that cumulative exposure to abnormal high precipitation has a larger negative effect among children whose mothers do not have primary school education than among children whose mothers have at least a primary school degree.

Our findings underscore the significance of social inequality in human development in the African continent caused by climate change . Currently over 400 million children live in Africa and the number is expected to rise in the coming decades. Increasing climate change may threaten the health, food supply, and water security of African children and families who have less resources to mitigate the effects. Our findings suggest that climate change may further exacerbate the situation by affecting children's learning and create a vicious circle for the next generation.

Our study has several limitations. Our analysis is based on survey data of surviving children and their families. High infant and child mortality in the focusing areas may underestimate the effects of environmental hazards on children's education. Similarly, because we only focus on children and families who have lived in their current residence for at least 15 years, individuals or families moving as a result of changing environments are not included in our analysis. Future studies with high-quality data on individuals' residential history could use the analytic approach adopted here to replicate our findings. We are also unable to identify the specific mechanisms in explaining the detrimental effects of cumulative exposure to extreme weather events. It would be valuable to know the pathway of how climate effects manifested and which pathway matters most. While the findings from this study should not be considered as causal evidence given the limitations of using cross-sectional data, they offer better evidence for long-term and cumulative effects of climate change on human capital accumulation in developing contexts. A followup study could further investigate whether this cumulative effect is additive or multiplicative.

REFERENCES

Alderman, H., Behrman, J. R., Lavy, V., & Menon, R. (2001). Child health and school enrollment: A longitudinal analysis. Journal of Human resources, 185-205.

Cai, W., Borlace, S., Lengaigne, M., Van Rensch, P., Collins, M., Vecchi, G., ... & Jin, F. F. (2014). Increasing frequency of extreme El Niño events due to greenhouse warming. Nature climate change, 4(2), 111-116.

Chen, G., Guo, Y., Abramson, M. J., Williams, G., & Li, S. (2018). Exposure to low concentrations of air pollutants and adverse birth outcomes in Brisbane, Australia, 2003–2013. Science of the Total Environment, 622, 721-726.

Currie, J., & Hyson, R. (1999). Is the impact of health shocks cushioned by socioeconomic status? The case of low birthweight. American Economic Review, 89, 245–250.

Currie, J., & Stabile, M. (2006). Child mental health and human capital accumulation: the case of ADHD. Journal of health economics, 25(6), 1094-1118.

Conte Keivabu, R., & Cozzani, M. (2022). Extreme heat, birth outcomes, and socioeconomic heterogeneity. Demography, 59(5), 1631-1654.

De Janvry, A., Finan, F., Sadoulet, E., & Vakis, R. (2006). Can conditional cash transfer programs serve as safety nets in keeping children at school and from working when exposed to shocks?. Journal of development economics, 79(2), 349-373.

Freudenreich, H., Aladysheva, A., & Brück, T. (2022). Weather shocks across seasons and child health: Evidence from a panel study in the Kyrgyz Republic. World Development, 155, 105801.

González, F. A. I., Santos, M. E., & London, S. (2021). Persistent effects of natural disasters on human development: quasi-experimental evidence for Argentina. Environment, Development and Sustainability, 23(7), 10432-10454.

Hanna, R., & Oliva, P. (2016). Implications of climate change for children in developing countries. The Future of Children, 115-132.

Harrold, M., Agrawala, S., Steele, P., Sharma, A., Hirsch, D., Liptow, H., ... & Mathur, A. (2002). Poverty and climate change: reducing the vulnerability of the poor through adaptation.

Islam, M. M. (2015). The effects of low birth weight on school performance and behavioral outcomes of elementary school children in Oman. Oman medical journal, 30(4), 241.

Joshi, K. (2019). The impact of drought on human capital in rural India. Environment and Development Economics, 24(4), 413-436.

Khalid Ijaz, M., & R Rubino, J. (2012). Impact of infectious diseases on cognitive development in childhood and beyond: potential mitigational role of hygiene. The Open Infectious Diseases Journal, 6(1).

Khalili, Niloofar, et al. "Effect of drought on smallholder education expenditures in rural Iran: Implications for policy." Journal of environmental management 260 (2020): 110136.

Liu, X., Behrman, J., Hannum, E., Wang, F., & Zhao, Q. (2022). Same environment, stratified impacts? Air pollution, extreme temperatures, and birth weight in south China. Social Science Research, 102691.

Maccini, S., & Yang, D. (2009). Under the weather: Health, schooling, and economic consequences of early-life rainfall. American Economic Review, 99(3), 1006-26.

Miguel, E., & Kremer, M. (2004). Worms: identifying impacts on education and health in the presence of treatment externalities. Econometrica, 72(1), 159-217.

Nguyen, C. V., & Minh Pham, N. (2018). The impact of natural disasters on children's education: Comparative evidence from Ethiopia, India, Peru, and Vietnam. Review of Development Economics, 22(4), 1561-1589.

Park, R. Jisung, Joshua Goodman, Michael Hurwitz, and Jonathan Smith. (2020). “Heat and Learning.” American Economic Journal: Economic Policy 12(2):306–39.

Petrou, S., Sach, T., & Davidson, L. (2001). The long-term costs of preterm birth and low birth weight: Results of a systematic review. Child: care, health and development, 27(2), 97-115.

World Meteorological Organization (WMO). (2021). *State of the Climate in Africa, 2020*. WMO-No. 1275.

Rosales-Rueda, M. (2018). The impact of early life shocks on human capital formation: Evidence from El Niño floods in Ecuador. Journal of health economics, 62, 13-44.

Shah, M., & Steinberg, B. M. (2017). Drought of opportunities: Contemporaneous and long-term impacts of rainfall shocks on human capital. Journal of Political Economy, 125(2), 527-561.

Santos, I. (2007). Disentangling the effects of natural disasters on children: 2001 earthquakes in El Salvador. Kennedy School of Government, Harvard University.

Zivin, J. G., Song, Y., Tang, Q., & Zhang, P. (2020). Temperature and high-stakes cognitive performance: Evidence from the national college entrance examination in China. Journal of Environmental Economics and Management, 104, 102365.

APPENDICES: MAPPING THE PATTERNS ACROSS TEN AFRICAN COUNTRIES

We compute the measure of cumulative climate hazards exposure and primary school education at the individual level for people aged 14 to 17 from the DHS survey and for regression analysis. To better understand the geographic patterns of the primary school completion and climate change across the ten countries, we create heat maps for our sample observations on the Africa continent (see in Appendix for interactive maps, link: https://szkaifeng.github.io/climate_africa.github.io/). We compute the mean of primary school completion rate and climate abnormality at the cluster level. We use the GPS information from the DHS survey to map the results. Each circle represents one cluster from our sample, whereas the diameter reflects the estimated population size within the 2km (urban) or 10km (rural) buffer surrounding the cluster in 2015. Figure S1 presents the heat map for primary school completion rate. The yellow colour indicates higher completion rate and the dark blue indicates a low completion rate. Note that the observation time varies by countries ranging from 2017 to 2021 (See table 1). There is large geographic variation in primary school education completion rate across the ten African countries. While there is not a clear pattern in primary school completion rate across countries, some geographic patterns within countries are worth mentioning. People living in populous areas tend to have a higher primary school completion rate. In Nigeria and Cameroon, children living near the coastal area have a higher primary school completion rate than children living inland.

Figure S2 to S5 present the four measures of cumulative exposure to climate change hazard: abnormally high precipitation, abnormally low precipitation, abnormally high temperature, and abnormally low temperature. Again, there are fairly large variations in these measures across ten countries. In contrast to primary school education where the variations are more spread out, we observe that the climate measures patterns are more clustered in geographic locations. Children in the coastal areas in Benin and part of Nigeria seem to experience the lowest exposure to abnormal climate hazards.

Figure S6 to S10 present the bivariate heat maps of the interrelationship between primary school education and abnormal climate change. We use primary school education completion rate to compute the dropout rate and divide it into three categories: low dropout if completion rate above 0.9, high dropout if completion rate below 0.45, and the middle category with 0.45 to 0.9 completion rate. We divide the measure of cumulative climate hazard evenly into three categories so that every category has the same number of clusters. Combining these two categorical measurements will bring as a 3 by 3 scale as shown in the legend figure in Appendix. The grey shade indicates that the dropout rate and cumulative climate hazard are both in their lowest category. The dark black shade indicates that the cumulative dropout rate and climate hazard are both in their highest category. We see a stratified pattern in Nigeria that children with low cumulative climate hazard exposure also have low primary school dropout rate. However, the pattern is not so obvious in other countries (see regression analysis in the main text for more details).