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Authors
Diamond-Smith, Nadia G
Epstein, Adrienne
Zlatnik, Marya G
et al.

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The association between timing in pregnancy of drought and excess rainfall, infant sex, and birthweight

Evidence from Nepal

Nadia G. Diamond-Smith[a*], Adrienne Epstein[b], Marya G. Zlatnik[c], Emily Treleaven[d]

Background: Past research on the impact of climatic events, such as drought, on birth outcomes has primarily been focused in Africa, with less research in South Asia, including Nepal. Existing evidence has generally found that drought impacts birthweight and infant sex, with differences by trimester. Additionally, less research has looked at the impact of excess rain on birth outcomes or focused on the impact of rainfall extremes in the preconception period. Using data from a large demographic surveillance system in Nepal, combined with a novel measure of drought/excess rainfall, we explore the impact of these on birthweight by time in pregnancy.
Methods: Using survey data from the 2016 to 2019 Chitwan Valley Study in rural Nepal combined with data from Climate Hazards InfraRed Precipitation with Station, we explored the association between excess rainfall and drought and birthweight, looking at exposure in the preconception period, and by trimester of pregnancy. We also explore the impact of excess rainfall and drought on infant sex and delivery with a skilled birth attendant. We used multilevel regressions and explored for effect modification by maternal age.
Results: Drought in the first trimester is associated with lower birthweight (β = −82.9 g; 95% confidence interval [CI] = 164.7, −1.2) and drought in the preconception period with a high likelihood of having a male (odds ratio [OR] = 1.41; 95% CI = 1.01, 2.01). Excess rainfall in the first trimester is associated with high birthweight (β = 111.6 g; 95% CI = 20.5, 202.7) and higher odds of having a male (OR = 1.48; 95% CI = 1.02, 2.16), and in the third trimester with higher odds of low birth weight (OR = 2.50; 95% CI = 1.40, 4.45).
Conclusions: Increasing rainfall extremes will likely impact birth outcomes and could have implications for sex ratios at birth.

Keywords: Drought; Excess rainfall; Birthweight; South Asia; Food security

Introduction

South Asia has the highest rates of low birthweight (LBW, defined as infants born at less than 2,500 g) globally, with 28% of infants born LBW.[1] Babies born LBW are at higher risk of infant mortality and morbidity than those born at normal birthweights, and longer-term outcomes such as childhood mortality, cognitive and developmental delays, and comorbidities later in life such as cerebral palsy and other neurodevelopmental conditions, asthma, hypertension, and other chronic health conditions.[2,3] Risk factors for LBW globally, and in Nepal, our country of focus, are multifaceted. These include socio-demographic contributors such as maternal age, wealth, and health status/comorbidities; access to high-quality pregnancy and delivery care; maternal nutrition and stress in pregnancy; and also environmental factors during pregnancy, such as air pollution and temperature.[4–10] For example, previous literature has found differential effects of environmental exposures, such as air pollution, on LBW by trimester of pregnancy, with greater negative impacts seen in the first and last trimesters.[11]

One environmental stressor that may impact LBW is rainfall. In Sub-Saharan Africa, drought exposure in infancy and childhood is associated with poor longer-term outcomes, including health-related consequences, such as lower adult height and higher prevalence of LBW among offspring, and economic consequences, such as lower educational attainment and lower household wealth.[12] Another study drawing on data from Sub-Saharan Africa also found exposure to drought increased

[a]Department of Epidemiology and Biostatistics and Institute for Global Health Sciences, University of California, San Francisco, San Francisco, California; [b]Department of Epidemiology and Biostatistics, University of California, San Francisco, San Francisco, California; [c]Division of Maternal Fetal Medicine, Program on Reproductive Health and the Environment, Department of Obstetrics, Gynecology, & Reproductive Sciences, University of California, San Francisco, San Francisco, California; and [d]Institute for Social Research, University of Michigan, Ann Arbor, Michigan

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*Corresponding Author. Address: Department of Epidemiology and Biostatistics and Institute for Global Health Sciences, University of California, San Francisco, 550 16th Street, 3rd Floor, San Francisco, CA 94158. E-mail: nadia.diamond-smith@ucsf.edu (N. G. Diamond-Smith).

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What this study adds

This study adds to our knowledge about the impact of both excess rain and drought on birthweight in South Asia (Nepal) which is an understudied area of the globe. It explores the impacts by trimester and also looks at exposure preconception, thereby refining our understanding of how and when in pregnancy climate variability impacts birth outcomes. It also looks at the impact of extreme climate events on the sex of the infant, adding to our knowledge of how stresses in pregnancy differentially lead to spontaneous miscarriage.

LBW, potentially by affecting food insecurity and/or nutritional impacts, in turn affecting intrauterine growth.[8] Further analyses by these authors highlighted the importance of measuring the timing of rainfall exposure in pregnancy.[13] There is evidence of a similar negative relationship between drought and LBW in Brazil.[14]

Most of the previous literature on birth outcomes and precipitation is focused on Sub-Saharan Africa, less on South Asia, specifically in Nepal. One of the few studies from Nepal looked at whether interannual variability in weather [measured using the Normalized Difference Vegetation Index (NDVI) which assesses change in vegetation] was associated with child growth stunting, and found evidence of short-term negative impacts but mixed results of longer-term impacts on stunting.[15] Again using the NDVI, other authors looked at the impact of exposure to change in the NDVI by trimester and found evidence that child height is positively linked to NDVI during pregnancy for boys, and in early infancy for girls in Nepal.[16] A working paper using data from India found that excess rainfall in a women's birth year is associated with improved education outcomes (not for men), and that rainfall shocks also have a differential effect based on wealth.[17] Research in India has found that exposure to drought in utero is associated with lower weight-for-age scores and malnutrition.[18] Evidence from Nepal has found that birth month is associated with neonatal death and low birth weight, with babies born in August at the highest risk, which the authors hypothesize is due to food insecurity in pregnancy.[19]

Nepal, especially the Terai region, where this study is focused, is a predominantly agricultural area, with multiple growing seasons and variability within the year (monsoon, dry period, etc.). Previous research in this part of Nepal found seasonal variation in eating practices (and subsequent variation in dietary diversity) among women, which was associated with infant outcomes and maternal outcomes (maternal Body Mass Index and arm circumference and infant growth-related).[20] Changes in dietary diversity during pregnancy affect the overall level of nutrition, which impacts overall maternal health, and anemia specifically, which is a risk factor for LBW. Another, related, primary pathway through which excess rainfall or drought could impact birth outcomes, such as LBW, is through increasing food insecurity, which could reduce the quality and/or quantity of food that women consume in the preconception or pregnancy periods.[13] Previous research in Nepal has found that food insecurity is associated with LBW.[21] Over half of households in Nepal are food insecure, and this has been found to be associated with maternal and child health and nutrition-related outcomes.[22,23]

In addition to exposures in pregnancy, there is evidence that prepregnancy stressors and exposures are associated with LBW.[24] A recent framework for understanding the population-environment link for maternal and child health highlighted the need to study the preconception period as well.[25] We have been unable to find literature on preconception drought or rainfall and birth outcomes such as LBW, however, there is evidence of an impact of preconception drought on child-reduced growth.[26] There is even evidence of intergenerational effects of rainfall, with one paper from Africa finding that drought in a woman's mother's preconception period was associated with a woman's subsequent risk of maternal mortality.[27]

There is also evidence that in utero exposures and stressors, including environmental stressors, are associated with fetal sex. The rationale, as advanced by Trivers and Willard[28] is that males born in good ecological conditions will out-reproduce females because strong males in times of plenty can produce offspring at a higher frequency. In poor ecological conditions, females will out-reproduce males. From the evolutionary perspective of the mother, it is therefore advantageous to have sons in good times, and daughters when times are bad. This theory—the Trivers–Willard Hypothesis—has been shown to hold for population-wide stresses due to environmental conditions.[29–31] In human populations, there is evidence of a biological mechanism through which sex ratios are affected by stresses. There is evidence that stresses that the mother experiences whereas the fetus is in utero, such as terrorism, extreme temperatures, and economic instability, can lead to the spontaneous abortion of male fetuses and thus alter the sex ratio.[32,33] In Nepal, as in much of South Asia, son preference exists, and there is evidence of imbalanced sex ratios at birth, favoring males.[22] Thus, any analysis of the sex of birth must consider both behaviors that might impact the sex ratio (sex-selective abortion) alongside the impact of environmental stressors (such as rainfall).

Given the limited current literature from South Asia on the link between rainfall (drought or excess rainfall) and birth outcomes, specifically LBW, we aimed to analyze the association between drought during each trimester of pregnancy and the 3 months preconception, and LBW. We conceptualized several pathways through which drought or rainfall might impact birthweight (Figure 1). The first is through in utero shocks or stress, which in turn would impact maternal health, and thus impact LBW, or could directly impact LBW through preterm birth. This is also the pathway through which stresses in pregnancy could lead to differential miscarriage or spontaneous abortion by sex. Drought could also impact food security, which would directly impact maternal health and nutrition (also causing stress), and lead to LBW. Excess rainfall could also increase the transmission of some infectious diseases, such as malaria, which is associated with anemia, LBW, and preterm birth through malaria in pregnancy.[34,35] Excess rain can lead to more breeding grounds for mosquitos and could wash away breeding grounds, so act in either direction (increasing or decreasing risk) and droughts can turn rivers into strings of pools, which are preferred breeding sites for mosquitos. Finally, we hypothesized that there could be an access-related pathway, whereby either excess rainfall or drought could potentially limit women's ability to access skilled birth attendants (either due to economic constraints or physical barriers due to floods for example). Although this should not directly impact LBW, it would be associated with other poor health outcomes and could be used as a proxy for poor access to quality health care broadly. Drought is likely especially correlated with economic constraints in settings like the Terai region of Nepal where the economy is heavily dependent on agriculture. Environmental stressors, such as air pollution, might interact with precipitation changes, however, these are not the main focus of this paper. Other pathways might exist but are not the focus of this study as they are not as applicable to this population or geography.

Methods

Data source

We used data from the Chitwan Valley Family Study (CVFS), a longitudinal cohort study in the western Chitwan Valley in south central Nepal (Figure 2). The study area is bordered by rivers to the north, west, and south, and by forest on the east. The urban center is in the northeast of the study area, and the area is increasingly rural towards its western borders. In 1995, a population-representative sample of 171 geographically-defined neighborhoods including 5–15 households was drawn; all households in the sampled neighborhoods were then enrolled in the CVFS.[36] Since 1996, all household members have been followed through periodic interviews and a monthly household registry. Household members are retained in the study regardless of whether they move outside the study area temporarily or permanently. Newly-formed households that include study participants from existing households, or households that move into the boundaries of a study neighborhood, are enrolled. The CVFS has maintained extremely low loss to follow-up rates over time.[37]

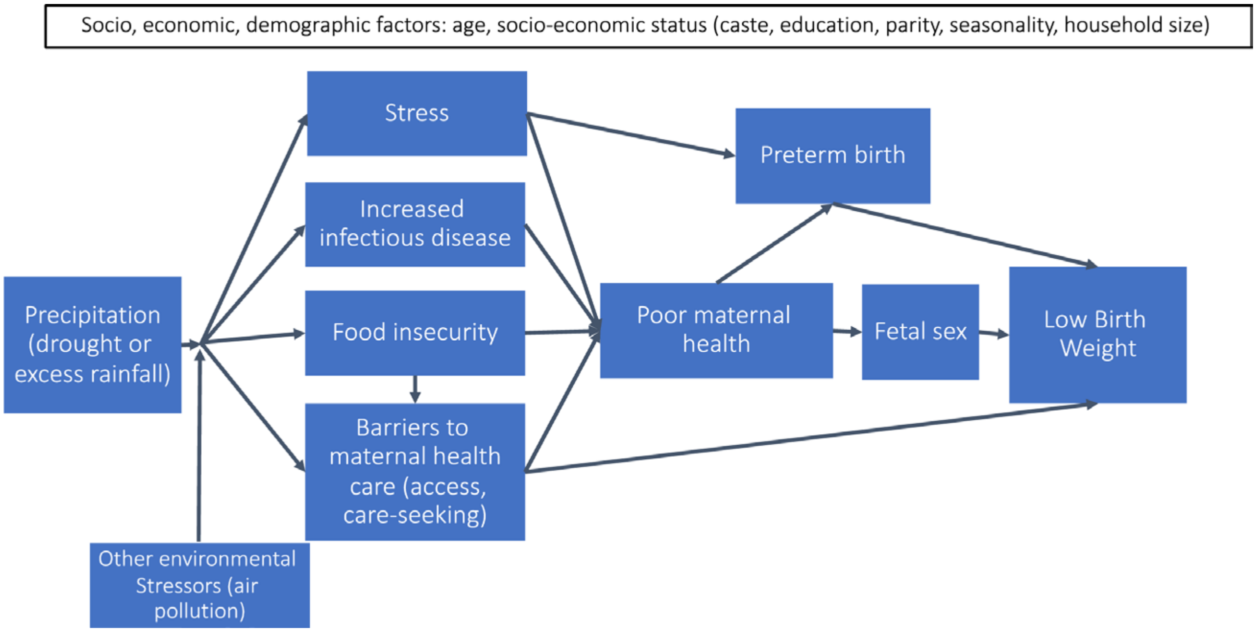

Figure 1. Conceptual model of pathways of focus between precipitation and low birthweight.

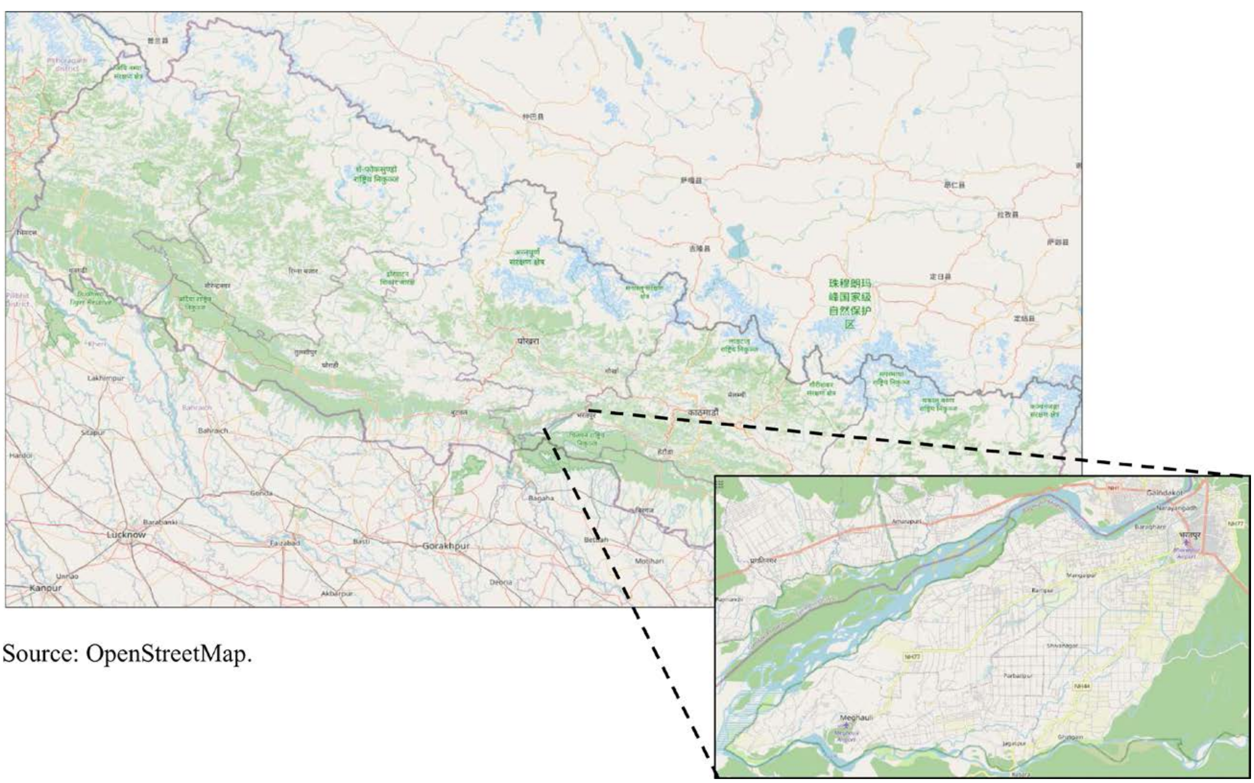

Figure 2. Map of the Chitwan Valley Family Study area. Source: OpenStreetMap.

The CVFS conducted two rounds of data collection that included child health indicators in 2016 and 2019. The 2016 sample included all children under 18 years of age in CVFS households in the Chitwan district; the 2019 sample included all children under 10 years of age in CVFS households in the Chitwan district, and children under 10 years of age included in the 2016 data collection whose household left the Chitwan district but still resided in Nepal. At both time points, in an interviewer-administered survey, mothers self-reported the weight at birth for each child. Interviewers recorded whether the mother reported birthweight based on recall (90.5%) or from a document, such as a health card (9.5%). Mothers also reported the site of delivery and attendant at birth for each child, and their own and their husband or partner's educational attainment. The analytic sample for the current study is restricted to children under 5 years of age at the time of data collection to reduce recall bias.

We also drew upon the CVFS household registry in this analysis. The household registry records the location and composition of all households enrolled in the study at monthly intervals, and basic socio-demographic characteristics of household members, such as age and ethnicity.

Measures

Our primary exposure variables were drought and heavy rains. Both measures were defined using Climate Hazards InfraRed Precipitation with Station data, which combines satellite and weather data to create rainfall estimates of 0.05 decimal degree resolution from 1981 onward.[38] The CVFS includes precise geo-locations for each neighborhood. Using Global Positioning System data, we linked rainfall raster data from Climate Hazards InfraRed Precipitation with Station to each CVFS neighborhood.

Both drought and heavy rains were defined as deviations from long-term precipitation trends. To operationalize these deviations, we compared rainfall in the exposure period to the same period in the 29 previous years by generating a ranking of the rainfall and converting this ranking into a percentile. Drought was defined as rainfall lower than the 30th percentile relative to the previous 29 years, and heavy rainfall was defined as rainfall higher than the 70th percentile relative to the previous 29 years, as are used internationally as standards. We explored drought and heavy rainfall as an exposure variable at four-time points: the 3 months preconception, the first trimester, the second trimester, and the third trimester of pregnancy. We created binary variables indicating exposure to drought (vs. none) and excess rainfall (vs. none) in each time period of interest. A person was coded as being exposed to drought in a specific trimester or preconception period if her neighborhood experienced drought in that time period as defined above. Similarly, a person was coded as being exposed to excess rainfall in a specific trimester or preconception period if her neighborhood experienced heavy rainfall in that time period as defined above. Since we do not have data on exact gestational age, it is possible that these windows do not exactly align with each individual's baby trimester and preconception period. However, for ease of interpretation and since we think for most infants this will roughly align with the three trimesters and 3 months preconception, we will use these terms.

Our primary outcome variable was birthweight, which we explored as a continuous variable (weight in grams) and as a binary variable for LBW, with the cutoff being <2,500 g to indicate LBW.[39] We did not have data on gestational age and do not know if babies were born preterm or at term. Secondary outcomes include delivery in the presence of a skilled birth attendant and the sex of the baby.

We adjusted for key variables that are associated with birthweight. These include maternal age (continuous), mother and father's education levels (categorical), ethnicity (categorical), household size (continuous), and the number of children under 5 years of age in the household (continuous). We also included an indicator variable representing the birth month to adjust for seasonality.

Analysis

To assess the association between drought or heavy rainfall and birth outcomes, a series of multilevel regressions were specified for each outcome. For birthweight, we specified linear mixed effects models and for LBW, the presence of a skilled birth attendant, and for child sex, we specified logistic mixed effects models. All models included random intercepts at the neighborhood level to account for clustering. For all outcomes, we assessed the association between the outcomes and drought/heavy rainfall variables at all time points, with the exception of the presence of a skilled birth attendant, which we hypothesize would only be influenced by precipitation in the third trimester.

We evaluated the presence of effect modification by maternal age by generating interaction terms between maternal age and exposure variables. We then included the interaction term and main effects in the models. We considered an alpha significance level of 0.10 for the interaction coefficient.

Results

At the time of data collection, children in our sample were a mean of 2.5 years of age [Standard Deviation (SD) 1.7], and slightly more were male (54.5%) (Table 1). The mean birthweight in our sample was 3,066 g (SD 545.6), and 8.9% of infants were thus classified as LBW (<2,500 g). Women in our sample had a mean age of 21.2 (SD 4.6). The largest proportion of women had higher than high school education (38%) or secondary education (38%). Husbands had similar levels of education. Most of the sample belonged to the Brahmin/Chhetri caste (42.1%). The mean household size was 7.5 people, with a mean of 1.3 children under 5 years in each household. Around one-fifth to one-fourth of women experienced drought or excess rain at each of the time points.

Drought in the first trimester was associated with lower birthweight (β = −82.9 g; 95% confidence interval [CI] = 164.7, −1.2) (Table 2) whereas excess rain in the first trimester was associated with higher birthweight (β = 111.6 g; 95% CI = 20.5, 202.7) (Table 3). Excess rain in the third trimester was associated with higher odds of LBW (odds ratio [OR] = 2.50; 95% CI = 1.40, 4.45). Drought in the preconception period was associated with increased odds of having a male baby (OR = 1.41; 95% CI = 1.01, 2.01), whereas excess rain in the first trimester was associated with having a male baby (OR = 1.48; 95% CI = 1.02, 2.16). We did not find evidence for an association between delivery with a skilled birth attendant and either drought or excess rainfall. All models adjusted for maternal, paternal, and

Table 1.

Mean (SD)	%(n)
Characteristics	
Age (years); mean (SD)	2.5 (1.7)
Male, % (n)	55 (480)
Outcomes	
Birthweight; mean (SD)	3,066 (546)
Low birthweight, % (n)	8.9 (78)
Skilled birth attendant, % (n)	33 (294)
Maternal covariates	
Mother's age; mean (SD)	21 (4.6)
Mother's education level, % (n)	
None	4.9 (43)
Primary	14 (120)
Secondary	39 (339)
SLC	13 (114)
Higher	38 (265)
Father's education level	
None	3.0 (27)
Primary	14 (120)
Secondary	34 (299)
Secondary level certification (completed high school)	20 (173)
Higher	29 (262)
Ethnicity	
Brahmin/Chhetri	42 (371)
Hill Janajati	17 (149)
Dalit	15 (133)
Newar	6.1 (54)
Terai Janajati	19 (170)
Other	0.5 (4)
Household size; mean (SD)	7.5 (2.9)
Number of children <5 in household; mean (SD)	1.3 (0.5)
Exposure	
Drought before conception, % (n)	22 (196)
Drought in first trimester, % (n)	25 (218)
Drought in second trimester, % (n)	27 (240)
Drought in third trimester, % (n)	26 (231)
Heavy rains before conception, % (n)	24 (209)
Heavy rains in first trimester, % (n)	21 (187)
Heavy rains in second trimester, % (n)	21 (184)
Heavy rains in third trimester, % (n)	28 (244)

Table 2.

Drought-outcome relationship				
	Drought exposure period			
Outcome	Preconception	First trimester	Second trimester	Third trimester
Birthweight, linear effect estimate	37 (−50, 124)	−83* (−165, −1.2)	29 (−48, 107)	10 (−69, 89)
Low birthweight, OR	0.82 (0.42, 1.6)	0.70 (0.36, 1.4)	0.78 (0.43, 1.4)	0.75 (0.41, 1.4)
Skilled birth attendant, OR				1.0 (0.73, 1.4)
Male sex, OR	1.4* (1.0, 2.0)	1 (0.72, 1.4)	1.1 (0.78, 1.5)	0.97 (0.71, 1.3)

Models include random effects for neighborhood and household and are adjusted for birth month, mother's age, ethnicity, father's education, mother's education, household size, and the number of children <5 years in the household.
*<0.05.

Table 3.

Heavy rains-outcome relationship				
	Heavy rains exposure period			
Outcome	Preconception	First trimester	Second trimester	Third trimester
Birthweight, linear effect estimate	−8.4 (−95, 79)	112* (21, 203)	−0.8 (−92, 91)	−23 (−104, 57)
Low birthweight, OR	1.2 (0.65, 2.2)	1.2 (0.63, 2.3)	1.5 (0.7, 2.9)	2.5** (1.4, 4.5)
Skilled birth attendant, OR				1.07 (0.76, 1.51)
Male sex, OR	1.1 (0.79, 1.6)	1.5* (1.0, 2.2)	1.2 (0.84, 1.8)	1.1 (0.82, 1.6)

Models include random effects for neighborhood and household and are adjusted for birth month, mother's age, ethnicity, father's education, mother's education, household size, and the number of children <5 years in the household.
*<0.05,
**<0.01.

household-level characteristics. We reran these models (except for models with infant sex as the outcome) controlling for the sex of the infant and it did not impact the outcome; since we hypothesize that sex is on the causal pathway, we have not included it in the models. We also ran sensitivity analyses for more conservative definitions of drought (<20th percentile) and excess rainfall (>80th percentile) and found similar results (not shown), with one exception.

Analysis of effect modification by maternal age (Figure 3) shows that drought preconception and during early pregnancy (in the first trimester) were most harmful to older mothers. Older women who experienced drought in these time periods were more likely to have LBW infants. For example, the risk ratio comparing drought to no drought exposure during the first trimester among 20-year-olds is 1.01 (95% CI = 0.97, 1.05), whereas among 40-year-olds it is 1.13 (95% CI = 1.04, 1.22).

Discussion

We find evidence for an association between drought and LBW in a highly agriculturally dependent region of rural Nepal, which appears to depend on the timing of pregnancy when a woman experiences drought. The first trimester is critical—drought in the first 3 months of pregnancy is associated with lower birthweight, and excess rainfall is associated with higher birthweight. Given that we know that the experience of drought or rainfall occurred before the birth of the infant and is not based on maternal recall, there is strong evidence of an effect of the rainfall/drought on birthweight, although we cannot be sure this is causal. There could be several explanations for this finding if there is indeed a causal relationship. If the pathway between rainfall (excess or too little) is through the impact that this rainfall ultimately has on crop yields (a food security pathway), then it is potentially the effect of having too little food later in pregnancy that ultimately impacts birthweight, given the delay in rainfall and crop growth. Previous research on the impact of drought on crop yields in Nepal has found that there are impacts of drought on crop yield and these differ by type of crop and region, and also these associations can span multiple months—for example, drought anywhere from 1 to 6 months before the crop season can impact output.[40] Thus, it is possible that depending on the timing of pregnancy and drought within the year, the impact of drought may be in that specific trimester or the following ones. Our models account for the month of the year, but more analyses would be needed to see if the impacts are stronger in certain times of the year compared with others.

Another potential pathway of first trimester rainfall and LBW is through anemia in the first trimester.[41,42] This pathway could be through food access and subsequent nutrition (iron), but also through malaria, which can cause anemia in pregnancy. Though not the focus of our study, this part of Nepal is endemic for malaria, though it should be noted that Chitwan has very few cases per year. Past research in Africa has found that malaria in the first trimester is associated with an increased risk of LBW.[43] If excess rainfall leads to more malaria transmission at that point in time, then we would expect to see the opposite of our findings. Another potential way that anemia could increase with drought could be if drought impacted women's access to iron-folic acid tablets at health facilities. A study on heat in Nepal found that in times of extreme heat women were less likely to seek prenatal care (where they would also get their iron-folic acid tablets), and thus, if drought was associated with high temperatures it is possible that this could also be occurring in our study population.[44] More research that combined temperature and rainfall data could help shed light on this potential pathway.

Stress in pregnancy has been found to be associated with birthweight, specifically in the first trimester.[45] It is possible that drought in the first trimester leads to more stress in women's lives, either because of the psychosocial impact of what drought means for the future (crop failure), the immediate impact on crop failure, or the potential to do more labor (potentially having to search farther for wood or water, or work more in the fields). Previous research has found that when there are excess crops women had to work in the fields more, which negatively impacted stress; this additional labor also reduced their caloric input because they had less time to eat.[20]

We find an association between excess rain in the third trimester and increased risk of LBW. If this finding was capturing

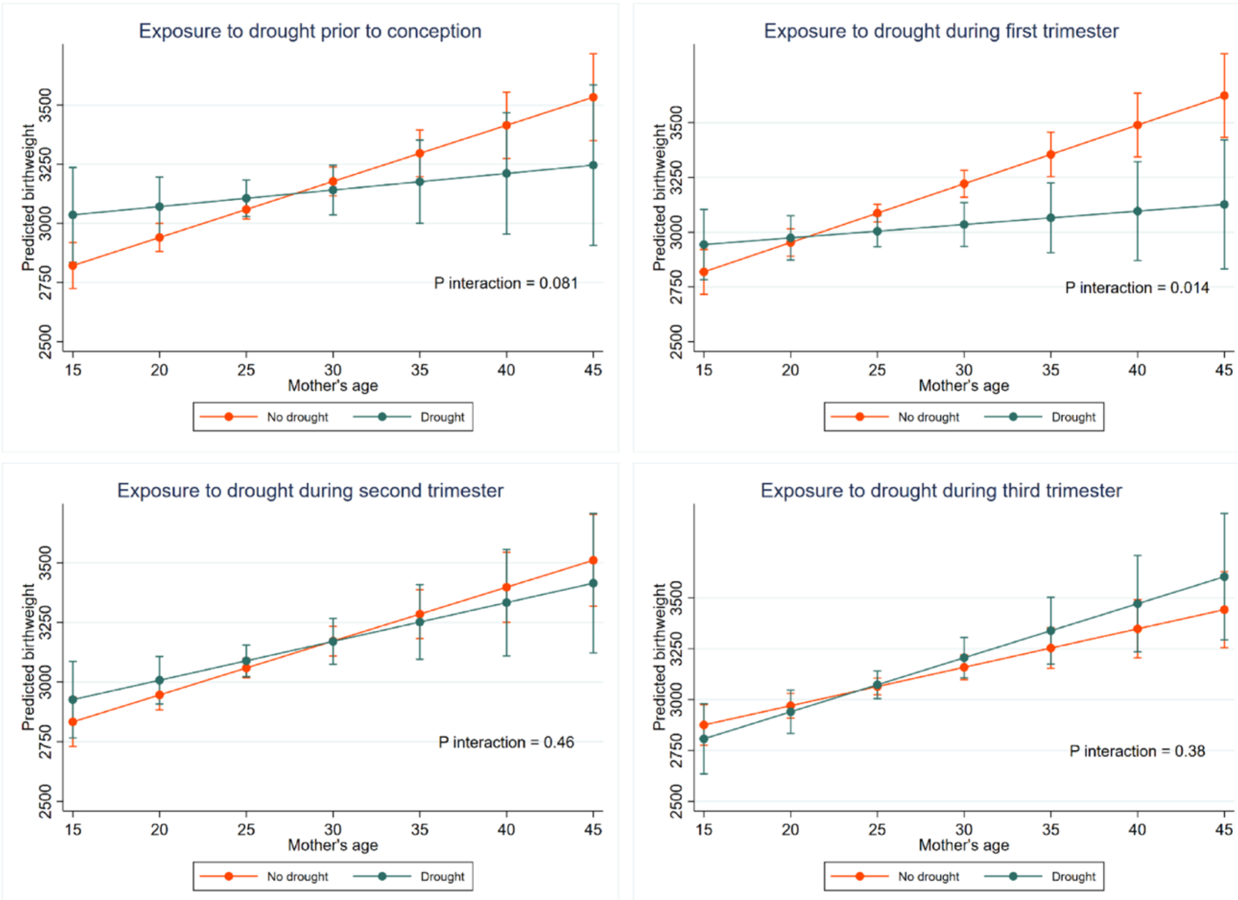

Figure 3. Effect modification by maternal age for the association between drought and birthweight.

a pathway through food security through short-term impacts on growth, we might expect the association to be in the other direction (less LBW). However, given that we see a negative impact of excess rain on LBW, we hypothesize that instead, this could be evidence of additional stress caused by excess rain potentially leading to more agricultural work in the later stages of pregnancy. Too much excess rain could also ruin crops or make harvesting impossible, thereby reducing food. Anemia in the third trimester has been found to be associated with LBW, and thus, if excess rainfall could lead to anemia, then this could be the pathway of impact.[46] This finding could be evidence of a food security/nutritional pathway (less access to iron-rich foods due to rainfall) or could potentially be an access pathway, specifically, if heavy rains restricted women's ability to travel (roads washed out, difficult to walk far, etc.) they might not be able to get iron-folic acid tablets in the last critical months of pregnancy. However, we find no association between drought or rainfall and the type of provider that a woman delivered with, so these factors might not ultimately impact all forms of care access. It could also be that women who planned to deliver at a health facility ultimately overcome barriers to delivery but maybe are not able to overcome barriers to antenatal care.

Another important possible explanation for our findings is that we are measuring the outcome of preterm birth. Since we do not have data on gestational age, many of the infants that we are including as LBW might actually be preterm babies, who have a lower birthweight because they are born early. Previous research in South Asia (and globally) has found that stresses in pregnancy, including exposure to intimate partner violence and perceived stress in general, are associated with preterm birth.[47,48] Trimester-specific research found that stress in the first and second trimesters was associated with preterm birth.[45] Anemia in pregnancy is also associated with preterm birth, which could be a marker of poor nutritional intake.[49] Food insecurity is also a contributor to preterm birth, again due to poor nutrition intake.[50] Drought has also been found to be associated with stress, mental health, intimate partner violence, and food insecurity.

Our analysis of effect modification shows that the impact of drought and excess rain on LBW differs by the age of the mother—with older mothers being more affected compared with younger mothers. Maternal age is consistently associated with both LBW and preterm birth in many previous studies in low- and middle-income countries (LMICs). However, a recent analysis of data from Finnish siblings suggests that when controlling for within-woman/family factors, there is little association between age and LBW, and suggests that other unobservable maternal or infant health factors may ultimately be responsible.[51] Our findings suggest that women at advanced maternal age may be more at risk than younger women of LBW when exposed to additional stressors caused by rainfall patterns. Previous research on the impact of environmental exposures such as smoking and air pollution on LBW and preterm birth have also found modification by maternal age.[52,53] Older women may have higher risk pregnancies for several reasons related to health and confounded by socio-economic status, parity, and other life stressors.[54] Thus, our findings may be shedding light on one of the unobservable factors contributing to the perceived association between maternal age and LBW in LMIC settings.

Excess rainfall in the first trimester is associated with a higher likelihood of having a male infant. As discussed above, previous research has found that stress in pregnancy is associated with a lower likelihood of delivering a male due to differential miscarriage by sex, and these findings suggest that there may be some protective effect of the anticipation of a good harvest. There is some evidence that preconception stress is associated with lower odds of having a male infant, which contradicts our findings.[33] More research on the effect of preconception stress on the conception of male compared with female fetuses is needed. In a setting with son preference and access to abortion, it is possible that people choose to abort or not abort fetuses based on their sex due to changing climate conditions, and thus we could be detecting behavioral factors as opposed to biological ones.

Our findings contribute to the literature on the impact of both more and less than usual rainfall on LBW, looking at trimester-specific impacts, using a novel measure and robust, longitudinal household-level data, thereby extending the limited literature in Nepal on this topic. However, our study has several limitations. Data on birthweight was self-reported, in almost all cases based on memory of the mother (vs. a document), and thus suffers from recall bias. Delivery outside a health facility is not uncommon in this setting; women with home births may have more unreliable reporting of birthweight than those who delivered in a health facility. We lack controls for some measures of maternal and newborn health, including gestational age at delivery and preterm birth, maternal weight gain during pregnancy, anemia, maternal prepregnancy weight and height, and others that could help us understand potential pathways of impact, including household food security. Because we lack measures of gestational age at birth, trimester rainfall exposure may be subject to measurement error, particularly for preterm births. Future research should also include an estimation of coexposure to air pollution (both household and outdoor) and extreme temperature along with rainfall and explore the role of migration. Finally, this data is only from one region of Nepal, which limits generalizability, however, this also allows for less heterogeneity in terms of the types of crops grown/growing season.

Climatic conditions, in this case, above or below the normal rainfall, are associated with birth outcomes and infant sex. With increasing climate variability due to climate change, including excess rainfall or drought, we are likely to see more extreme rainfall conditions. This could have impacts on birthweight, which sets infants on a life course trajectory of poorer health and development.

Conflicts of interest statement

The authors declare that they have no conflicts of interest with regard to the content of this report.

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Ethical approval for the collection of birth outcome data was provided by the Nepal Health Research Council and the University of Michigan.

Data from the Chitwan Valley Family Study are available for public and restricted use through the Data Sharing for Demographic Research repository at ICPSR (https://www.icpsr.umich.edu/web/DSDR/series/646). CHIRPS precipitation data are publicly available at https://www.chc.ucsb.edu/data/chirps.

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