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Drought and Illness among Young Children in Uganda, 2009–2012

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Abstract. Changing precipitation patterns resulting from climate change are likely to have deleterious effects on health. We examined historical relationships between precipitation and diarrhea, cough, and fever among children aged 0–24 months in Uganda, a drought-prone region. Using data from the Uganda National Panel Survey from 2009 to 2012 (2,324 observations), we specified logistic regression models evaluating the relationships between deviations from annual and 30-day precipitation and caregiver-reported diarrhea, cough, and fever, adjusting for sociodemographic characteristics and including enumeration of area-fixed effects. Nonlinearities were assessed using restricted cubic splines. We observed nonlinear (J-shaped) relationships between deviations from annual precipitation and the three child illness outcomes. These J-shaped relationships represented steep reductions in illness with increasing precipitation at lower levels of rainfall and a leveling off at higher levels, with a small increase at higher levels. We did not find evidence for a relationship between 30-day precipitation and childhood illness. Trends of reduced rainfall in Uganda are likely having negative effects on child health.

INTRODUCTION

Over the past several decades, the world has seen major advances in child health. Under-five mortality has fallen by more than half, from 93 deaths per 1,000 live births in 1990 to 39 deaths per 1,000 live births in 2017.[1] The status of child nutrition has also made great strides; the global prevalence of stunting has fallen from 33% in 2000 to 23% in 2016.[2] Despite these successes, the health impacts of human-induced climate change have the potential to slow—or even reverse—these gains.

In many regions of the globe, climate change has led to extreme precipitation events and droughts.[3] These may have detrimental impacts on child health. For example, studies have found associations between undernutrition and rainfall shocks (drought and flooding).[4–8]

There is less evidence for the relationship between precipitation and childhood illness. Studies that have found associations have focused primarily on precipitation shocks, including droughts and flooding events. They have documented associations between drought and respiratory illness, diarrhea, and fever.[7,9,10] Definitions of shocks are inconsistent across the literature; some are defined using a percentile in the observation period and others as deviations from long-term trends.[10,11] Other studies rely on government or academic reports.[7,12,13] However, most are not nationally representative. Few have treated precipitation as a continuous variable. Considering a binary variable masks variation in exposure and fails to capture nonlinearities. This is crucial because there may be thresholds of precipitation at which risk of illness changes.

Uganda has demonstrated a 34% decline in average precipitation from 1983 to 2016 and the potential for a reduced growing season.[14] In 2018, the country ranked 164th out of 187 in under-five mortality.[15] There are no studies on the effects of precipitation on child illness in Uganda; however, the impacts of rainfall are expected to be location specific.

In this analysis, we use the nationally representative Uganda National Panel Survey to evaluate the relationship between deviations from trends in precipitation and childhood illness. We contribute to the literature by measuring the impacts of rainfall on child health in a region that is currently experiencing reductions in annual precipitation. We consider both long-term (annual) and short-term (30-day) exposures to capture both broader precipitation changes and extreme events. We assess nonlinearities using a continuous measure of precipitation deviations, evaluating whether there are thresholds of precipitation at which risk changes. This is important given the lack of a priori knowledge.

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MATERIALS AND METHODS

We use three rounds of the Uganda National Panel Survey (2009–2010, 2010–2011, and 2011–2012). At each wave, respondents from the same households were surveyed from 322 randomly selected enumeration areas (EAs). Households were sampled at different times across the calendar year to represent variations in season. For this analysis, households were included only if they had children aged 0–24 months at the time of survey. Children were added to the sample as they were born into survey households and excluded as they surpassed 24 months of age in subsequent waves. They were excluded if their household was not geo-located or if they had missing covariates or outcomes.

We considered three binary outcomes: caregiver-reported diarrhea, cough or difficulty breathing, and fever within the 2 weeks before the survey. These outcomes were selected as they are the only three child illness indicators reported in the household survey.

Precipitation was measured using monthly raster files extracted from the Climate Hazards Group InfraRed Precipitation with Stations database, available at 0.05° resolution starting in 1981.[16] A continuous value for monthly rainfall (in millimeters) was extracted at the coordinates of each household. Annual cumulative precipitation before the survey date was calculated; this value was ranked relative to annual precipitation in the 26 previous years to generate a percentile. For example, a value of 0.5 indicates rainfall in the year before the survey was the median in the

27-year window. Short-term exposure was measured as precipitation during the survey month (30 days). This value was ranked relative to that month in the 26 previous years (e.g., if the survey occurred in January, the rainfall in January was compared with rainfall in the 26 previous Januaries). Measuring precipitation as a percentile relative to historical patterns is standard in the literature, as it removes sociogeographic variation associated with historically dryer or wetter places.[17]

Logistic regression models were specified with robust standard errors clustered at the household level. We tested for nonlinear relationships between the outcome and precipitation deviations using restricted cubic splines with the number of knots determined using Akaike's information criterion. We tested for overall significance of the spline curves using likelihood ratio tests comparing models with spline terms and those with a linear predictor. Models included a fixed effect term for the month of survey collection to control for seasonality and were adjusted for gender and age, breastfeeding status, an indicator of urban residence, socioeconomic quintile (determined by a principal component analysis), access to improved water source and improved sanitation facilities (binary variables defined using WHO standards), and remoteness (distance to the nearest road). Model fit was assessed using the Hosmer–Lemeshow goodness-of-fit test. We evaluated the presence of influential observations by generating *dfbeta* versus fitted value plots. Analyses were carried out in R-cran version 3.4 (R Foundation for Statistical Computing, Vienna, Austria) and Stata version 14.2 (StataCorp, College Station, TX).

RESULTS

Of the 2,032 children younger than 24 months surveyed across the three waves, a total of 2,207 observations of 1,814 children within 315 EAs (an average of seven observations per EA) were included in the analytic sample (Table 1). During the first wave, children were, on average, 13.4 months old (SD 5.0 months). The mean annual precipitation was lowest in the year before the first survey wave and increased in the two subsequent waves. Illness was most common in the first wave: 35% of respondents reported diarrhea, 33% cough, and 50% fever.

Likelihood ratio tests suggested that analyses with 12-month precipitation deviations had improved fit with restricted cubic splines. Results from these models reveal similar relationships between annual precipitation and the three outcomes (Figure 1A–C), with a sharp decline in the marginal probability of each outcome at lower levels of precipitation, a flattening of the relationship at approximately the 60th percentile of annual rainfall, and an increase at approximately the 80th percentile. This equates to a marginal risk ratio (RR) comparing children living in areas with the 15th percentile of historical annual precipitation (the threshold of drought considered previously in the literature[17]) with the 50th percentile of 1.3 (95% CI: 1.1, 1.5) for diarrhea, 1.2 for cough (95% CI: 1.0, 1.3), and 1.3 for fever (95% CI: 1.1, 1.4).

Unlike our findings using the 12-month precipitation as an exposure, we did not find evidence for a relationship between rainfall during the survey month and caregiver-reported diarrhea (marginal RR per 1 percentile increase: 1.1, 95% CI: 0.81–1.4), cough (marginal RR per 1 percentile increase: 1.1, 95% CI: 0.85–1.5), or fever (marginal RR per 1 percentile increase: 0.88, 95% CI: 0.72–1.1). Hosmer–Lemeshow goodness-of-fit tests indicate good fit for all models ($P > 0.05$).

DISCUSSION

The results from this analysis suggest that lower levels of annual precipitation may have deleterious impacts on child

TABLE 1
Characteristics of children aged 0–24 months in the Uganda National Panel Survey at each survey wave

	Wave 1 (2009–2010), *n* = 580 observations	Wave 2 (2010–2011), *n* = 773 observations	Wave 3 (2011–2012), *n* = 854 observations
Household-level characteristics			
Urban, % (*n*)	15 (85)	17 (130)	16 (135)
Distance to the nearest road (km), mean (SD)	7.9 (7.4)	8.4 (8.3)	8.0 (7.6)
Rainfall during the survey month (mm), mean (SD)	173.9 (80.2)	184.4 (95.6)	189.7 (114.1)
Improved water source, % (*n*)	75 (434)	77 (596)	78 (662)
Improved sanitation, % (*n*)	51 (298)	45 (348)	44 (374)
Percentile of rainfall during the survey month relative to 26 previous years, mean (SD)	0.49 (0.29)	0.50 (0.30)	0.58 (0.31)
Rainfall in 12 months before the survey (mm), mean (SD)	1,804.8 (389.4)	2,148.0 (388.9)	2,332.1 (312.5)
Percentile of rainfall in 12 months before survey relative to 26 previous years, mean (SD)	0.24 (0.29)	0.59 (0.24)	0.85 (0.13)
Individual-level characteristics			
Age (months), mean (SD)	13.4 (5.0)	11.8 (7.0)	11.6 (6.5)
Male, % (*n*)	55 (321)	47 (362)	44 (376)
Currently breastfed, % (*n*)	75 (427)	82 (623)	85 (705)
Reported diarrhea 2 weeks before the survey, % (*n*)	35 (201)	24 (182)	22 (184)
Reported cough 2 weeks before the survey, % (*n*)	33 (192)	18 (138)	28 (242)
Reported fever 2 weeks before the survey, % (*n*)	50 (290)	31 (236)	34 (294)

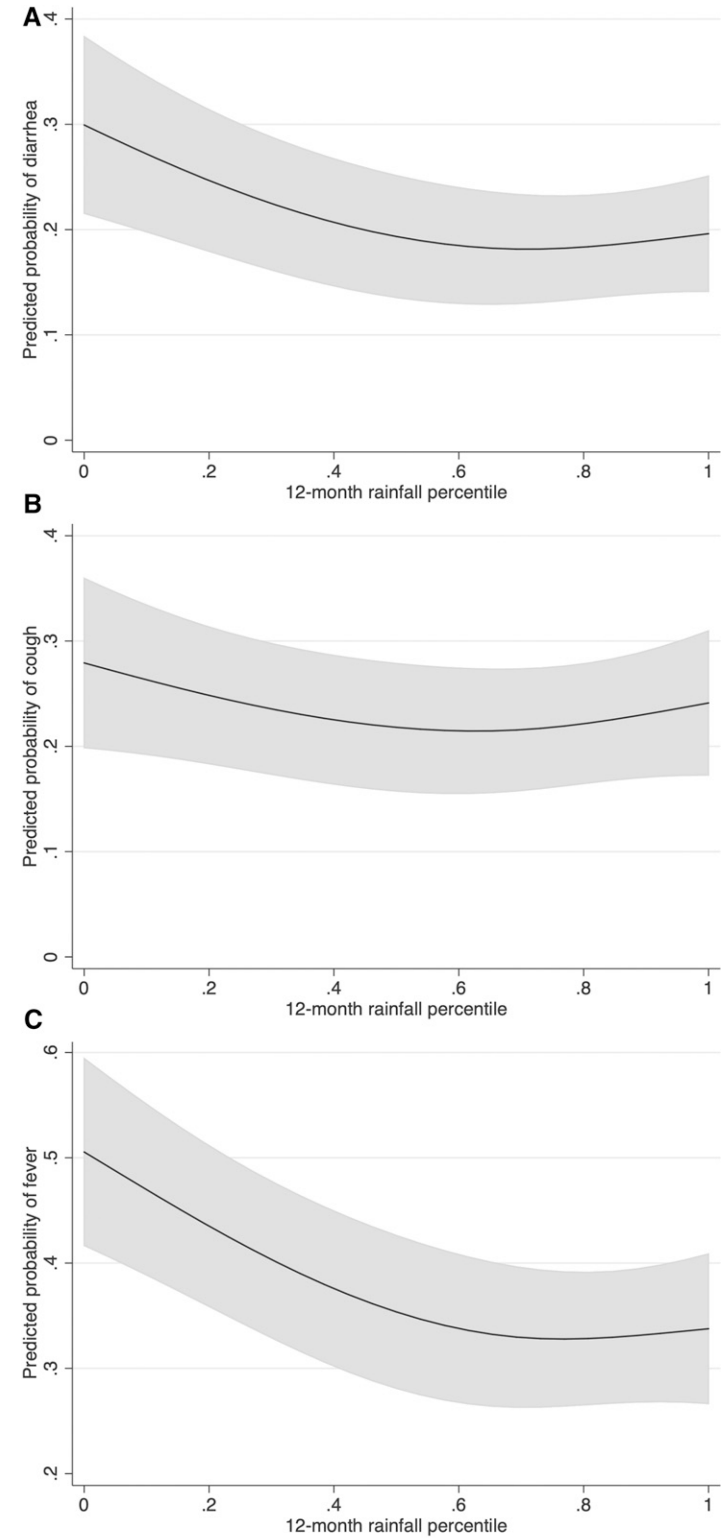

FIGURE 1. (**A**–**C**) Adjusted predicted probabilities and 95% CIs of caregiver-reported diarrhea, cough, and fever among children younger than 24 months resulting from logistic regression with restricted cubic splines modeling the relationship between each outcome and annual precipitation deviations (in percentiles).

health. These results highlight the potential impacts of reduced annual rainfall on illness. Uganda has been experiencing increased periods of drought since the 1980s; therefore, there may already be deleterious effects.[14] We did not find evidence for a relationship between short-term exposure to precipitation and childhood illness, potentially because 30 days is insufficient time to impact illness trajectories. However, this explanation is in contrast with previous work that has linked precipitation extremes (both excessive rains and drought) with diarrhea and fever (malaria) in very short time windows.[18–20] Another possibility is that Uganda did not experience short-term extreme levels of precipitation, and higher precipitation deviations represented reprieve from dry spells.

There are a number of hypothesized mechanisms linking drought and illness. Lower levels of rain may lead to poor nutrition, impacting a child's natural immunity. For example, lower precipitation is associated with stunting and drought is associated with micronutrient deficiencies, wasting, and delayed growth.[4,6,8] In addition, drought may affect air quality. For example, dust storms resulting from drought may be associated with respiratory illness and aerosol emissions from fires in drought-prone areas may lead to respiratory diseases.[10,12] Reduced precipitation may impact water availability and hygiene practices, which can contribute to diarrheal disease.[21]

This analysis is limited by its outcome, as caregiver-reported illness may be prone to mismeasurement and bias. The recall window for outcomes was 14 days; however, research suggests that recall beyond 7 days is error prone.[22] Without clinical confirmation, there likely remains mismeasurement of the three outcome variables. Despite this, caregiver symptom-based reporting has been validated and shown to have relatively high sensitivity and specificity, particularly among children less than 2 years of age.[23] In addition, these outcomes have been widely published.[13,24] Although the prevalence of caregiver-reported fever appears high, especially during the first survey wave when half of the caregivers reported fever, this magnitude is consistent with other studies in sub-Saharan Africa over a similar time period.[25] Nevertheless, future work should examine these relationships with improved measurement.

Projecting changes in rainfall patterns is inherently challenging and uncertain. Projections suggest that Uganda may begin to experience higher rates of heavy rain during the rainy season, resulting in a high likelihood of flooding events.[26] We observed only a slight increase in illness at higher levels of precipitation; this may be because extreme levels of heavy rain were not observed over the study window. Future work should focus on the potential health impacts of these events.

Despite uncertainties in climate change projections, these results suggest that the current trends of reduced rainfall are likely adversely impacting child health outcomes. Anticipating these illnesses during times of reduced rainfall may allow for earlier interventions and allocation of resources to areas of need.

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