Rainfall and Birth Outcome: Evidence from Kyrgyzstan

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Kien Le & My Nguyen[1]

Abstract

This study evaluates the extent to which fetal exposure to rainfall shocks influences birth weight outcomes in Kyrgyzstan, one of the most climate change vulnerable countries in Central Asia. We detect detrimental impacts of rainfall shocks during the prenatal period on birth weight. Specifically, a 0.1 log point increase in in-utero rainfall relative to the local norm reduces birth weight by 23.4 grams (or 0.84%). Furthermore, children born to poor mothers and mothers residing in rural areas are disproportionately affected. The adverse impacts of prenatal exposure to rainfall shocks could be partly attributed to prenatal care, diseases, and nutrient intakes. Besides, the impacts tend to concentrate in the first trimester of pregnancy.

Keywords: Birth Weight, Rainfall, Climate Change, Kyrgyzstan

Declarations of interest: None

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1 Introduction

Being regarded as one of the major global challenges, climate change has caused changing precipitation patterns, with extreme weather events becoming more frequent and intense (Alexander, 2016). For example, precipitation patterns such as the total annual rainfall and the maximum number of consecutive dry days have significantly changed by ±10mm and ±1.6 days per year respectively. Rainfall intensity such as the fraction of annual total rainfall in very wet days and the amount of rainfall per wet day has increased by 20% and 0.4mm respectively. The World Health Organization (WHO) projects that climate change would lead to 250,000 additional deaths per year between 2030 and 2050 (WHO, 2018). The cost climate change can impose on human health is insurmountable, estimated to be 2-4 billion USD per year by 2030 (WHO, 2018). As one aspect of climate change, rainfall is expected to immensely affect human health, with young children being particularly vulnerable because their underdeveloped immune systems expose them to a higher risk of being inflicted and succumbing to complications (Lawler, 2011).

This paper investigates the extent to which prenatal exposure to rainfall shocks influences infant health measured by birth weight in the context of Kyrgyzstan. We are particularly interested in this country because of several reasons. First, the country has experienced rapid change in rainfall pattern highlighted by an increase of 6.9mm per decade from 1961 to 2016 and an expected additional 19.2 - 31.2mm by 2040 – 2059 (Harris, 2020; World Bank, 2021). Second, the adaptive capacity is very low in many areas of the economy due to its large rural population, the prevalence of small-scale family-based farms, significant shortages of medical supplies and healthcare personnel. Third, the mountainous terrain of the country further amplifies the impacts of excessive rainfall by raising the risks of floods, landslides, and mudslides. Fourth, under-nutrition is currently a critical public health problem where low birth weight and vitamin deficiencies are major barriers to the country in achieving its Millennium Development Goals.

Our study utilizes the Kyrgyzstan Demographic and Health Survey to obtain information on almost 4,000 birth cases from 2007 to 2012. We also obtain records of monthly rainfall from land-based stations across the country. We find that a 0.1 log point increase in in-utero rainfall relative to the local norm decreases the weight at birth of Kyrgyzstani children by 23.4 grams (or 0.84%). Furthermore, those born to poor mothers and mothers residing in rural areas are disproportionately affected. The adverse impacts of prenatal exposure to rainfall shocks could be partly attributed to prenatal care, diseases, and nutrient intakes. Besides, the impacts seem to concentrate in the first trimester of pregnancy.

The findings call for effective measures from Kyrgyzstani policymakers to minimize the health cost of rainfall shocks. Implementing disease control programs and providing adequate nutrient intake as well as prenatal care for pregnant women can help protect infant health in areas prone to rainfall shocks. The vulnerable group of the population, i.e., children born to poor mothers and mothers residing in rural areas, should receive extra attention since they tend to bear the most serious impacts of rainfall shocks.

2 Literature Review

Our quantitative analysis is guided by the theory of Corman et al. (1987) where infant health is modeled as an argument of the utility maximization problem during the prenatal period faced by the parents. The solution to the utility maximization problem is infant health expressed as a function of maternal health and health inputs during the prenatal period (e.g. nutrients, medical services, etc.). Rainfall shocks have been documented to affect both maternal health and health inputs during pregnancy. For example, rainfall shocks have been documented to make various diseases more prevalent, engender psychological distress, and induce violence against women (Umbers et al. 2011; Levy et al. 2016; WHO, 2018; Chemin et al. 2013; Vanden Eynde 2018). Besides, rainfall shocks have also been shown to worsen not only household ability to afford medical services, vaccines, and nutrients, but also the availability of healthcare supplies (Shah and Steinberg, 2017; Amare et al. 2018; Baten et al. 2020; Chambers et al. 2020).

Empirically, our study is directly related to the strand of literature exploring the link between in-utero climatic shocks and infant health. Closest to ours is the work of Chacón-Montalván et al. (2021) showing that prenatal exposure to excessive rainfall can lower the birth weight of Brazilian infants by 183 grams. In addition, within the context of the U.S, Currie and Rossin-Slater (2013) show that excessive rainfall during the pregnancy period is associated with unfavorable birth outcomes such as lower birth weight, abnormal conditions, and birth complications. Our work is also related to studies focusing on the impacts of temperature shocks. For example, an additional hot day is associated with a 5.5-10.2 grams reduction in birth weight of American children (Deschênes et al., 2009), a temperature shock of 1.5 standard deviations above the local norm reduces the birth weight of children in Andean states by 43 grams (Molina and Saldarriaga, 2017), a one standard deviation increase in temperature relative to the local norm also decreases the Vietnamese child's weight at birth by 67 grams (Le and Nguyen, 2021a).[2]

This study contributes to the literature that explores the relationship between in-utero shocks and infant health. We connect the epidemiology literature with climatic issues, thus expanding our current knowledge of the climate-human health relationship. Specifically, by focusing on the

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[2] Our study can also be related to studies on the impacts of in-utero rainfall on nutritional statuses several years after birth (Dimitrova and Bora, 2020; Le and Nguyen, 2021b), and studies on the impacts of other events on the birth weight of infants, such as political violence, nutrition deprivation, and power outage (Le and Nguyen, 2020; Almond and Mazumder, 2011; Burlando, 2014).

context of Kyrgyzstan, we provide additional evidence on the adverse effects of rainfall shocks on birth outcomes, thus confirming the results found in prior studies for other contexts (Currie and Rossin-Slater, 2013; Chacón-Montalván et al., 2021). The study further contributes to the inconclusive literature on the relative importance of intrauterine exposure timing by providing evidence for the importance of the first trimester. Finally, as Kyrgyzstan is one of the most climate change vulnerable countries in Central Asia (UNICEF, 2017), our estimated cost of rainfall shocks to infant health could be particularly useful to Kyrgyzstan policymakers.

3 Study Area and Data

3.1 Study Area

Kyrgyzstan is a land-locked country with a population of around 6.5 million as of 2020. The country is classified as a lower-middle-income economy with almost 70% of the population lives in rural areas and nearly 25% of the population lives below the poverty line. The agricultural sector here is not efficient due to the widespread of small-scale family-based farms and land degradation. Consequently, Kyrgyzstan faces moderate to severe food insecurity affecting almost 24% of its population (World Food Program, 2020). Furthermore, the country's average elevation is 2,750 meters above sea level making it highly susceptible to natural hazards such as landslides, mudslides, and avalanches.

The healthcare system in Kyrgyzstan is constrained severely by antiquated infrastructure without central heating, hot water, and sewage systems. Moreover, there are significant shortages of medical supplies and healthcare personnel due to the lack of funds and low pay. Undernutrition is a critical public health problem where low birth weight and vitamin deficiencies are major barriers to the country in achieving its Millennium Development Goals. Such a problem is estimated to cost the country around $32 million in lost productivity annually due to reduced cognitive and physical development (UNCIEF, 2011).

Climate change has raised the frequency and variability of extreme rainfall events, immensely affecting almost all aspects of the country. Historically, climate observations show increases in the annual total rainfall trend of 6.9mm per decade for the period of 1961 – 2016 (Harris, 2020). Moreover, it is projected that the country would also experience a 1.6 - 2.6mm increase in monthly precipitation by 2040 – 2059, thus raising the risks of floods, landslides, and mudslides, especially in the mountainous regions (World Bank, 2021). Because of such economic, geographic, and climatic factors coupled with the lack of capacity to adapt, UNICEF rates the country as one of the most climate change vulnerable countries in Central Asia (UNICEF, 2017).

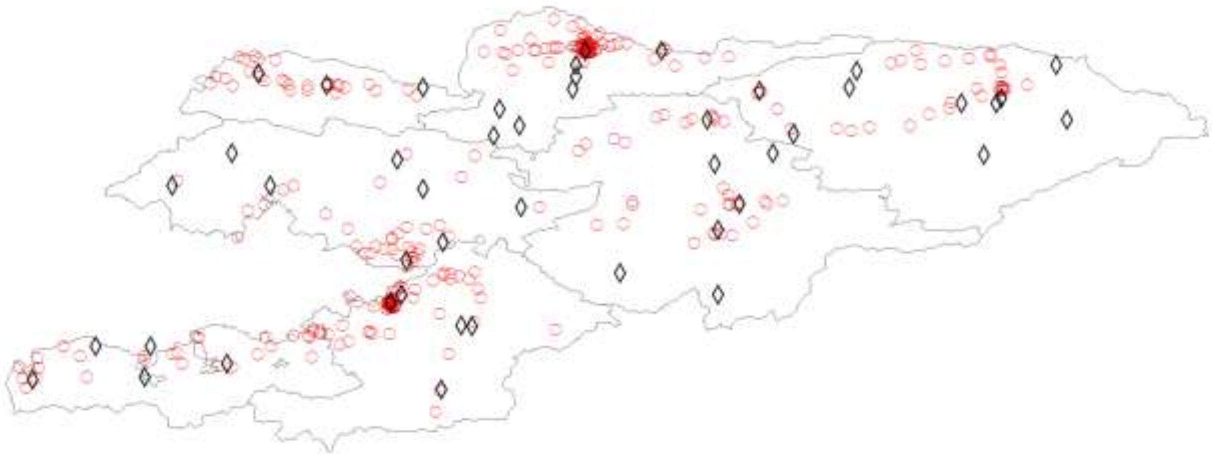
3.2 Data

Data on birth cases – We draw from the Demographic and Health Survey (DHS) for the data on birth outcomes of Kyrgyzstani children. The Kyrgyzstan DHS data is part of the DHS program that is responsible for the collection and dissemination of nationally representative data on health and population in developing countries. The DHS especially focuses on women of reproductive ages (15-49) and their birth history, which allows us to have the information on birth outcomes of their children. The drawback of the Kyrgyzstan DHS is that the only birth outcome available is the child's weight at birth without the gestational age. The Kyrgyzstan DHS's sample is representative at the national level and separately for urban and rural areas. The sample was selected in two stages based on a representative probability method. In the first stage, over 300 clusters were selected from a complete list of enumeration areas employed in the 2009 Population and Housing Census. In the second stage, households in each of the selected clusters were then randomly selected for participation in the survey.

To construct our estimation sample, we place two restrictions on the data. First, we only utilize the DHS waves in which birth weight information of children is available. Second, we only use the DHS waves accompanied with the Global Positioning System (DHS-GPS) because households in the DHS-GPS are geo-referenced. Specifically, the residential cluster into which the child's household falls (the lowest geographic level) can be identified with a pair of latitude and longitude. Such detailed spatial information allows us to extract the rainfall record of each residential cluster so that we can measure the extent to which the child was prenatally exposed to rainfall. With these two restrictions, we end up using the Wave 6 of the Kyrgyzstan DHS-GPS data (corresponding to the year 2012).

Data on rainfall – Our rainfall data are retrieved from the Global Historical Climatology Network-monthly (GHCNm). The GHCNm provides monthly rainfall from land-based stations across Kyrgyzstan between 2000 and 2015. We assign rainfall information to each residential cluster based on the historical records of its closest rainfall stations. In Figure 1, the spatial distribution of rainfall stations and residential clusters are presented in black diamonds and red circles, respectively. It is worth noting that some of the stations have missing rainfall data for some months. Therefore, we substitute these missing values with rainfall estimates from the Climatic Research Unit Time Series (provided by the United Kingdom's National Center for Atmospheric Science at the University of East Anglia's Climatic Research Unit). The rainfall estimates from this dataset are computed for micro spatial units (i.e. 0.5°×0.5° cells) according to the distance-weight average of the nearby stations. Thus, missing data from one station are substituted with distance-weighted-average values from several nearby stations.

Figure 1: Distribution of Rainfall Stations across Kyrgyzstan



Note: Rainfall stations are illustrated by black diamonds. Residential clusters are in red circles.

Following the literature, we construct our rainfall measure as the deviation of rainfall the child was prenatally exposed to from the long-run local average of rainfall in the child's residential cluster. Specifically, our rainfall measure is adapted from Maccini and Yang (2009) as follows,

$$Log\ Deviation\ of\ Rainfall = LogTR_c^{9M} - LogLRAR_C^{2000-2015}$$

where our main explanatory variable is Log Deviation of Rainfall, measuring the rainfall shocks the child was exposed to during the intrauterine period. $LogTR_c^{9M}$ represents the log of total rainfall during the nine months in utero in the child's residential cluster. $LogLRAR_C^{2000-2015}$ stands for the log of the long-run local average of rainfall in the child's cluster during the same period of the year where the long run refers to the period of 2000-2015. For example, let us consider a child in utero between October 2004 and June 2005. The measure of rainfall shock the child was prenatally exposed to is the difference between the log of total rainfall between October 2004 and June 2005 in the child's residential cluster and the log of the cluster's long-run (2000-2015) average rainfall between October and June.

Summary Statistics – Our final estimation sample consists of 3,962 Kyrgyzstan children. Descriptive statistics of dependent and independent variables are displayed in Panels A and B of Table 1, respectively. As shown in Panel A, the average birth weight and log birth weight of Kyrgyzstani children are 3,255 kilograms and 1.167 respectively.

Table 1: Summary Statistics

	Mean (1)	SD (2)	Obs. (3)
Panel A: Dependent Variables			
Birth Weight in Kilogram	3.255	0.500	3,962
Log Birth Weight	1.167	0.166	3,962
Panel B: Independent Variables			
Log Deviation of Rainfall	-0.024	0.199	3,962
Deviation of Temperature	0.253	0.583	3,962
Male Child	0.512	0.500	3,962
Child's Birth Order	2.435	1.408	3,962
Singleton Birth	0.984	0.126	3,962
Mother's Age at Birth	26.91	5.804	3,962
Mother's Education	12.21	2.516	3,962
Mother's Weight	61.57	31.78	3,962
Male Household Head	0.828	0.377	3,962
Household Head's Education	11.75	2.495	3,962
Number of Children	2.644	1.322	3,962
Household Size	6.228	2.051	3,962
Household Wealth Index	2.804	1.338	3,962
Rural Areas	0.745	0.436	3,962

Note: Household Wealth Index includes 5 wealth quintiles ranging from lowest to highest. These quintiles are calculated based on household's ownership of selected assets. Poor households (47%) and non-poor households (53%) are those in the bottom two and upper three quintiles respectively.

As shown in Panel B, our main explanatory variable, the Log Deviation of Rainfall, takes the mean value of -0.024. We also have temperature as an independent variable, which is calculated analogously to rainfall but without taking log. The deviation of temperature from the local long-run average has a mean value of 0.253 degrees Celsius. Around 51% of the children are boys. The average birth order is 2.4. The majority (98%) of births are singleton births. The average maternal age at birth is approximately 27. On average, mothers complete around 12 years of education and weigh 61.5 kilograms. Household size takes an average of 6.2 members with around 2.6 members are children. Roughly 75% and 83% of households reside in the rural areas and are headed by a male household head, respectively. The mean value of the household wealth index is 2.8.

4 Empirical Methodology

In investigating the relationship between prenatal exposure to rainfall shocks and birth weight outcomes, we employ the following regression,

$$Y_{ijym} = \beta_0 + \beta_1 LDR_{jym} + \lambda_j + \gamma_y + \delta_m + X'_{ijym}\Omega + \epsilon_{ijym}$$

where the set of subscripts *{i, j, y, m}* stands for child i (i.e. birth case i), mother j, birth year y, and birth month m, respectively. The variable Y_{ijym} is our outcomes of interest, including child's birth weight in normal and log forms. Our main explanatory variable is LDR_{jym} which is the measure of rainfall shocks the child was prenatally exposed to. This variable is calculated as the difference between the log of total rainfall during the in-utero period in the child's residential cluster and the log of the cluster's long-run (2000-2015) average rainfall within the same time of the year.

Besides, we also control for a vector of mother and child characteristics X'_{ijym}, such as (i) mother's age at birth, mother's age at birth squared, years of education, weight, household head gender, household head's years of education, number of children in the household, household size, whether the household lives in rural areas, as well as wealth index fixed effects, and (ii) child's gender, birth order, an indicator for singleton birth, and the deviation of temperature during the prenatal period. The error term is captured by ϵ_{ijym}. Standard errors throughout our analysis are clustered at the residential cluster level.

To identify the causal relationship between rainfall shocks and birth weight, the model relies on the inclusion of the set $\{\lambda_j, \gamma_y, \delta_m\}$ that stands for mother, birth year, and birth month fixed effects, respectively. First, the mother fixed effects (λ_j) capture all observed and unobserved attributes of mother j that remain constant across births, thus controlling for any time-invariant characteristics of the mother (e.g. selection into conception months and unobserved heterogeneity in family endowments). Second, temporal fixed effects (γ_y, δ_m) further control for changes in time-variant characteristics affecting birth outcomes across months and years (e.g. season of birth, changes in living standards and healthcare quality over time).

The coefficient of interest is β_1, which captures the impacts of prenatal exposure to rainfall shocks on birth weight outcomes. Within this empirical setup, we exploit both the variations across and within mothers in the rainfall deviation relative to the local long-run average rainfall to identify the impacts of rainfall shocks. Thus, the underlying assumption is that the deviations of rainfall from the location-specific norms are random events across and within mothers. As a result, the rainfall deviations to which the child was prenatally exposed are also random. This assumption is justified in prior studies which also explore the health impacts of rainfall (Skoufias and Vinha, 2012; Dimitrova and Bora, 2020).

5 Results

5.1 Main Results

The estimated impacts of in-utero exposure to rainfall shocks on birth weight are presented in Table 2. Each column is a separate regression and the column heading indicates the outcome variable. The outcome variables are birth weight in kilogram in Columns 1 to 3 and the log of birth weight in Columns 4 to 6. In the table, Columns 1 and 4 display the estimates from our most parsimonious specification where we only control for the main explanatory variable, LDR_{jym}, which is the measure of rainfall shocks the child was prenatally exposed to. In Columns 2 and 5, we further control for mother and child characteristics as well as the residential cluster, birth year, and birth month fixed effects. Finally, Columns 3 and 6 represent our most extensive specification with the inclusion of mother fixed effects.

According to the estimates from our most parsimonious specification (Columns 1 and 4), a 0.1 log point increase in rainfall relative to the location-specific mean is associated with an approximately 8.2 gram reduction in birth weight (Column 1) or a 0.28% decline in birth weight (Column 4). However, the estimate from the most parsimonious specification only reflects the correlation between rainfall shocks and birth weight as important factors that could jointly affect the main explanatory and outcome variables are not accounted for. Therefore, we proceed to include an exhaustive set of mother and child characteristics as well as the residential cluster, birth year, and birth month fixed effects in Columns 2 and 5. The estimating results suggest that a 0.1 log point increase in rainfall relative to the location-specific mean leads to a 19.9 gram reduction in birth weight (Column 2) or a 0.74% decline in birth weight (Column 5).

Finally, according to our most extensive specification in Columns 3 and 6 where we further account for all observed and unobserved time-invariant characteristics of the mothers, there exists statistically significant evidence that being prenatally exposed to rainfall shocks adversely affects child's weight at birth. Specifically, a 0.1 log point increase in rainfall relative to the location-specific mean is associated with an approximately 23.4 gram reduction in birth weight (Column 3) or a 0.84% decline in birth weight (Column 6). These estimates highlight the detrimental impacts of rainfall shocks on early human capital formation.

Table 2: Rainfall and Birth Weight - Main Results

	Y = Birth Weight in Kilogram			Y = Log Birth Weight		
	(1)	(2)	(3)	(4)	(5)	(6)
Log Deviation of Rainfall	-0.082**	-0.199**	-0.234***	-0.028**	-0.074**	-0.084***
	(0.040)	(0.097)	(0.091)	(0.013)	(0.032)	(0.031)
Deviation of Temperature		0.007	0.019		-0.000	0.003
		(0.028)	(0.029)		(0.009)	(0.010)
Male Child		0.107***	0.132***		0.033***	0.040***
		(0.022)	(0.022)		(0.007)	(0.007)
Child's Birth Order		0.036	0.059		0.009	0.018
		(0.027)	(0.038)		(0.009)	(0.013)
Singleton Birth		0.845***	0.798***		0.319***	0.301***
		(0.071)	(0.099)		(0.023)	(0.041)
Mother's Age at Birth		0.000	0.037		0.000	0.010
		(0.004)	(0.048)		(0.001)	(0.015)
Mother's Education		0.012**			0.004**	
		(0.006)			(0.002)	
Mother's Weight		0.010***			0.003***	
		(0.001)			(0.000)	
Male Household Head		0.031			0.007	
		(0.034)			(0.011)	
Household Head's Education		0.007			0.003	
		(0.006)			(0.002)	
Number of Children		0.002			0.003	
		(0.028)			(0.009)	
Household Size		-0.009			-0.002	
		(0.007)			(0.002)	
Observations	3,962	3,956	1,954	3,962	3,956	1,954
Mother Characteristics	.	X	X	.	X	X
Child Characteristics	.	X	X	.	X	X
Fixed Effects - Cluster	.	X	X	.	X	X
Fixed Effects - Mother	.	.	X	.	.	X

Note: *p < 0.1, **p < 0.05, ***p < 0.01. Robust standard errors are clustered at the residential cluster level. Each column represents the coefficients in a separate regression. The column headings indicate dependent variables. Mother Characteristics include mother's age at birth, mother's age at birth squared, years of education, weight, household head gender, household head's years of education, number of children in the household, household size, whether the household lives in rural areas, as well as wealth index fixed effects. Child Characteristics include child's gender, birth order, an indicator for singleton birth, and the deviation of temperature during the prenatal period. Fixed Effects - Cluster include birth month, birth year, and residential cluster fixed effects. Fixed Effects - Mother include birth month, birth year, and mother fixed effects.

5.2 Heterogeneity

Next, we proceed to explore the heterogeneous effects of in-utero rainfall by mother's wealth and place of residence. The estimating results are displayed in Table 3. In each panel, each column represents a separate regression and the column heading indicates the outcome variable. The panel name signifies the dimension of heterogeneity. All estimates come from the most extensive specification (similar to Columns 3 and 6 in Table 2).

First, we want to examine if children born to poor and nonpoor mothers are differentially affected by rainfall. Poor mothers are defined as those coming from households with the wealth index lying in the bottom and the next bottom quintiles of the within-country wealth distribution. Likewise, nonpoor mothers are those coming from households with the wealth index lying in the upper three quintiles. As shown in Panels A and B, children born to poor mothers tend to be disproportionately affected. Specifically, a 0.1 log point increase in rainfall during the in-utero period decreases the weight at birth of children born to poor mothers by 43.2 grams (or 1.6%). However, the impacts are much smaller in magnitude for children born to nonpoor mothers and the estimates are statistically insignificant.

Exploring the impacts of in-utero rainfall shocks along the line of mother's place of residence in Panels C and D, we find that children born to rural mothers tend to be affected more seriously. A 0.1 log point increase in rainfall relative to the location-specific norms during the in-utero period is associated with a 30.1 gram (or 1.1%) reduction in birth weight among children born to rural mothers (Panel C). For children born to urban mothers, the estimated impacts are statistically indistinguishable from zero (Panel D).

Taken together, we find that the adverse impacts of prenatal exposure to rainfall shocks on birth weight tend to fall disproportionately on children of disadvantaged backgrounds, i.e., those born to poor mothers and those born to mothers residing in rural areas.

Table 3: Rainfall and Birth Weight - Heterogeneity Analysis

	Birth Weight in Kilogram (1)	Log Birth Weight (2)
Panel A: Poor Mothers		
Log Deviation of Rainfall	-0.432***	-0.155***
	(0.146)	(0.052)
Observations	911	911
Panel B: Non-Poor Mothers		
Log Deviation of Rainfall	-0.120	-0.044
	(0.120)	(0.039)
Observations	1,043	1,043
Panel C: Rural Mothers		
Log Deviation of Rainfall	-0.301***	-0.110***
	(0.103)	(0.035)
Observations	1,519	1,519
Panel D: Urban Mothers		
Log Deviation of Rainfall	0.062	0.023
	(0.208)	(0.068)
Observations	435	435
Mother Characteristics	X	X
Child Characteristics	X	X
All Fixed Effects	X	X

Note: *p < 0.1, **p < 0.05, ***p < 0.01. Robust standard errors are clustered at the residential cluster level. Each column represents the coefficients in a separate regression. The column headings indicate dependent variables. Mother Characteristics include mother's age at birth, mother's age at birth squared, years of education, weight, household head gender, household head's years of education, number of children in the household, household size, whether the household lives in rural areas, as well as wealth index fixed effects. Child Characteristics include child's gender, birth order, an indicator for singleton birth, and the deviation of temperature during the prenatal period. All Fixed Effects include birth month, birth year, and mother fixed effects.

5.3 Mechanism Analysis

Based on the conceptual framework (Section 2), the potential channels through which rainfall shocks affect child's weight at birth are those related to the areas of maternal health and utilization of health inputs. In this section, we proceed to conduct a mediation analysis on some of these channels available in the data. The estimating results are provided in Tables 4 and 5. In these tables, Column 1 reports baseline estimates similar to Columns 3 and 6 of Table 2. Then, from Columns 2 to 4, we gradually introduce mediating variables to the baseline regression. These mediating variables transmit the effect of rainfall shocks on birth weight, and the mediated effect can be estimated by taking the difference in the coefficients on rainfall shocks.

Our first mediating variable is Prenatal Care, which is a zero-one indicator taking a value of one if the woman had prenatal visits at health facilities (i.e. places where services are provided by doctors, nurses/midwives, obstetricians/gynecologists, or other trained professionals). Being taken care of by professionals at health facilities is critical for ensuring maternal health and receiving health inputs. Insufficient prenatal care might compromise the health of the fetus, thus devastating to newborn's weight (Makate and Makate, 2017; Swartz et al., 2017). As shown in Column 2 of Table 4, infants born to mothers who received prenatal care during pregnancy weigh 73 grams more than those born to mothers who did not. More importantly, the coefficient on rainfall shocks decreases from 0.234 to 0.218 suggesting that 6.8% of the impact of rainfall shocks on birth weight works through the channel of prenatal care during pregnancy. The mediated effect is around 6% of the main effect when using the log of birth weight as the outcome (Column 2, Table 5).

The second mediating variable is Intestinal Diseases, which is a zero-one indicator taking a value of one if the woman was infected by bacteria, viruses, or parasites during pregnancy. As rainfall shocks have been documented to make diseases more prevalent (Umbers et al.2011; Levy et al. 2016; WHO, 2018), it is expected that pregnant women experiencing rainfall shocks are more likely to be infected, thus affecting fetuses' development. Evident from Column 3 of Table 4, infants born to mothers who had intestinal diseases during pregnancy weigh 108 grams less than those born to mothers who did not. The coefficient on rainfall shocks further decreases from 0.218 to 0.211 suggesting that an additional 3% of the impact of rainfall shocks on birth weight works through the channel of intestinal diseases during pregnancy. The mediated effect is around 2.4% of the main effect when using the log of birth weight as the outcome (Column 3, Table 5).

Table 4: Rainfall and Birth Weight - Mechanism Analysis

	Y = Birth Weight in Kilogram			
	(1)	(2)	(3)	(4)
Log Deviation of Rainfall	-0.234***	-0.218**	-0.211**	-0.204**
	(0.091)	(0.091)	(0.091)	(0.091)
Prenatal Care		0.073**	0.106***	0.104**
		(0.035)	(0.041)	(0.041)
Intestinal Diseases			-0.108*	-0.117*
			(0.067)	(0.068)
Nutrients				0.045*
				(0.026)
Observations	1,954	1,954	1,954	1,954
Mother Characteristics	X	X	X	X
Child Characteristics	X	X	X	X
All Fixed Effects	X	X	X	X

Note: *p < 0.1, **p < 0.05, ***p < 0.01. Robust standard errors are clustered at the residential cluster level. Each column represents the coefficients in a separate regression. The column headings indicate dependent variables. Mother Characteristics include mother's age at birth, mother's age at birth squared, years of education, weight, household head gender, household head's years of education, number of children in the household, household size, whether the household lives in rural areas, as well as wealth index fixed effects. Child Characteristics include child's gender, birth order, an indicator for singleton birth, and the deviation of temperature during the prenatal period. All Fixed Effects include birth month, birth year, and mother fixed effects.

Table 5: Rainfall and Log Birth Weight - Mechanism Analysis

	Y = Log Birth Weight			
	(1)	(2)	(3)	(4)
Log Deviation of Rainfall	-0.084***	-0.079***	-0.077**	-0.074**
	(0.031)	(0.031)	(0.031)	(0.031)
Prenatal Care		0.025**	0.034**	0.034**
		(0.012)	(0.014)	(0.014)
Intestinal Diseases			-0.040*	-0.044**
			(0.022)	(0.022)
Nutrients				0.016*
				(0.009)
Observations	1,954	1,954	1,954	1,954
Mother Characteristics	X	X	X	X
Child Characteristics	X	X	X	X
All Fixed Effects	X	X	X	X

Note: *p < 0.1, **p < 0.05, ***p < 0.01. Robust standard errors are clustered at the residential cluster level. Each column represents the coefficients in a separate regression. The column headings indicate dependent variables. Mother Characteristics include mother's age at birth, mother's age at birth squared, years of education, weight, household head gender, household head's years of education, number of children in the household, household size, whether the household lives in rural areas, as well as wealth index fixed effects. Child Characteristics include child's gender, birth order, an indicator for singleton birth, and the deviation of temperature during the prenatal period. All Fixed Effects include birth month, birth year, and mother fixed effects.

Our third mediating variable is Nutrients, which is a zero-one indicator taking a value of one if the woman received nutrients important to the fetus's development, such as iron, folate, or other vitamins. Since rainfall shocks can reduce household accessibility to such nutrients, we also expect that pregnant women experiencing rainfall shocks are less likely to receive nutrients, thus ultimately affecting birth outcomes. As reported in Column 4 of Table 4, infants born to mothers who received nutrients during pregnancy weigh 45 grams more than those born to mothers who did not. The coefficient on rainfall shocks further decreases from 0.211 to 0.204 suggesting that another 3% of the impact of rainfall shocks on birth weight works through the channel of nutrients during pregnancy. The mediated effect is around 3.6% of the main effect when using the log of birth weight as the outcome (Column 4, Table 5).

Collectively, our mediation analysis provides evidence that the adverse impacts of rainfall shocks on birth weight could be attributed to prenatal care, diseases, and nutrient intakes. The accumulated effects of these three channels are 12.8% and 12% of the impacts of rainfall shocks on birth weight and the log of birth weight, respectively.

5.4 Trimester Analysis

While there is a consensus in the literature on the impacts of in-utero exposure to negative shocks, the relative importance of exposure timing is still a subject of debate. Particularly, whereas first-trimester exposure to negative shocks is documented to decrease birth weight (Burlando, 2014; Molina and Saldarriaga, 2017; Le and Nguyen, 2020), there is evidence that second-trimester exposure can be devastating to newborns' health (Field and Diego, 2008; Guendelman et al., 2008;

Almond and Mazumder, 2011). Nevertheless, there are studies highlighting the harmful effects of adverse shocks in the third trimester (Currie et al., 2009; Deschênes et al., 2009).

In this section, we proceed to examine exposure at which trimester has the largest impact on birth weight. To do so, we replace the single Log Deviation of Rainfall variable with three variables that indicate the deviation of rainfall from the location-specific norms during each of the trimesters, namely, 1st Trimester Log Deviation of Rainfall, 2nd Trimester Deviation of Rainfall, and 3rd Trimester Deviation of Rainfall. These variables are constructed in an analogous manner to the main explanatory variable Log Deviation of Rainfall (Section 3). The estimating results are reported in Table 6.

Table 6: Rainfall and Birth Weight - Trimester Analysis

	Birth Weight in Kilogram (1)	Log Birth Weight (2)
1st Trimester Log	-0.079*	-0.028**
Deviation of Rainfall	(0.042)	(0.014)
2nd Trimester Log	-0.031	-0.012
Deviation of Rainfall	(0.040)	(0.013)
3rd Trimester Log	-0.011	-0.005
Deviation of Rainfall	(0.031)	(0.010)
Observations	1,954	1,954
Mother Characteristics	X	X
Child Characteristics	X	X
All Fixed Effects	X	X

Note: *p < 0.1, **p < 0.05, ***p < 0.01. Robust standard errors are clustered at the residential cluster level. Each column represents the coefficients in a separate regression. The column headings indicate dependent variables. Mother Characteristics include mother's age at birth, mother's age at birth squared, years of education, weight, household head gender, household head's years of education, number of children in the household, household size, whether the household lives in rural areas, as well as wealth index fixed effects. Child Characteristics include child's gender, birth order, an indicator for singleton birth, and the deviation of temperature during the prenatal period. All Fixed Effects include birth month, birth year, and mother fixed effects.

According to Table 6, the detrimental impacts of rainfall shocks tend to concentrate in the first trimester. Specifically, a 0.1 log point increase in rainfall relative to the location-specific mean during the first trimester decreases the child's weight at birth by 7.9 grams (or by 0.28%). The estimates for the second and the third trimesters are substantially smaller and are statistically indistinguishable from zero. Collectively, our results are consistent with studies showing the relative importance of first-trimester exposure to negative shocks (Burlando, 2014; Molina and Saldarriaga, 2017; Le and Nguyen, 2020).

5.5 Other Measures

In this section, we test the robustness of our main results by employing different measures of rainfall shocks. The results are displayed in Table 7. First, in Panel A, we replace our log deviation of rainfall with a standardized measure. Specifically, Standard Deviation of Rainfall is the difference between total rainfall during the in-utero period in the child's residential cluster and the long-run average of total rainfall of the cluster within the same period of time, then divided by the long-run standard deviation of total rainfall. As shown in Panel A, we still detect adverse impacts of rainfall shocks on birth weight. Specifically, a one standard deviation increase in in-utero rainfall relative to the long-run local average decreases the child's weight at birth by 52 grams (or by 1.9%). The estimates are statistically significant.

Next, in Panel B, we use the percentage measure of rainfall. Particularly, Percentage Deviation of Rainfall is the difference between total rainfall during the in-utero period in the child's residential cluster and the long-run average of total rainfall of the cluster within the same period of time, then divided by the long-run average of total rainfall. Employing this percentage measure, we still uncover the negative relationship between in-utero rainfall shocks and birth weight. A one percentage point increase in rainfall relative to the location-specific norm is associated with the 2.4 gram (0.087%) decline in the child's weight at birth.

In Panels C, we introduce the squared term of our main explanatory, Squared Log Deviation of Rainfall, to the baseline regression. Since the squared term of the log form might not be commonly utilized, we also have Deviation of Rainfall (similar to the main explanatory but without taking log) and its squared term as the explanatory in Panel D. The negative estimates of the squared terms suggest an increasing trend in the impacts of rainfall, however, we do not have enough statistical evidence to support this argument.

Table 7: Rainfall and Birth Weight - Other Measures

	Birth Weight in Kilogram (1)	Log Birth Weight (2)
Panel A: Standardized Measure		
Standard Deviation of Rainfall	-0.052**	-0.019**
	(0.022)	(0.007)
Observations	1,954	1,954
Panel B: Percentage Measure		
Percentage Deviation of Rainfall	-0.240**	-0.087***
	(0.097)	(0.033)
Observations	1,954	1,954
Panel C: Squared Term - Log Deviation of Rainfall		
Log Deviation of Rainfall	-0.231**	-0.086**
	(0.105)	(0.036)
Squared Log Deviation of Rainfall	-0.026	-0.017
	(0.341)	(0.113)
Observations	1,954	1,954
Panel D: Squared Term - Deviation of Rainfall		
Deviation of Rainfall	-0.082***	-0.030***
	(0.028)	(0.010)
Squared Deviation of Rainfall	-0.016	-0.006
	(0.029)	(0.009)
Observations	1,954	1,954
Panel E: Within 30 km from Stations		
Log Deviation of Rainfall	-0.235**	-0.080**
	(0.101)	(0.034)
Observations	1,383	1,383
Mother Characteristics	X	X
Child Characteristics	X	X

All Fixed Effects	X	X

Note: *p < 0.1, **p < 0.05, ***p < 0.01. Robust standard errors are clustered at the residential cluster level. Each column represents the coefficients in a separate regression. The column headings indicate dependent variables. Mother Characteristics include mother's age at birth, mother's age at birth squared, years of education, weight, household head gender, household head's years of education, number of children in the household, household size, whether the household lives in rural areas, as well as wealth index fixed effects. Child Characteristics include child's gender, birth order, an indicator for singleton birth, and the deviation of temperature during the prenatal period. All Fixed Effects include birth month, birth year, and mother fixed effects.

Finally, we exclude households living more than 30 kilometers away from the closest weather stations, then rerun the baseline regressions. This exercise is to examine whether our estimated impacts of rainfall shocks are driven by measurement errors. The magnitude of the estimated impacts is very close to the baseline ones (Columns 3 and 6 of Table 2). The statistical significance levels are slightly reduced, but this can be expected due to the reduction in the number of observations making estimations less efficient.

5.6 Discussion

Collectively, we have presented compelling evidence on the relationship between rainfall shocks during the prenatal period and birth weight in the context of Kyrgyzstan. We find that a 0.1 log point increase in in-utero rainfall relative to the location-specific mean is associated with an approximately 23.4 gram (or 0.84%) reduction in child's weight at birth. The adverse impacts of prenatal exposure to rainfall shocks on birth weight tend to fall disproportionately on children of disadvantaged backgrounds. Our trimester analysis supports the relative importance of first-trimester exposure to rainfall shocks.

Guided by the theoretical discussion in Section 2, our mechanism analysis shows that 6.8% and 2.2% of the impact of rainfall shocks on birth weight works through the channel of prenatal care and nutrient consumption during pregnancy. The findings are supported by prior studies showing that rainfall shocks lower not only household ability to afford healthcare consumption but also the availability of healthcare supplies (Shah and Steinberg, 2017; Amare et al. 2018; Baten et al. 2020;

Chambers et al. 2020). Besides, the mechanism analysis also suggests an additional 3% of the impact of rainfall shocks on birth weight works through the channel of intestinal diseases during pregnancy. This point is supported by studies showing that rainfall shocks can make diseases more prevalent, thus imperiling the health of both the mothers and the fetus (Umbers et al.2011; Levy et al. 2016; WHO, 2018).

Overall, our findings are consistent with prior studies on the relationship between in-utero climatic shocks and newborn health. Specifically, fetal exposure to rainfall shocks can lead to lower birth weight of American and Brazilian children (Currie and Rossin-Slater 2013; Chacón-Montalván et al. 2021). Experiencing temperature shocks during the prenatal period is also reported to decrease birth weight in the U.S, Vietnam, and Andean states (Deschênes et al., 2009; Le and Nguyen, 2021a; Molina and Saldarriaga, 2017).

Given the similarities in the outcome and approach, we are able to compare our estimate to the one reported by Chacón-Montalván et al. (2021). Specifically, they find that prenatal exposure to excessive rainfall (2 standard deviations above the local norm) can lower the birth weight of Brazilian infants by 183 grams. However, according to Panel A of Table 7, we find that excessive rainfall can reduce the birth weight of Kyrgyzstani children by 104 grams (52 grams for each standard deviation). Compared to their estimate, ours is much smaller in magnitude, thus suggesting the heterogeneous effects across geographic regions and calling for more studies to reconcile the difference.

Regarding the impacts of the prenatal environment, our study also contributes to the debate on the relative importance of exposure timing. By presenting evidence that the detrimental impacts of rainfall shocks on birth weight tend to concentrate in the first trimester, our findings lend support to studies emphasizing the relative importance of first-trimester exposure to negative shocks (Burlando, 2014; Molina and Saldarriaga, 2017; Le and Nguyen, 2020).

6 Conclusion

This paper contributes to the literature by finding evidence for the detrimental impacts of rainfall shocks in the prenatal period on the birth weight of Kyrgyzstani children. Such adverse impacts of prenatal exposure to rainfall shocks on birth weight tend to fall disproportionately on those born to poor mothers and those born to mothers residing in rural areas. The trimester analysis supports the relative importance of first-trimester exposure to rainfall shocks. The mechanism analysis provides evidence that the adverse impacts of rainfall shocks on birth weight could be attributed to prenatal care, diseases, and nutrient intakes.

As climate change drastically raises the intensity and frequency of the incidences of extreme rainfall events (Alexander, 2016), our study highlights the health cost of climate change. Being rated as one of the most climate change vulnerable countries in Central Asia (UNICEF, 2017), it is important for Kyrgyzstan to implement effective measures to minimize the adverse impacts of rainfall shocks. For example, the provision of nutrients and healthcare for pregnant women coupled with disease control programs can protect babies in areas prone to rainfall shocks. Children of disadvantaged backgrounds, i.e., those born to poor mothers and those born to mothers residing in rural areas, should be prioritized since they tend to be disproportionately affected.