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Rainfall shocks and child health in rural Pakistan

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Original Article

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Abstract

In utero exposure to income shocks has a lasting effect on child well-being. In an agricultural economy, fluctuations in rainfall directly affect household income. In this paper, we investigate the short- and long-run impact of pre-pregnancy, prenatal, and early-life exposure to fluctuations in rainfall on height for a sample of 2290 children in rural Pakistan. Given the widespread canal irrigation system prevalent in the country, we also investigate how fluctuations in river water flows affect child health. We find that fluctuations in rainfall during the pre-pregnancy period have the most lasting effects on the stature of children in the short and long run. Exposure of a mother to a 1 standard deviation reduction in rainfall during the pre-pregnancy period led her child to be 0.17 standard deviations (0.53 cm) shorter by age four. This negative impact of a pre-pregnancy rainfall shock on height persisted over time; the child continued to be 0.12 standard deviations (0.83 cm) shorter, on average, by 13 years of age. However, we find that the effect of pre-pregnancy rainfall fluctuations on children's height is smaller in districts that have access to irrigation facilities.

Introduction

Human capital accumulation is a key driver for attaining long-run economic growth.[1-4] Yet, one of the main challenges that developing countries face today is an insufficient level of human capital. Exposure to weather-induced shocks (like droughts, famines, floods, tsunamis, etc.) is cited as a major factor that affects investment in human capital.[5] The extent to which human capital investments are affected depends on the ability of poor households to smooth consumption and/or assets[6] through formal credit or insurance markets,[7] government social protection schemes, or informal risk-sharing mechanisms.[8,9] While poor households engage in consumption smoothing,[10] they are unable to safeguard themselves completely against the adverse effects of weather shocks in developing countries.[5,11–15] Furthermore, if these shocks are experienced during gestation or early life, they are especially costly, having adverse effects on child health,[16] educational attainment,[17,18] adult health, and socioeconomic status,[19] as well as labor market outcomes and income.[18] Thus, weather-induced shocks have significant short- and long-run consequences on human capital investments and the welfare of poor households in developing countries. The present study is also motivated by a global wave of climate change, due to which, the frequency and severity of weather shocks are expected to rise in the future. Therefore, it is important for governments in developing countries to come up with effective strategies in order to minimize the adverse effects of weather shocks.

We examine the short- and long-run impact of pre-pregnancy, prenatal, and early-life exposure to fluctuations in rainfall on child health in rural areas of Pakistan. We work with a continuous measure of exposure to rainfall shocks and look at fluctuations in rainfall during the agricultural season(s) preceding pregnancy, during gestation, and over the first year after a child's birth. We also investigate how fluctuations in river water flows (which determine water availability through irrigation), over and above rainfall variability, affect child health. Our main outcome of interest is child height, which captures long-term investments in child health. The reduced-form model is estimated using the ordinary least squares (OLS) technique for two time periods: short and long run when a child is 4 and 13 years of age, on average. We use rainfall data from the Pakistan Meteorological Department (PMD). Child-level data is from two waves of the Pakistan Panel Household Survey (PPHS) for a sample of 2290 children, first surveyed in 2001 and again in 2010.

Our main finding is that fluctuations in rainfall during the pre-pregnancy period have the most lasting effect on the stature of children in the short and long run. On average, this effect is smaller in districts with access to irrigation. These findings have important policy implications for two reasons. First, they reveal the most crucial interval within the critical growth period for offering timely interventions that may offset adverse consequences of weather shocks on child health. This is an area of great policy relevance in a country like Pakistan where poverty and stunting rates are high; 37.2% of the country's population is below the poverty line – having less than \$3.65 a day[20] and around 40% of children under 5 years of age (which is around 12 million children) are stunted.[1] This rate of stunting has persisted for the past three decades.[21] A large body of work documents the serious consequences of stunting on a child's life trajectory by affecting physical health, brain and cognitive development, educational attainment, productivity, and income-earning potential.[9] At the macro level, the widespread prevalence of stunting in Pakistan results in GDP losses (in the range of 5%–7%), reinforces poverty, and limits growth.[22] It is estimated that if the current stunting rate is reduced to under 5% by 2040, it could lower poverty by 5 percentage points (pp) and increase real GDP by 7 pp.[21] It is also pertinent to mention that Pakistan – the fifth most populous country in the world – has a relatively young nation; 40% of the population (which approximates 83.7 million children) is less than 15 years of age.[23] Addressing the issue of stunting through timely and well-targeted interventions needs to take center stage in a development policy agenda that aims to make this mass of 83.7 million children vital assets for the country. To that end, our findings reveal critical windows for investing in child and maternal health.

Second, findings in this paper shed light on the nature of interventions that may perhaps be most effective in protecting maternal and child health against weather-induced income shocks in rural-agricultural households. These are promoting wider access to irrigation and providing social protection to expectant mothers. Findings show that despite rainfall fluctuations, access to irrigation can help smooth out income, consumption, and nutritional intake, thus allowing children in disadvantaged children to catch up on their growth deficit over time. The significant and persistent effect of rainfall during the season before conception highlights the importance of ensuring and protecting mothers-to-be. So, instead of a broad-based unconditional program targeting all females, offering a conditional social protection program involving cash transfers and nutritional supplements for expectant mothers could play an important role in minimizing the negative short- and long-run effects of weather shocks on health and well-being. In fact, the largest social safety net program in the country, the Benazir Income Support Programme running since 2008 (with around 9 million beneficiaries and a disbursement of PKR 128 billion over the fiscal year 2023), has been an unconditional cash transfer program targeting poor women.

This paper is related to the literature on weather shocks and their impact on the welfare of households in developing countries. This strand of literature has shown that lack of rainfall leads to crop failure, a decline in per-hectare yields, and a reduction in agricultural income.[24] Other studies have shown the short- and long-term effects of economic shocks in general and weather shocks in particular on human capital outcomes,[25,26] though these effects may be partially or fully offset by government social protection programs.[27,28] In the United Kingdom, prenatal economic shocks for expectant mothers adversely affect birth outcomes.[29] In Brazil, in utero exposure to negative rainfall shocks is linked with lower birth weight and a higher mortality rate.[30] In India, exposure to positive rainfall shocks during gestation and the first 3 years of life is associated with a greater probability of enrolling in school, a lower probability of repeating a grade, and a higher level of cognitive development as measured by children's performance on verbal and numeracy tests.[17] In Indonesia, women who experienced higher rainfall during their birth year attained better health and a higher level of schooling as well as socioeconomic status as adults.[19] In rural Indonesia, exposure to weather shocks at 2 years of age has the most significant and lasting impact on cognitive development.[31] In Columbia, temperature shocks adversely affected health outcomes, but rainfall shocks did not.[32]

Contrary to this strand of literature, there is another subset of studies that find that excess rain may negatively impact human capital accumulation due to a higher incidence of water-borne diseases and the subsequent rise in morbidity, greater labor force participation of mothers in the agricultural market, and adverse effects of excessive rainfall on crop output.[33–36] In Pakistan, the adverse effect of flooding on morbidity is offset by a positive effect on food availability, leading to a weak overall effect on child health in rice-growing regions of the country.[37] Apart from weather shocks, a large body of work documents how exposure to other kinds of shocks (such as war, terrorism, fasting, influenza pandemic, etc.) affects well-being.[8,38] For instance, prenatal exposure to fasting for expectant mothers increases the risk of their children being stunted and underweight in the future,[39] while others do not find negative effects of prenatal fasting on child health.[40]

This study is also linked with the literature on the importance of early child health and nutrition. Starting with Barker's "fetal origins" idea,[41,42] it is now well established that early life is a critical period for growth and development. Nutritional insults during this critical period of growth are likely to have long-run implications for the child's income, productivity, educational attainment, and physical as well as mental health status during adulthood. These long-run effects are expected to work through two main pathways. First, inadequate nutrition is likely to affect current health, which is expected to have an adverse effect on future health status, labor market productivity, and income-earning potential. Many studies have shown that children with poor health and nutrition during early years grow up to be shorter[6,43] and more vulnerable to chronic health diseases.[44–47] The second mechanism is predicted to work through schooling and learning; nutritional deficits (e.g., protein deficits) during early life have been associated with impaired growth of the brain, affecting cognition, and learning.[48–51] Adverse nutritional conditions during gestation and early life may also delay entry into school, increase the probability of dropping out of school, and reduce years of schooling.[52–54] Within this broad literature, a smaller strand of studies shows how timely interventions during the critical growth period can improve adult outcomes. For instance, receiving additional medical care at birth reduces mortality and improves academic achievement in the long run.[55] When stunted children between 9 and 24 months are enrolled in a nutritional supplement and stimulation program, as adults, they demonstrate better cognitive and psychosocial behavior relative to the control group.[56] Providing cash transfers and nutritional information to expectant mothers in poor households in Nigeria improved the health outcomes of children and increased self-employment activities of women with effects persisting beyond the end of the program.[57]

The study makes several contributions while addressing caveats within the current literature, that is, wide use of discrete variables to capture exposure to shocks, reliance on aggregate annual deviations, lack of salience to the pre-pregnancy period, and not accounting for deviations in water available for irrigation purposes in contexts where agriculture is supported by irrigation. We use continuous measures of rainfall shocks and study how fluctuations in rainfall during agricultural periods preceding pregnancy, during pregnancy, and the child's first year of life affect height in the future. In addition

[1]A child with height-for-age z score more than 2 standard deviations below the median in World Health Organization's growth standards is classified as stunted.

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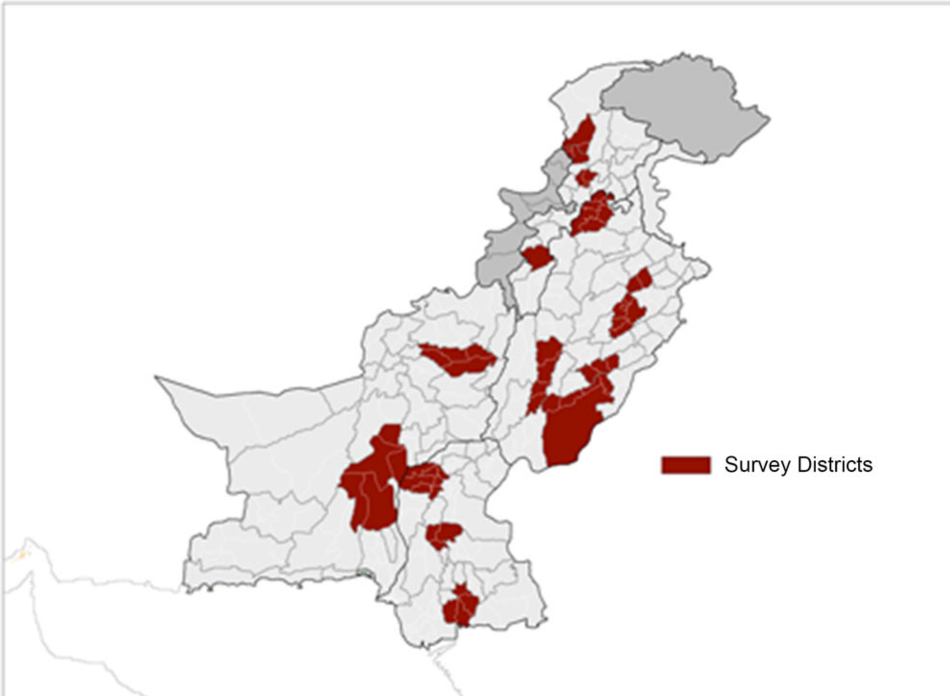

Figure 1. Survey districts.

to rainfall, we also control for deviations in river water flows, which determine water availability for irrigation purposes in large areas of the country. Finally, this is the first study, which explores the direct reduced-form relationship between rainfall variation and child height in the context of rural Pakistan. The wide geographic, climatic, and cultural variation in households covered by PPHS ensures representativeness of findings for rural Pakistan.

The rest of this study is organized as follows: Section 2 discusses the data and lays out the conceptual and empirical framework for examining the relationship between rainfall shocks and child health at different time horizons. Section 3 presents the results and a series of tests to assess the robustness of findings, while Section 4 discusses the main results and concludes the paper.

Methods

Data

The paper is based on child- and household-level data provided by PPHS for the years 2001 and 2010, respectively. The PPHS data spans 14 districts, spread across all 4 provinces of Pakistan (Fig. 1). The module containing child health information was administered to ever-married women between 15 and 45 years who had given birth over the preceding 6 years. The PPHS (2001) sample comprises 2290 children, who were 1 year or older at the time of the survey in 2001.

There is a high prevalence of stunting in the sample of children being studied (Table 1). Approximately 60% of the children fall in the category of severely or moderately stunted. Only about one-third of the children are adequately nourished. Furthermore, the children under study seem to belong to poor families; a large majority of them are malnourished as discussed above, 87% of the mothers are illiterate, another 8% have completed primary or less, and approximately 63% live in a non-cemented house. The sample comprises an almost equal percentage of boys and girls (Table 2).

The climate across most regions of the country is predominantly semi-arid. Pakistan experiences the monsoon season between June and September each year. More than 50% of the annual rainfall is received during these summer months. The degree of dependence on rainfall in these areas hinges upon the availability of canal-irrigated water and subsoil water, accessible through tube wells. Of the sample of 14 districts, which are being studied, 9 have access to canal irrigation (the percentage of cultivated area that is irrigated in each district is shown in Fig. 2. In these areas, dependence on rainwater is not as severe as in some other areas of North Punjab, Khyber Pakhtunkhawa, and Baluchistan that are primarily rain-fed. In the presence of artificial sources of water for agriculture, it is possible that the extent to which children are affected by the adverse consequences of rainfall fluctuations depends on access to canal irrigation facilities. For these irrigated districts, it is important to recognize that in addition to rainfall, variations in river water flows may also be important in affecting agricultural production.

Conceptual framework

This section provides a conceptual framework that outlines the relationship between shocks and child health as documented by earlier literature.[58,59] Many studies have used a similar framework to study the contemporaneous effects of early-life exposure to shocks as well as their impact on future health outcomes.[43,60] We consider a household, which maximizes expected utility (as shown by 1), where utility U depends on child health H, consumption of goods and services C, leisure L, and characteristics of the household and the principal caregiver X_h. Households maximize utility subject to a health constraint and a budget constraint (shown by 2 and 3).

$$\underset{H,C,L}{Max}\ U = U(H, C, L; X_h) \tag{1}$$

$$\text{subject to } H = f(Y, X_i, X_h, X_E; \mu) \tag{2}$$

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Table 1. Prevalence of stunting

Category	WHO cutoffs	Children in each category (%)
Severe stunting	z=<−3	43.37
Moderate stunting	−3<z=<−2	20.39
Normal nutrition/growth	−2<z=<+2	31.45
High nutrition/growth	z>+2	4.79

This table shows the percentage of stunted children in the PPHS (2001) sample of 2290 children. Height-for-age z score allows a comparison of each child in PPHS with the median child of the same age and gender in the National Center for Health Statistics/World Health Organization (WHO) international reference population from the United States. It denotes the number of standard deviations by which a child is taller or shorter than a median child from the reference population. According to WHO, a child with a height-for-age z score of less than −2 is classified as stunted. Height-for-age z scores have been estimated using a STATA macro package (2007) provided by the WHO.

$$P_C C + WL + P_Y Y = FI \tag{3}$$

The health constraint is expressed through a health production function, in which health H is a function of health inputs Y that include physical and nonphysical inputs like nutrients, vaccinations, medicines, childcare, etc., child characteristics X_i, household as well as principal caregiver's characteristics X_h, community and environmental factors X_E, and factors that may not be observed by the researcher μ. Environmental factors stem from the state of health and sanitation in the community, the prevalent disease environment, and shocks experienced by the household. Child-level unobservable factors could include the child's innate healthiness, genetic immunity, and intrinsic growth potential. In addition, there could be household- or community-level unobservable factors such as parent's health knowledge as well as tastes and cultural norms prevalent in the household or the community, which may influence physical and nonphysical inputs received by the child. Apart from the health constraint, household's utility maximization is also subject to a full income FI budget constraint, which combines the value of household's labor income and nonlabor income as well as the time endowment. The price of consumption goods and services, leisure, and health inputs is denoted by P_C, W, and P_Y.

Based on this constrained optimization problem, we obtain a reduced-form child health demand function given by (4), where $\hat{X}_h = (X_h, FI_h)$, $\hat{X}_E = (X_E, P_C, P_Y, W)$, and rainfall shocks are captured by $\hat{X}_E$. The precise form of Φ (.) will be dependent on preferences of the household, as well as on the functional form of the health production function.

$$H = \Phi(\hat{X}_i, \hat{X}_h, \hat{X}_E, \mu) \tag{4}$$

We linearize this reduced form by applying a first-order Taylor series expansion. We focus on a single dimension of child health, that is, physical growth as measured by height. For the vector of child characteristics X_i, we include the age and gender of the child; for the vector of household characteristics $\hat{X}_h$, we include the education and height of the principal caregiver as well as size and wealth status of the household, while rainfall variation around the time a child was conceived and born and ratio of district population to health facilities are captured by the vector of environmental and community characteristics $\hat{X}_E$.

This conceptual framework helps in identifying the underlying theory of change for positive and negative rainfall shocks (shown in Fig. 3). Such shocks are first expected to have an agricultural impact, leading to an economic impact, followed by a nutritional impact that eventually results in a health impact.

While this will be the broad theory of change underlying rainfall shocks – such shocks may activate different pathways depending on whether the shock was positive or negative. Some key distinctions between both types of shocks are as follows: first, resource availability: abundance of water in one and scarcity of water in the other. Second, differential economic effects: in the case of abundance, we would expect immediate impacts in terms of crop damage and asset/property loss with short-term disruption in agricultural output. While we would expect similar adverse effects on agricultural output in case of water scarcity, the effects will take relatively longer to manifest and will be more prolonged depending on the duration of the water shortage. Third, health risks will vary: periods of water abundance are associated with a higher incidence of water-borne diseases, while periods of water scarcity are associated with nutritional deficiencies, malnutrition, stunting, and limited access to clean drinking water. Lastly, each type of shock may lead to differential coping techniques.

Empirical framework

We want to understand how fluctuations in rainfall during the pre-pregnancy period, gestation, and the first year after birth may affect a child's physical growth in the short and long run. This is expressed in equation (5), where y_{ihdp} is the height-for-age z score observed for child i in household h, district d, and province p. Two main factors motivate the use of height-for-age z score as the outcome indicator. First, it has been widely used in the child health as a suitable measure for capturing a person's long-term health. Second, the literature has documented that height is correlated with various outcomes during adulthood.

With details on birth, gender, and stature of children provided in PPHS data, the height-for-age z score has been estimated using a STATA macro package (2007) provided by the World Health Organization (WHO). The conversion to z score allows a comparison of each child in PPHS with the median child of the same age and gender in the National Center for Health Statistics/ WHO international reference population from the United States. A positive (negative) y_i denotes the number of standard deviations by which child i is taller (shorter) than the median child from the reference population. Superscript t denotes two time periods: the short run and the long run. For the short run, we use height-for-age z score measured in 2001 as the dependent variable. For studying long-run effects, the dependent variable is the height-for-age z score observed in 2010.

$$\mathbf{y}^t_{ihdp} = \alpha + \beta \times \mathbf{R} + \varepsilon_{ihdp} \tag{5}$$

On the right-hand side, the main variable of interest is rainfall during the year prior to birth and the birth year. Existing studies in this area use annual deviations in rainfall to study the effect of rainfall shocks.[19,61] The drawback of this approach is that it is likely to suffer from a "smoothing" effect. By focusing on average annual deviations in rainfall, seasonal variations are smoothed out. This may dampen the effect of rainfall shocks on height as positive deviations may be offset by negative deviations, thus canceling the effect of each other. A second drawback of this approach is that it does not allow us to comment on the importance of the timing

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Table 2. Summary statistics

Variable	Obs.	Mean	Std. dev.	Min	Max
hfa_zscore_2001	2290	−2.38	2.19	−6.00	5.97
z-rain in last season before conception	2290	0.31	1.12	−1.20	4.88
z-rain in season(s) during gestation	2290	0.21	1.33	−1.92	6.23
z-rain in first season after birth	2290	−0.03	1.00	−1.73	4.88
z-rain in second season after birth	2290	−0.09	0.94	−1.73	4.88
District population/health facilities	2290	8484	3135	897	15,069
Child age (in months)	2290	43.83	17.96	12	83
Male	2290	0.51	0.50	0	1.00
Log of maternal height	2290	5.02	0.14	1.79	6.16
Highest grade attended by mother	2290	0.71	2.22	0	16
Uncemented house	2290	0.62	0.48	0	1
Owns land	2290	0.52	0.50	0	1
Dependency ratio	2290	1.47	0.85	0.09	7
Punjab	2290	0.33	0.47	0	1
Sind	2290	0.34	0.47	0	1
Khyber Pakhtunkhwa	2290	0.21	0.40	0	1
Baluchistan	2290	0.12	0.33	0	1

hfa_zscore_2001 is the standardized height z scores in 2001. The rainfall variables have been standardized as z scores and represent deviations from long-run average rainfall during an agricultural season in a given study period. The ratio of total district population divided by number of health facilities is for year 1994. "Male" is an indicator variable equal to 1 if the child is a male, "uncemented house" is an indicator variable equal to 1 if the child's family lives in an uncemented house, and "owns land" is equal to 1 if the child's family owns agricultural land, 0 otherwise. Dependency ratio represents the ratio of household members less than 15 and more than 64 years of age over total household members between 15 and 65 years of age. Punjab, Sind, Khyber Pakhtunkhwa, and Balochistan are province dummy variables equal to 1 if the surveyed child belonged to the respective province and 0 otherwise.

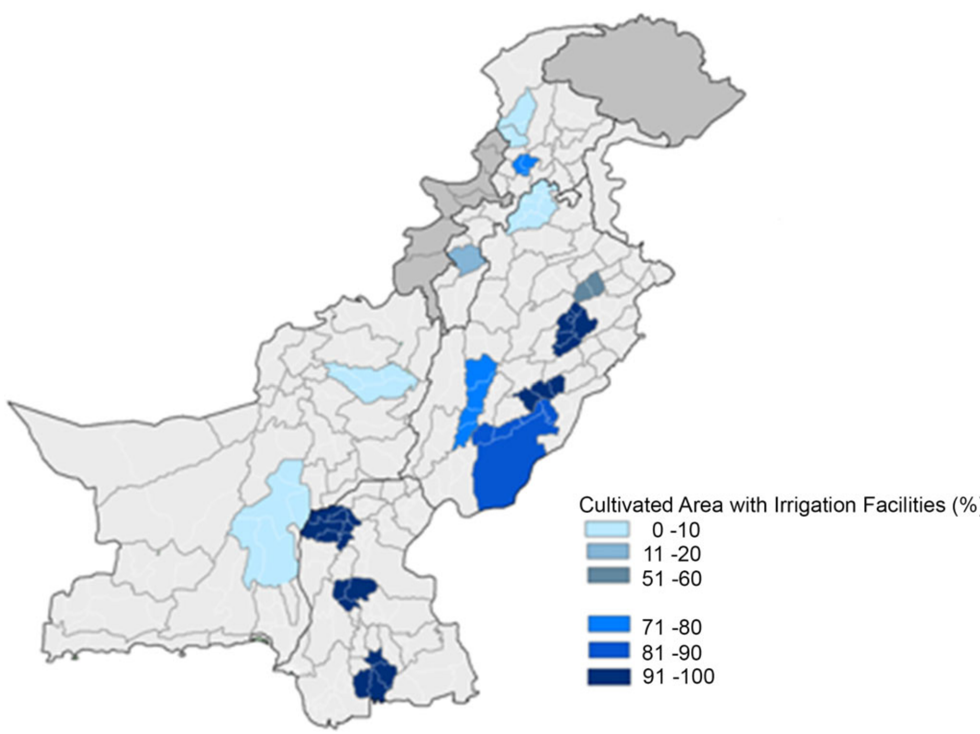

Figure 2. Percentage of cultivated area that is irrigated in the study districts.

effect in studying the impact of rainfall on the outcome indicator. For rural households, agricultural production is a dominant channel through which the effects of rainfall may transmit to children's height. These considerations motivate me to define rainfall variables according to agricultural seasons observed in each child's birth district.

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Figure 3. Theory of change.

In Pakistan, there are two main growing periods during a typical agricultural year. These are Kharif (meaning autumn) and Rabi (meaning spring). Kharif crops are typically grown during the summer months and harvested during the autumn months, while Rabi crops are generally cultivated during the winters and harvested during spring. Thus, the Kharif season normally runs from April to September, while the Rabi season extends between October and March with regional variation in the precise onset of the Kharif and Rabi season. The precise duration of each season varies across as well as within provinces, depending upon the area and the crop being planted.

The sample of children surveyed in PPHS was born between 1995 and 2001. Using district-wise data on crop area as a percentage of the total cropped area from the Agricultural Census 1990, we first identify the main Kharif and Rabi crops grown in each child's birth district. A crop, which has the highest share of cultivated area in each season, is classified as the main Kharif and Rabi crop. Next, we find a district-wise crop calendar for the key Kharif and the Rabi crop identified in the preceding step (Table 3). Wheat is the most widely grown Rabi crop, while cotton and rice are the most common Rabi crops cultivated in the sample districts.

Next, we synchronize each child's month and year of birth with the Kharif and Rabi months in the child's birth district. This enables us to identify four agricultural seasons around the time the child is conceived and born. As an example, consider the subsample of children born in one of the districts under study, that is, Faisalabad between January and December 1995. For this subsample of children, the four agricultural seasons of interest used for constructing the rain variables are shown in Table 4. The seasons have been identified according to each child i's month and year of birth as well as the crop calendar for Kharif and Rabi crops prevalent in the district. The superscript t represents the year in which child i was born. For a child born in January 1995, the last season before conception was Kharif 1993, the two seasons while the child was in utero were Rabi 1994 and Kharif 1994, while the first two seasons after birth were Rabi 1995 and Kharif 1995. As a final step, we constructed standardized rainfall variables for each of these four seasons. The same approach was followed for identifying agricultural seasons of interest around the time of birth and for constructing rainfall variables for children born in all other sample districts.

In equation (5), R is thus a vector of four rainfall variables, where R_{1dp}^{BC} denotes rainfall in the last agricultural season before conception, R_{2dp}^{IU}shows rainfall in the agricultural season while the child is in utero, R_{3dp}^{AB1} represents rainfall during the first agricultural season after birth, while R_{4dp}^{AB2} is rainfall during the second agricultural season after the child's birth. Subscripts d and p denote district and province, respectively. All the rainfall variables have been standardized (as shown in equation (6)) and represent deviations from long-run average rainfall over the given study period. R_{dp} is the sum of monthly rainfall over the Kharif (or Rabi) months m in district d, province p. $\overline{R_{dp}}$ shows long-run average rainfall during the Kharif (or Rabi) season, while σ_{dp}^{R} represents standard deviation of rain over the same time period.

$$R_{dp} = \frac{\sum_m R_{dp} - \overline{R_{dp}}}{\sigma^{R_{dp}}} \tag{6}$$

We assume that exposure to inter-district as well as intra-district variations in rain is exogenous relative to children's height-for-age z score, conditional on controlling for all those factors that may be correlated with height-for-age or rainfall during the period of study. Thus, we modify equation (5) so that the basic estimating equation controls for background characteristics as shown in equation (7), where X is a vector of child, maternal, household, and community characteristics. These include child's gender, age and age square, maternal height, maternal education, condition of the child's dwelling, land ownership status of the household, family's dependency ratio, and ratio of district population to health facilities in 1994 (the year preceding the birth of the eldest child in the sample). The term ρ_p represents province fixed effect dummy variables in order to control for time-invariant unobserved heterogeneity at the province level, while ε_{ihdp} is the error term. We cluster standard errors at the village level.

$$\mathbf{y}_{ihdp}^{t} = \alpha + \beta_1 R_{1dp}^{BC} + \beta_2 R_{2dp}^{IU} + \beta_3 R_{3dp}^{AB1} + \beta 4 R_{4dp}^{AB2} + \delta \mathbf{X} + \rho_p + \varepsilon_{ihdp} \tag{7}$$

We estimate equation (7) for two time periods: short-run, when the eldest child in the sample is around 6 years old, and long run, when the eldest child in the sample is around 15 years of age. Therefore, for the short-run model, outcome variable y_i is the height-for-age z score for child i in 2001 (provided by the first wave of PPHS data). For the long-run model, outcome variable y_i is the height-for-age z score for the same child i in 2010 (provided by the second wave of PPHS data). In contrast, rainfall variables on the right-hand side are the same for both time periods as they capture rainfall conditions in the child's past, around the time of conception and birth.

After controlling for background characteristics and provincial fixed effects, we will explore whether the impact of rainfall fluctuations on child height is sensitive to the presence of irrigation facilities in the district, as well as various child and household characteristics. Following a multistep approach, which involved (i) looking at deviations in rainfall over shorter spans of time instead of annual fluctuations and (ii) following a district instead of a national crop calendar for identifying agricultural seasons, allows us to define the rain variables more precisely than would otherwise have been possible.

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Table 3. District-wise crop calendar

District	Kharif crop	Rabi crop	*Jan^{t+1}*	*Feb^{t+1}*	*Mar^{t+1}*	*Apr^{t+1}*	*May$^{t\wedge}$*	*Jun^{t}*	*Jul^{t}*	*Aug^{t}*	*Sep^{t}*	*Oct^{t}*	*Nov^{t}*	*Dec^{t}*
Punjab														
Attock	Maize	Wheat												
Haifzabad	Rice	Wheat												
Faisalabad	Rice	Wheat												
Vehari	Cotton	Wheat												
Bahawalpur	Cotton	Wheat												
Muzaffargarh	Cotton	Wheat												
Sind														
Larkana	Rice	Wheat												
Nawab Shah	Cotton	Wheat												
Badin	Rice	Wheat												
Balochistan														
Khuzdar	Cotton	Wheat												
Loralai	Vegetables	Wheat												
Khyber Pakhtunkhawa (KP)														
Lakki Marwat	Fodders	Wheat												
Mardan	Maize	Wheat												
Dir	Maize	Wheat												

^For districts of KP, the month of May denotes *May^{t+1}* instead of *May^{t}*.

Table 4. Agricultural seasons of interest

	CONCEPTION		BIRTH	
KH^{t-2} SEASON	(Apr)$^{t-1}$	RB^{t-1} KH^{t-1} SEASONS	(Jan)^{t}	RB^{t} KH^{t} SEASONS
	CONCEPTION		**BIRTH**	
RB^{t-1} SEASON	(May–Jul)$^{t-1}$	KH^{t-1} SEASON	(Feb–Apr)^{t}	RB^{t} KH^{t} SEASONS
	CONCEPTION		**BIRTH**	
RB^{t-1} SEASON	(Aug–Oct)$^{t-1}$	KH^{t-1} RB^{t} SEASONS	(May–Aug)^{t}	KH^{t} RB^{t+1} SEASONS
	CONCEPTION		**BIRTH**	
KH^{t-1} SEASON	(Nov^{t-1}–Feb$^{t)}$	RB^{t} SEASON	(Sep–Nov)^{t}	KH^{t} RB^{t+1} SEASONS
	CONCEPTION		**BIRTH**	
KH^{t-1} SEASON	(Mar^{t})	RB^{t} KH^{t} SEASONS	(Dec)^{t}	RB^{t+1} KH^{t+1} SEASONS

Notes: As an example, this table shows the four agricultural seasons of interest for the subsample of children born in Faisalabad. The seasons have been identified according to each child *i*'s month and year of birth as well as the crop calendar for Kharif and Rabi crops prevalent in the district. The superscript *t* represents the year in which child *i* was born. For a child born in January 1995, the last season before conception was Kharif 1993, the two seasons while the child was in utero were Rabi 1994 and Kharif 1994, while the first two seasons after birth were Rabi 1995 and Kharif 1995. As a final step, we constructed standardized rainfall variables for each of these four seasons. The same approach was followed for identifying agricultural seasons of interest around the time of birth and for constructing rainfall variables for children born in all other sample districts.

Unlike some papers in the literature that use an Instrumental Variables approach to study the impact of economic shocks, we estimate reduced-form results of the impact of rainfall fluctuations around the time of conception and birth on children's future health outcomes for two reasons. First, an IV approach was not feasible with the current data at hand. In order to use rainfall as an instrument for income or consumption, data on household income or mother's food consumption during the periods before

Table 5. Short- and long-run effects of fluctuations in rainfall on child height

Dependent variable: height-for-age z score	(1)	(2)	(3)	(4)
Pre-pregnancy rainfall	0.173**	0.118**	0.262**	0.154*
	(0.0722)	(0.0522)	(0.131)	(0.0785)
Prenatal rainfall	0.0506	−0.0444	0.135	−0.0778
	(0.0547)	(0.0406)	(0.0905)	(0.0624)
Post-birth first season rain	0.139*	0.0402	0.109	0.0468
	(0.0823)	(0.0517)	(0.145)	(0.0710)
Post-birth second season rain	0.0142	0.0149	0.101	0.103
	(0.0883)	(0.0395)	(0.149)	(0.0723)
Constant	−0.0722	−1.193	−0.140	−1.129
	(7.979)	(1.561)	(7.920)	(1.537)
Observations	2,290	1,302	2,290	1,302
R-squared	0.098	0.102	0.100	0.105
Controls	Yes	Yes	Yes	Yes
Province fixed effects	Yes	Yes	Yes	Yes
Quadratic rain terms	No	No	Yes	Yes

Notes: *, **, *** denote significance at 10%, 5%, and 1%, respectively. The dependent variable is height-for-age- z score. Short-run results are presented in columns 1 and 3. Long-run results are presented in columns 2 and 4. The model is estimated using ordinary least squares. Standard errors are shown in parentheses and are clustered at the community level.

conception, during pregnancy, and after birth was required. Unfortunately, such information is not available in the dataset. Second, there is also some evidence in the literature that challenges the validity of using rainfall as an instrument and shows that rainfall shocks fail the necessary "exclusion" restriction.[62,63]

Results

Short- and long-run results

Short run refers to the time when children are between 1 and 6 years of age. Long run refers to the time when children are between 9 and 15 years of age.

I estimate the model given in equation (7). The impact of rain shocks on height-for-age z score in the short run is shown in column 1 of Table 5. Here the dependent variable is children's height-for-age z score observed in 2001 when the first round of PPHS data was collected. The first important finding, which can be observed from column 1, Table 5, is that rainfall during the last season before the child is conceived has a significant and positive effect on the height-for-age z score. An increase in rain in the last season before conception is associated with an increase in height of children in the short run. Children in districts where rainfall was 1 standard deviation higher than the normal during the last season before their conception are 0.17 standard deviations taller compared to children conceived in districts where a similar increase in rainfall did not occur. The second important finding, which emerges from column 1, Table 5, is that rain during the season of birth has a significant and positive effect on the height-for-age z score. On average children who experienced a one standard deviation increase in rainfall during the birth season grew up to be 0.14 standard deviations taller in the short run compared to their counterparts who did not experience an increase in rainfall. The birth season rainfall variable is only marginally significant (at 10%) and has a smaller coefficient compared to rain in the last season before conception. A third important observation that can be drawn from column 1, Table 5, is that rain in the agricultural season(s) while the child is in utero and during the second agricultural season after birth does not affect the height-for-age *z* score significantly.

Originating with Barker's ideas about "fetal origins," it is now well established both in the field of epidemiology as well as economics that nutritional deficiencies during gestation can have lasting effects on a person's life. In light of this stream of literature, one would have expected that rain shocks while the child is in utero would have significant effects on a child's height in the future, but contrary to a priori expectation, the in utero rain variable is insignificant. It would be wrong to interpret this result as implying that gestation is not an important period for development. Instead, the insignificance of this rain variable may be explained by noting that our model only captures changes in rainfall, but not changes in consumption. While it serves as a proxy of the quality of harvest in the child's birth district, it does not inform us about the intra-household pattern of consumption. Therefore, it is possible that a decrease in rain during gestation may not necessarily translate into a decrease in consumption of the expectant mother, because once the family is aware of the pregnancy, it may use alternative mechanisms to ensure that the expectant mother's nutrition is not compromised during this time. More importantly, the insignificance of the in utero rain variable could be explained by the fact that rain is likely to have a lagged effect on income (more on this below). Below-normal rain during gestation may have no significant effect on short- and long-run height if it was preceded by a good harvest in the previous season, which allowed the household to realize positive income gains by the time the child was conceived.

A comparison of coefficients on the four rain terms helps us understand the importance of timing in thinking about the effects of rainfall. The insignificance of rain during in utero and in the second season after birth coupled with the marginal significance of rain during the birth season shows that changes in rain during the last season before the child is conceived are most critical in affecting children's stature. Since this variable captures rainfall variation before a child is conceived and born, it is possible to comment on the underlying channel through which it affects children's height. Fluctuations in rainfall may affect a child's stature through various pathways; these include economic effects through output and prices, as well as noneconomic effects transmitting through the prevalent disease environment and maternal time inputs invested in the child. Since the pre-conception rainfall variable captures changes in rainfall, which take place before a child has been conceived or born, it is reasonable to expect that changes in this variable will affect a child's height through the economic channel; quality of the harvest before conception will affect household income and (or) prices.[2] Both factors may influence maternal consumption, nutrition, and through that her child's health once she has conceived. On the

[2]A similar argument is made in a study on rain shocks and child nutrition in Nepal [64]. For children up to 3 years of age, they show that rain during the last completed monsoon season purely captures the income effect while rain during the current monsoon season encompasses the effect on income as well as the prevalent disease environment.

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contrary, there is no reason to believe that variation in before-conception rainfall would affect human capital outcomes in the future through noneconomic channels such as the disease environment and time inputs.

The long-run results, with height-for-age z score in 2010 as the dependent variable, are shown in column 2 of Table 5. We find that the short-run impact of rain during the birth season on child's height is transitory, dissipating in the long run. On the other hand, the impact of rain during the last season before conception remains persistent. A 1 standard deviation increase in rainfall during the last season before conception is expected to increase the height-for-age z score by 0.12 standard deviations. Thus, a shortfall of rain right before a child has been conceived is expected to have deleterious effects on physical growth, both in the short and the long run. Part of the before-conception-rain effect on stature, which manifests in the short run, seems to be offset as we move from the short run to the long run. This is evident as we compare the magnitude of β_1 in the short- and long-run regression. Though the significance level remains at 5%, the magnitude of β_1 is smaller in the long-run regression compared to the short-run regression. This suggests that it is possible for children to adapt and adjust to early-life shocks during the growth years.

Additionally, we tested whether rainfall shares a nonlinear relationship with height-for-age z score. We augmented the model with quadratic rainfall terms for each of the four seasons being studied and found that none of the quadratic rain terms were significant. Our main result, that is, significance of rainfall fluctuations during the pre-pregnancy period, stayed robust to including quadratic rainfall terms in the model (as shown in columns 3 and 4 in Table 5).

We would expect positive versus negative rainfall shocks to have different effects depending on the duration and the intensity of the shock. For instance, in case of water scarcity, there may be long-lasting effects – with adverse impacts not just on the current agricultural cycle/harvest but on following periods as well. This becomes all the more important in the context of an arid/semi-arid climatic landscape that Pakistan possesses. To address the concern about positive and negative rainfall shocks possibly having differential impacts on child health, we disaggregated each of the four rainfall variables into positive and negative fluctuations and re-estimated specification 7. For each of the four periods being studied, we ran F tests to check the null hypothesis that positive rainfall deviations have the same effect on child height as negative rainfall deviations. On the basis of these F tests, we fail to reject the null for each of the four periods under study.

A closer look at rainfall patterns during the period under study (1994–2001) reveals that while positive fluctuations in rainfall were moderate, there were no sharp negative variations during this period in any of the regions under study. This could in part explain why we do not observe a statistically significant difference between positive and negative shocks for the time period and region of interest.

Can access to irrigation mitigate adverse effects of rainfall shocks?

In order to test whether the effect of rainfall shocks varies by the extent of irrigation facilities, we interact rainfall variables with district-level indicators on the percentage of cultivated area that is irrigated in 1990 and re-estimate specification 7. Results for this augmented specification are shown in Table 6 (column 1 for short run and column 2 for long run). Three main observations can be made from these results: first, that before-conception rainfall and birth season rainfall emerge as significant. Second, the availability of irrigation facilities for agriculture may be a successful strategy for protecting children against the negative short-run consequences of rain shocks. This is evident from the statistically significant and negative coefficient on the interaction term between rainfall and irrigated land ratio (column 1, Table 6). Finally, on average, children are taller in districts with access to irrigation facilities, as shown by the significant and positive coefficient on irrigated land ratio (column 1, Table 6).

Moreover, in districts where irrigation facilities are available, in addition to rainfall shocks, it is also important to account for changes in river water flows because in these areas river water flows play a critical role in determining water availability as well as quality of the harvest during each agricultural season. Keeping this in mind, we look at deviations in river water flows in the Indus River and its western tributaries between fiscal year 94 and fiscal year 2001 (shown in Table 7). As a rule of thumb, we look at deviations in annual river flows for two years. These are (i) for the year, which affected the last harvest before a child was conceived, and (ii) for the subsequent year. In irrigated districts, depending upon a child's month of conception and the prevalent crop calendar, for some children, the two river flow variables represent deviations in water in the year of conception and the year of birth, while for other children they represent fluctuations during the year before conception and the year of conception and birth. For children born in non-irrigated districts, both river water variables take on a value of zero. Specification 7 is augmented with the two standardized river flow variables and re-estimated. The results are presented in column 3 (short run) and column 4 (long run) of Table 6.

The inclusion of the river water variables does not change the pattern of significance of the four rain variables; only before-conception rain is significant, while all other rain variables remain insignificant in both short- and long-run results. Moreover, the inclusion of the river water variables increases the coefficient on before-conception rain from 0.173 and 0.118 in the baseline results (columns 1 and 3, Table 5) to 0.182 and 0.126 (columns 3 and 4, Table 6) for both the short- and long-run regression, respectively. By themselves, none of the river water variables are significant in the short run. In the long run, children born in districts with a higher river flow in the year before conception grow up to be taller on average.

Availability of water is likely to have a lagged effect on agricultural produce, household income, and child nutrition. In our analysis, short run refers to year 2001 – the insignificance of the coefficient on river water flows in the short-run regression may possibly be because for most years before 2001, water was abundant. We observe this in Table 7, which shows annual deviations in river water flows relative to the long-run average. We see that for most of the years under the study period river water flows were in excess of the average implying that there was an abundant supply of water for irrigation and agriculture. However, starting in 2000, year after year annual river water flows were less than the long-run average flow and this trend continued for several years. Since long run refers to 2010 in our analysis, it is possible that water scarcity for irrigation over the course of several years made this a significant parameter in affecting child health in the long-run regression.[3]

[3]Additionally, we ran two diagnostic tests: the first is to ensure that modeling a linear relationship between height-for-age z score and river water flows is correct, and

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Table 6. Interaction effects by irrigated land ratio and river water flows

	(1)	(2)	(3)	(4)
Pre-pregnancy rainfall	0.366***	0.168**	0.182**	0.126**
	(0.127)	(0.0829)	(0.0711)	(0.0559)
Prenatal rainfall	0.0911	−0.0527	0.0289	−0.0407
	(0.0862)	(0.0738)	(0.0564)	(0.0395)
Post-birth first season rain	0.240**	0.109	0.118	0.0501
	(0.0962)	(0.0748)	(0.0825)	(0.0532)
Post-birth second season rain	−0.0282	−0.0441	−0.0131	0.0281
	(0.141)	(0.0649)	(0.0908)	(0.0399)
Pre-pregnancy rainfall*irrigated land ratio	−0.299*	0.114		
	(0.172)	(0.0844)		
Prenatal rainfall*irrigated land ratio	−0.0004	0.0140		
	(0.128)	(0.101)		
Post-birth first season*irrigated land ratio	−0.246	−0.141		
	(0.192)	(0.133)		
Post-birth second season*irrigated land ratio	0.119	−0.0739		
	(0.215)	(0.119)		
Irrigated land ratio (1990)	1.353**	0.105		
	(0.537)	(0.296)		
River water flows (year before birth)			−0.0641	0.239**
			(0.174)	(0.105)
River water flows (birth year)			−0.281	−0.154
			(0.173)	(0.105)
Constant	−0.548	−1.152	0.179	−1.332
	(7.880)	(1.563)	(7.993)	(1.532)
Observations	2,290	1,302	2,290	1,302
R-squared	0.105	0.104	0.100	0.106
Controls	Yes	Yes	Yes	Yes
Province fixed effects	Yes	Yes	Yes	Yes

Notes: *, **, *** denote significance at 10%, 5%, and 1%, respectively. Columns 1 and 2 include irrigated land ratio and its interaction with rainfall variables. Columns 3 and 4 include deviations in river water flows. Columns 1 and 3 present short-run results, while columns 2 and 4 show long-run results. The regressions were estimated with ordinary least squares. Standard errors are shown in parentheses and are clustered at the community level. The dependent variable is height-for-age z score.

Heterogeneous effects of rainfall shocks

In this section, we study whether the effects of rainfall shocks on child's height are sensitive to the characteristics of the child and his/her family. For this purpose, we augment the baseline model (equation (7) with interaction terms between rainfall and the respective variable of interest to gauge whether the effect of rainfall shocks is sensitive to child's age, gender, parental characteristics, socioeconomic status, and when the child was conceived.

Does it matter whether the child belongs to old age cohort at the time of survey?

Evidence from the existing literature suggests that height by age 4 is a good predictor of stature during adulthood. As mentioned earlier, the sample of children under study was between 1 and 6 years of age during the first round of data collection in 2001. This suggests that children in the older cohort (i.e., those between 4 and 6 years) have passed the critical period of early growth and may have had some time to recoup part or all of the negative growth effects of exposure to rain shocks around the time they were conceived and born. To test for this effect, a dummy variable equal to 1 if the child was more than 4 years of age at the time of the

the second is to check whether positive fluctuations (over and above the long-run average) have the same effect on height-for-age z score as negative deviations in river water flows below the long-run average. We found that none of the quadratic river flow terms are significant in the short- or long-run regression, supporting the assumption of a linear relationship between river water flows and height-for-age z score. Moreover, there was no statistical difference between positive and negative river flow terms in the short or the long run.

Table 7. Water flows in the Indus River system (1993–2001)

Year	Kharif	Rabi	Total annual	Deviation
FY94	129.18	28.14	157.31	−0.59
FY95	170.32	34.29	204.61	1.40
FY96	160.05	35.70	195.75	1.02
FY97	169.66	29.32	198.98	1.16
FY98	135.86	39.76	175.62	0.18
FY99	154.18	30.46	184.63	0.56
FY00	132.59	27.30	159.89	−0.49
FY01	106.53	20.44	126.97	−1.87

Notes: This table shows rim station inflows in billion cubic meters. The data has been taken from the Indus River System Authority. Fiscal year runs from July to June – for instance, fiscal year 94 denotes July 1993 to June 1994. Deviation has been calculated by taking the difference between annual flows from the long-run average level (between 1976–77 and 2008–09) and dividing it by the standard deviation for the same time period.

survey in 2001 (0 otherwise) is interacted with each of the four rain variables. The baseline model (equation (7)) is augmented with the "old age cohort" dummy variable as well as the rain*old age cohort interaction terms. Short-run results are shown in column 1 of Table 8, while long-run results are shown in column 1 of Table 9. In the short-run regression (column 1, Table 8), the pre-conception rain variable along with its interaction with "old age cohort" dummy emerges as marginally significant, while all other interaction terms are insignificant. The sign on the pre-conception rain and old age cohort dummy interaction term is opposite relative to the pre-conception rain variable, and the magnitude of the coefficient is only slightly smaller than the coefficient on pre-conception rain. These results may suggest that perhaps older children compensate for the negative growth effects. In the long-run regression (column 1, Table 9), we do not find the effect of rainfall during the pre-conception period to vary by whether the child belonged to the young or the old age cohort during the first round of data collection in 2001. This finding is not surprising, as by 2010, all the children have passed through their crucial growth years, so we find no differential effect of variation in pre-conception rainfall on the height of children between those who belonged to the old and the young cohort in 2001 (column 1, Table 9).

Does it matter whether the season before the child's conception is Kharif instead of Rabi?

So far, we find that rainfall fluctuations in the last season before conception have a significant effect on children's stature in the short run. This effect remains persistent in the long run. A related question, which arises, is that, does the impact of rainfall variation during the last season preceding conception, vary by whether this season is Kharif or Rabi? This question is of interest for two main reasons. The first relates to the Kharif and Rabi cropping pattern prevalent in the country. Two of Pakistan's leading export commodities, that is, cotton and rice, are grown during the Kharif season. Between 1990 and 2000, cotton and rice accounted for 51% and 6% of the country's total exports, on average. During the winter season, wheat is the main Rabi crop in Pakistan and serves as the primary staple food for the people. Since Rabi is associated with the growth of a food crop while Kharif with the cultivation of cash crops, it is possible that the income effect

Table 8. Short-run effects of rainfall shocks by age, timing of birth, and socioeconomic status

Dependent variable: hfa z score	(1)	(2)	(3)
Pre-pregnancy rainfall	0.273***	0.262**	0.188**
	(0.103)	(0.132)	(0.0720)
Prenatal rainfall	0.0879	0.0335	−0.0823
	(0.0999)	(0.0653)	(0.0738)
Post-birth first season rain	0.208	0.150**	0.0393
	(0.183)	(0.0725)	(0.0909)
Post-birth second season rain	−0.0369	0.00674	0.127
	(0.213)	(0.138)	(0.0938)
Old age cohort	0.234		
	(0.266)		
Pre-pregnancy season was Kharif		0.520***	
		(0.137)	
Uncemented house			−0.214
			(0.205)
Pre-pregnancy rainfall*X	−0.213*	−0.188	0.227**
	(0.111)	(0.162)	(0.108)
Prenatal rainfall*X	−0.0456	0.0492	−0.00802
	(0.123)	(0.133)	(0.103)
Post-birth first season rain*X	−0.114	−0.104	0.192
	(0.189)	(0.128)	(0.126)
Post-birth second season rain*X	0.0789	−0.0830	−0.171
	(0.227)	(0.158)	(0.179)
Constant	−0.0469	−0.520	−0.0080
	(7.989)	(7.910)	(7.935)
Observations	2,290	2,290	2,290
R-squared	0.100	0.104	0.101

Notes: *, **, *** denote significance at 10%, 5%, and 1%, respectively. Dependent variable is hfa z score in 2001. In column 1, X = "Old age cohort" which is an indicator variable equal to 1 if the child was 4 years or older at the time of survey in 2001. In column 2, X is an indicator variable equal to 1 if the pre-pregnancy agricultural season before the child was conceived was Kharif. In column 3, X = uncemented house, an indicator variable equal to 1 if the child belongs to an uncemented house and 0 if it is cemented. The regressions were estimated with ordinary least squares. Standard errors are shown in parentheses and are clustered at the community level.

associated with rain-induced fluctuations of agricultural production will be stronger for the Kharif season. The second reason is related with the distribution of rain through the agricultural year. With the exception of Dir, Lakki Marwat, and Mardan, more than 50% of the annual rainfall occurs during the monsoon season spread over June to September (Table 3). Variation in summer rainfall has immediate consequences in terms of affecting agricultural production during the Kharif season. Additionally, in irrigated districts, it also plays an important role in determining water availability in the Indus System's canal irrigation network. This is because in accordance with the Water Apportionment Act, the Indus River System Authority allocates water to each province on a fiscal year basis (running from July to June). Therefore, in irrigated districts, it is reasonable to expect that variation in rain during the summer months will not only impact the production of

Table 9. Long-run effects of rainfall shocks by age, timing of birth, and socioeconomic status

Dependent variable: hfa z score	(1)	(2)	(3)
Pre-pregnancy rainfall	0.183**	0.0221	0.199**
	(0.0802)	(0.0692)	(0.0835)
Prenatal rainfall	−0.0412	−0.0475	−0.0447
	(0.0605)	(0.0620)	(0.0633)
Post-birth first season rain	0.0200	0.0862	0.0361
	(0.0821)	(0.0651)	(0.0788)
Post-birth second season rain	0.0327	0.120	0.0689
	(0.0749)	(0.0781)	(0.0857)
Old age cohort	−0.0110		
	(0.184)		
Kharif season before pregnancy		0.0603	
		(0.0884)	
Uncemented house			0.0118
			(0.104)
Pre-pregnancy rainfall*X	−0.0222	−0.0277	−0.0891
	(0.110)	(0.0949)	(0.103)
Prenatal rainfall*X	−0.00919	0.0145	−0.0127
	(0.0859)	(0.116)	(0.0931)
Post-birth first season*X	0.0425	−0.110	0.00565
	(0.107)	(0.101)	(0.107)
Post-birth second season*X	−0.110	−0.0244	−0.147
	(0.107)	(0.127)	(0.110)
Constant	−1.255	−1.189	−1.206
	(1.558)	(1.634)	(1.604)
Observations	1,302	1,302	1,302
R-squared	0.103	0.104	0.105

Notes: *, **, *** denote significance at 10%, 5%, and 1%, respectively. Dependent variable is hfa z score in 2001. In column 1, X = "Old age cohort" which is an indicator variable equal to 1 if the child was 4 years or older at the time of survey in 2001. In column 2, X is an indicator variable equal to 1 if the pre-pregnancy agricultural season before the child was conceived was Kharif. In column 3, X = uncemented house, an indicator variable equal to 1 if the child belongs to an uncemented house and 0 if it is cemented. The regressions were estimated with ordinary least squares. Standard errors are shown in parentheses and are clustered at the community level.

the Kharif crop but will also have an effect on the subsequent winter crop. In order to test whether the effect of rainfall shocks is sensitive to the type of agricultural season, which prevails before the child is conceived and to explore how the timing of a child's conception affects stature in the future, equation (7) is augmented with a dummy variable equal to 1 (0) if the last season before conception was Kharif (Rabi), as well as with interaction terms between rainfall variables and the Kharif season dummy. These results are shown in column 2, Table 8 (for short run), and column 2, Table 9 (for long run).

The impact of rainfall shocks is not sensitive to the timing of a child's conception, as evident from the insignificance of all interaction terms between rainfall and the pre-conception season dummy in the short-run regression (column 2, Table 8) as well as in the long-run regression (column 2, Table 9). However, the pre-conception season dummy is significant in the short-run regression indicating that, on average, children who were conceived after a Kharif season are taller compared to children conceived after a Rabi season (column 2, Table 8). This positive effect on short-run height dissipates by age 13, which is the average age of children surveyed in 2010, as shown by the insignificant pre-conception season variable (column 2 of Table 9). Similar findings on the presence of significant effects of a child's timing of birth on health have been documented in some existing studies.[30,65]

Does it matter whether the child belongs to a poor household?

Are children from rich households able to compensate for the negative effects of shocks? To test for this, we include interaction terms between rainfall variables on the one hand and condition of the house on the other. In the short run, we find that children living in uncemented houses are more vulnerable to rainfall shocks which occur before they are conceived, compared to children residing in cemented houses; as is evident from the significant and positive coefficient on the interaction term between pre-conception rainfall and condition of house dummy variable (column 3, Table 8). However, this disadvantage disappears by the time children grow up as shown by the insignificant interaction terms in the long-run regression (column 3, Table 9).

Robustness checks

Rain shocks during cultivation and growth period

For a child, adequate nutrition during certain time periods is critical for growth and development. In much the same way, sufficient water during particular phases of the agricultural season will be essential for a good harvest. Broadly, the lifecycle of a crop is likely to go through two main stages: the cultivation and growth phase and the harvest phase. During the cultivation and growth phase, adequate water supply is crucial for ensuring a good quality of the harvest. Higher than normal rainfall is expected to be beneficial while lower than normal rainfall is considered destructive for crop yields during this phase. However, once the crop is ready to be harvested, it is not clear what will be the impact of rain fluctuations on crop yield. For some water-intensive crops such as rice, rain shocks may have no impact on the crop, while for other crops, such as cotton, higher than normal rain shocks may have disastrous effects on the crop. Due to this, it is possible that we are introducing noise in the rainfall variables by measuring deviations over a 6-month period. In an attempt to measure rainfall shocks more precisely, we limit our focus to the cultivation and growth period only. For each agricultural season, we exclude the harvest months (shown in Table 3), and reconstruct the rainfall variables to represent deviations from the normal during the cultivation and growth period only. Results with cultivation and growth rainfall variables are shown in panel A of Table 10 (short run in column 1 and long-run results in column 2). Switching from a 6-month interval to the cultivation and growth period does not alter the basic results, which were observed in Table 5.

Placebo test

We are looking at how a child's stature is impacted by rain fluctuations in agricultural seasons around the time a child is conceived and born. Is this relationship true or merely a spurious correlation driven by some other factors, which are not being accounted for in the model? In order to rule out this possibility, we conduct a placebo test by replacing rainfall in agricultural seasons surrounding children's conception and birth with Rabi and Kharif

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Table 10. Rainfall during crop cultivation and growth period and placebo rainfall

Panel A: Rainfall during cultivation and growth			Panel B: Placebo rain		
Dependent var: hfa z score	(1)	(2)	Dependent var: hfa z score	(1)	(2)
Pre-pregnancy rainfall	0.152*	0.0317	Placebo rain (Rabi 89)	−0.445	0.131
	(0.0833)	(0.0437)		(0.496)	(0.38)
Prenatal rainfall	0.00491	−0.0221	Placebo rain (Kharif 89)	−0.257	0.106
	(0.0529)	(0.0351)		(0.194)	(0.286)
Post-birth first season rain	0.153*	0.0165	Placebo rain (Rabi 90)	−0.172	0.0748
	(0.0810)	(0.0552)		(0.200)	(0.0765)
Post-birth second season rain	0.0310	0.0584	Placebo rain (Kharif 90)	−0.0136	−0.192
	(0.0896)	(0.0495)		(0.264)	(0.22)
Constant	−0.0360	−1.187	Constant	0.130	−1.709
	(7.979)	(1.609)		(9.293)	(1.64)
Observations	2,290	1302	Observations	2290	1302
R-squared	0.097	0.1	R-squared	0.105	0.11

Notes: *, **, *** denote significance at 10%, 5%, and 1%, respectively. In panel A, columns 1 and 2 show results with rainfall shocks during the cultivation and growth period. In panel B, columns 1 and 2 show results with placebo rainfall variables. Columns 1 and 3 present results for the short run, while columns 2 and 4 show results for the long run. The dependent variable is hfa z score. The regressions were estimated with ordinary least squares. Standard errors are shown in parenthesis and are clustered at the community level.

rainfall in 1989 and 1990. Since these variables will capture rainfall for a time when none of the children in the sample were born, we expect that these variables should have no impact on height. The short- and long-run results with the placebo rain variables are shown in Panel B of Table 10 (short-run results in column 1 and long-run results in column 2). The model passes the placebo test successfully, as revealed by the insignificant rain variables in the regression.

Selection bias due to attrition

A caveat of the dataset used in this study is that it has a high rate of attrition. Out of a sample of 2290 children in round 1, information on 988 children is missing for 2010. If there is a systematic pattern in the subsample of children, which was not covered in the 2010 survey, it would bias the sample under study and distort inference.

In order to explore this further, we construct a dummy variable, which takes a value of 1 if the child attrited (i.e., was surveyed in 2001 but not in 2010) and 0 if he (she) was surveyed in both years. We regress this variable on rainfall deviations, individual, household, and community characteristics as well as provincial fixed effect dummies. Almost all the right-hand side variables emerge as insignificant (Table 11), suggesting that OLS parameter estimates do not suffer from selection bias caused due to attrition. Two particular variables, which do emerge as significant in these regressions, are a household's dependency ratio; children from households with a higher dependency ratio are more likely to have participated in both rounds. If attrition was caused due to migration, it may be possible that large families were less likely to move and hence more likely to have participated in both rounds. Results also show that households in Khyber Pakhtunkhwa are less likely to have participated in both rounds. One possibility could be that the law and order conditions deteriorated in this province between 2001 and 2010. During the 9 years between PPHS (2001) and PPHS (2010), terrorist activities and subsequent military operations grew profoundly in Khyber Pakhtunkhwa. This might have had two implications: enumerators may have faced difficulties in carrying out data collection, and many of the missing households may have relocated to other regions because of large-scale internal displacement in Dir district and due to widespread Taliban activities in Lakki Marwat.

Discussion

The objective of this study was to examine the direct reduced-form effect of rainfall fluctuations around the time of conception and birth on the physical growth of children in rural areas of Pakistan. The study used child-level data from various rounds of PPHS and rainfall data from PMD. The model was estimated through OLS while controlling for a range of child, maternal, and household characteristics. This study makes several contributions to the existing literature on weather shocks and child health: it is the first paper on Pakistan that examines the relationship between rainfall fluctuations and child health, it explicitly studies the effect of rainfall fluctuations during the pre-pregnancy period (in addition to gestation and the birth year), it investigates rainfall fluctuations with respect to agricultural seasons in order to take into account their impact on crop production, it examines deviations in river flows (over and above fluctuations in rainfall), and it uses data that has a wide geographical and climatic spread, ensuring representativeness and external validity of the results.

Fluctuations in rainfall during the pre-pregnancy period have the most lasting effects on the stature of children in the short and long run. When rainfall was 1 standard deviation below normal during the agricultural season preceding a mother's pregnancy, her child grew up to be 0.17 standard deviations shorter by 4 years of age, on average. As the child grew older, the adverse impact on height, of pre-pregnancy rainfall, was only partially compensated. By 13 years of age on average, the child continued to be 0.12 standard deviations shorter relative to someone whose pre-conception period was not marked by a similar reduction in

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Table 11. Testing for attrition bias

Dependent variable: child attrited	(1)	(2)
Pre-pregnancy rainfall	0.0098	0.0114
	(0.0106)	(0.0102)
Prenatal rainfall	−0.0048	−0.0039
	(0.0113)	(0.0093)
Post-birth first season rain	−0.0007	0.0035
	(0.0119)	(0.0118)
Post-birth second season rain	−0.0059	−0.0069
	(0.0149)	(0.0130)
District population/health facilities	4.04e-05	4.39e-05
	(5.90e-05)	(6.01e-05)
Age (months)	0.0007	0.0006
	(0.0007)	(0.0007)
Male	0.0241	0.0261
	(0.0197)	(0.0200)
Log (maternal height)	−0.0790	−0.0620
	(0.0771)	(0.0811)
Maternal education	0.0174	0.0165
	(0.0974)	(0.0975)
Uncemented house	−0.0501	0.0598
	(0.0372)	(0.0366)
HH owns land	0.0495	0.031
	(0.0376)	(0.0920)
HH dependency ratio	−0.0801***	−0.0826***
	(0.0200)	(0.0121)
Sind	0.0206	0.0186
	(0.0553)	(0.0275)
Khyber Pakhtunkhwa	0.156**	0.159***
	(0.0691)	(0.0272)
Baluchistan	−0.0706	0.0620
	(0.0752)	(0.0811)
Constant	−0.312	
	(0.407)	
Observations	2290	2290
R-squared	0.061	

Notes: *, **, *** denote significance at 10%, 5%, and 1%, respectively. The dependent variable is a dummy equal to 1 if the child attrited (i.e., was surveyed in 2001 but not surveyed in 2010) and equal to 0 if the child was surveyed in both 2001 and 2010. Column 1 shows ordinary least squares estimates, while column 2 shows marginal effects calculated after a probit estimation.

rainfall. The average effect of fluctuations in pre-pregnancy rainfall on the height of children was smaller in districts that had access to irrigation facilities.

The economic channel, working through crop production, income, and prices, seems to be the most likely mechanism that explains the effect of fluctuations in pre-pregnancy rainfall on the stature of children in rural Pakistan. Since the pre-pregnancy rainfall shock took place before the child was conceived, it is unlikely that it affected height through changes in the prevalent disease environment. This argument can also be supported by the significant heterogeneous effect of pre-pregnancy rainfall on the extent of irrigation. Irrigation reduces dependence on rain-fed agriculture. If the economic channel was not the main mechanism underlying the relationship between pre-pregnancy rainfall and child height, access to irrigation would not have emerged as an effective strategy for offsetting the negative effects of pre-pregnancy rainfall shocks. Existing literature has shown that in India, agricultural production is the main channel through which weather shocks affect child mortality rates.[24] Like India, Pakistan is a water-scarce country and falls in the same geographic and climatic belt as India. Thus, it may be reasonable to postulate that, in Pakistan, weather shocks affect human capital outcomes through the same channel as in India.

We do not find a significant effect of rainfall fluctuations on child height during gestation. This may be because in spite of the negative rainfall shock, the family did not compromise on the nutritional requirements of the mother during pregnancy. In fact, existing literature provides evidence of compensatory behavior by mothers in the face of weather shocks in the form of prolonging the breastfeeding duration to minimize their child's nutritional deficit during economic hardship.[31] The lack of significance of rainfall fluctuations during gestation may also be due to the expected time lag between rainfall fluctuations and receipt of income, which will take place only after the crop has been harvested. Therefore, a family's income level and ability to access food, medicines, or healthcare services will most likely depend upon rainfall during the agricultural season before the mother starts expecting her child. As discussed earlier, we do find significant lasting effects of pre-pregnancy rainfall fluctuations on child height.

These findings have public policy implications for promoting the process of human capital accumulation in Pakistan – a country that faces a very high stunting rate and is increasingly vulnerable to climate change. Our results show the importance of timing and the need to have a more specific targeting criterion while designing an intervention. Since the time before pregnancy emerges as the most critical period, interventions that specifically target women of childbearing age as well as expectant mothers may be more effective than interventions that provide a general cover to all households below a certain minimum threshold of income. For example, a government social protection scheme can provide insurance directly to a household with a woman of childbearing age or an expectant mother either through cash transfers or food supplements in order to compensate for adverse rainfall conditions over the agricultural season before the mother started expecting her child. They also call for a greater emphasis on promoting access to irrigation in order to reduce the vulnerability of agricultural production on the magnitude and timing of rainfall. This will not only have immediate benefits like improvement in child and maternal health indicators but may also facilitate the process of achieving higher levels of educational attainment, labor productivity and economic growth in the long run.

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