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Extremes in water availability and suicide: Evidence from a nationally representative sample of rural Indian adults

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ABSTRACT

Background: Extremes in water availability, either exceptionally wet or dry conditions, can damage crops and may detrimentally affect the livelihood and well-being of people engaged in agriculture. We estimated the effect of water availability on suicide in rural India, a context where the majority of households are dependent upon agriculture.

Methods: We used data from a nationally representative sample of 8.5 million people who were monitored for causes of death from 2001 to 2013. Water availability was measured with high-resolution precipitation and temperature data (i.e., the Standardized Precipitation Evapotranspiration Index). We used a fixed effects approach that modeled changes in water availability within districts (n = 569) over time (n = 13 years) to estimate the impact on suicide deaths. We restricted our analysis to rural areas and to deaths occurring during the growing season (June–March) among adults aged 15 or older, and controlled for sex, age, region, and year. We used Poisson regression with standard errors clustered at the district level and total deaths as the offset.

Results: There were 9456 suicides and 249,786 total deaths in our study population between 2001 and 2013. Compared to normal growing seasons, the percent of deaths due to suicide increased by 18.7% during extremely wet growing seasons (95% CI: 6.2, 31.2) and by 3.6% during extremely dry growing seasons (95% CI: −17.9, 25.0). We found that effects varied by age.

Conclusions: We found extremes is water availability associated with an increase in suicide. Abnormally wet growing conditions may play an important, yet overlooked, role in suicide among rural Indian adults.

1. Introduction

In 2016, approximately 230,000 Indian adults died by suicide, which accounted for more than one-quarter of all suicides worldwide (India State-Level Disease Burden Initiative Suicide Collaborators, 2018). Suicide rates, exceptionally high throughout India, vary substantially by geographical area. Age-standardized rates are approximately three times higher in southern states compared with the rest of India, and rates are approximately two times higher among rural Indians compared with urban Indians (Patel et al., 2012). This geographical patterning indicates that large-scale social, economic, and environmental determinants may play a key role in suicide risk.

Extremes in water availability, either very dry (drought) or very wet (flood) conditions, is a potentially important environmental driver of suicide in rural India. Agriculture is a source of livelihood for a majority of rural Indian households (Ministry of Agriculture and Farmer Welfare, 2015), and extremes in water availability are linked with reduced crop yields (Singh et al., 2011; Auffhammer et al., 2012), which pose major threats to livelihoods and well-being. National statistics collected from the National Crime Records Bureau (NCRB) find that bankruptcy and indebtedness are the top causes of suicide among farmers and cultivators (National Crime Records Bureau, 2016). Poor crop yield may be especially detrimental to those engaged in subsistence agriculture: a study from the Indian state of Maharashtra found that crop loss and

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indebtedness were the main causes of suicide among small-scale farmers (88%) but not large-scale farmers (11%) (Mohanty, 2005).

While there are compelling reasons why extremes in water availability may affect suicide, strong population-based empirical research from India is lacking. A population-based study using suicide counts from the National Crime Records Bureau (NCRB) found that high temperatures – which the author inferred may damage crops – were associated with suicide (Carleton, 2017). While this population-based study provides the most rigorous evidence to-date, the study had some noted limitations, including using temperature as a proxy for growing conditions (Das, 2018) and using suicide data from the NCRB (Murari et al., 2018). Using temperature to infer crop damage is challenging because there are well-established links between high temperature and suicide in general (non-agrarian) populations across the globe (Page et al., 2007; Likhvar et al., 2011; Kim et al., 2011, 2016; Burke et al., 2018), and thus observed effects may be due to high temperature and not crop damage. In addition, using NCRB data presents challenges because suicide is highly stigmatized in India, and validation work indicates the NCRB underestimates suicide by at least 25% among men and 36% among women – and even more so among young women – (Patel et al., 2012) which may lead to biased estimates.

In this study, we build upon prior research to provide a more comprehensive assessment of the link between water availability and suicide. We use a validated measure of water availability measured at the local (district) level linked with a nationally representative sample of 8.5 million people whose cause of death was ascertained through comprehensive procedures. Using this dataset, we use temporal and spatial variation in water availability to estimate the effect of water availability on suicide among rural Indian adults.

2. Methods

2.1. Study population

Data came from the Million Deaths Study (MDS), which monitored the causes of death between the years 2001 and 2013 among approximately 8.5 million individuals living in randomly selected rural ‘small areas’ (Causes of death in India, 2009; Causes of death in India, 2004; Jha et al., 2006). These small areas were delineated by the decennial Indian census, which parsed all of India, encompassing India’s 28 states and 7 union territories, into approximately 1 million small areas. Using these small areas defined by the census, the Registrar General of India’s Sample Registration System (SRS) randomly selected urban and rural small areas to be monitored for all deaths twice a year. We restricted our sample to rural areas, which were defined by the Indian census as areas that met at least one of the following criteria: i) the area had less than 5000 people, ii) more than 25% of the male working population engaged in agricultural pursuits, or iii) the area had a density less than 1000 per square mile (Office of the Registrar G, 2001).

Rural areas were randomly selected by the SRS twice. In 2001, 4410 rural sample units, covering approximately 5.0 million people, were selected from the small areas defined by the 1991 census (Causes of death in India, 2009). In 2004, 4433 rural sample units, covering approximately 3.5 million people, were selected from the small areas defined by the 2001 census (Causes of death in India, 2004). Each small rural area was composed of approximately 150 households. We used data from both sampling frames (i.e., 2001–2003 & 2004–2013). The selected SRS areas are representative of the Indian population at the state level. Because suicide is rare among children, we restricted our analysis to people aged 15 or older. Our main unit of analysis was district, which on average contained approximately eight small rural areas selected by the SRS.

We included all districts that had small areas classified as rural by the SRS and were included in the MDS study. The MDS encompasses all of India, which was divided into 605 districts at the time of the study. Due to the small geographical area covered in the districts encompassing Delhi ($n = 9$) and Mumbai ($n = 2$), we combined these areas so that there was one district representing Delhi and one representing Mumbai, resulting in 594 districts. We also excluded three districts because they were island territories (i.e., Andaman and Nicobar; Lakshadweep) because effects may be different among people living on islands. Among the remaining 591 districts, 575 had rural small areas that were selected and followed by the SRS. District boundaries within India change over time, and we used district definitions preceding our study, from approximately 1998, so that we could model changes in consistent districts over time. We linked these districts with water availability data (i.e., SPEI) derived from another dataset, which is described in the variables section. Within India, districts have multiple names and multiple alterative spellings, and in a few cases ($n = 6$) we could not successfully link districts from these two data sources. Our final sample included 569 districts.

2.2. Variables

The underlying cause of death for all deaths occurring in the selected small areas was determined with an enhanced and validated form of verbal autopsy based on the World Health Organization’s 2012 instrument (World Health Organization, 2012), and which includes structured questions and a half-page local language narrative of the symptoms and treatments preceding death. In each home with a recorded death, a non-medical SRS field surveyor conducted a structured interview with the next of kin (Causes of death in India, 2009; Jha et al., 2019). The completed forms were randomly assigned to two independent physicians who were specially trained to determine the underlying cause of death (Causes of death in India, 2009; Jha et al., 2006). In cases where physicians did not agree on the cause of death, disagreements were adjudicated by a senior third physician. Cause of death was categorized using the International Classification of Disease, 10th edition (ICD-10), and suicide deaths were defined as those eventually assigned ICD-10 codes X60 to X84 (intentional self-harm). The SRS field surveyor also collected basic demographic information for each decedent, including age, gender, and urban or rural location.

The exposure was water availability during the summer (Kharif) and winter (Rabi) growing seasons, which we combined into one 10-month growing period from June 1 to March 31. Water availability was measured with the Standardized Precipitation Evapotranspiration Index (SPEI), which is derived by taking the difference between precipitation amount and potential evapotranspiration during a specified time period (Vicente-Serrano et al., 2010). Thus, values at approximately zero indicate normal water availability, positive values denote a surplus in water, and negative values denote a dearth in water (Vicente-Serrano et al., 2012). Validation work indicates that the SPEI can detect both extremely wet and dry conditions. A study in China found that positive (wet) and negative (dry) SPEI values corresponded to major drought and flood events recorded in the historical record (Zhang et al., 2015), and a study comparing SPEI values with ecosystem productivity found them highly correlated, especially in the Southern Hemisphere ($r = 0.93$) (Wang et al., 2018). Another study compared a number of drought indices (i.e., the Standardized Precipitation Index, plus four versions of the Palmer drought severity index) with streamflow, soil moisture, tree ring width, and wheat crop yields, and found that the SPEI most accurately captures drought (Vicente-Serrano et al., 2012).

We derived SPEI values using high-resolution (i.e., 0.05° degree) daily precipitation and temperature data, which we used to calculate average district-level SPEI values during the growing season (June 1 - March 31) for each year during our study period. Methods describing how these values are derived is available elsewhere, and the data are available publicly (Aadhar and Mishra, 2017a). We used established cut-points to create indicator variables for moderate (−0.8 to −1.2), severe (−1.2 to −1.6), extreme (−1.6 to −2.0), and exceptional (−2.0 or less) drought (Svoboda et al., 2002), and we applied corresponding cut-points to classify moderate (0.8–1.2), severe (1.2–1.6), extreme

(1.6–2.0), and exceptional (2.0 or more) wet conditions. Normal conditions were defined as SPEI values between −0.8 and 0.8.

Because prior research found that crop loss due to extremes in water availability was associated with suicide in certain regions (Mishra, 2006), we created an indicator variable for region, which was defined as Central (Chhattisgarh, Madhya Pradesh, Uttarakhand, Uttar Pradesh), Eastern (Bihar, Jharkhand, West Bengal, Odisha), Northeast (Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim, Tripura), Southern (Andhra Pradesh, Karnataka, Kerala, Lakshadweep, Puducherry, Tamil Nadu), Western (Dadra and Nagar Haveli, Daman and Diu, Goa, Gujarat, Maharashtra), and Northern (Haryana, Himachal Pradesh, Punjab, Rajasthan, Delhi, Chandigarh, Jammu and Kashmir). A map of these regions is shown in Appendix 1.

2.3. Analysis

We used temporal and spatial variation in water availability to estimate the effect of changes in water availability occurring within the same districts over time on the corresponding change in suicide counts using fixed effects regression. We chose a fixed effects approach over a random effects approach because information on potentially important confounders of the relation between drought and suicide, such as a district's level of economic development or dependence upon agriculture, were unavailable. A fixed effects approach, where districts serve as their own controls, accounts for unmeasured differences in time-invariant characteristics of districts by design. This includes differences in baseline suicide rates, which prior research indicates varies considerably by geographical area (Patel et al., 2012).

We created a dataset with four separate strata for each possible sex and age combination (i.e., male or female; aged 15 to 40, or 40 and older) for each district (n = 569) and each year (n = 13), resulting in 29,588 observations. Within each of these strata, we calculated the total number of deaths, the number of deaths due to suicide, and the corresponding measure of water availability, which was measured by the SPEI. Water availability was initially defined with a 9-level indicator variable (i.e., normal conditions; moderate, severe, extreme, or exceptional drought; moderate, severe, extreme, or exceptional wetness). Wald tests indicated effect estimates were similar for many categories of wetness or dryness, and thus we combined categories into 3 levels, including normal (SPEI between −1.6 and 1.6), extremely wet (SPEI greater than 1.6), and extremely dry (SPEI less than −1.6). We estimated standard errors clustered at the district level and used total deaths as the offset (Bertrand et al., 2004). We allowed trends in suicide rates to differ by region with a product term between year fixed effects and region.

We modeled suicide death counts with Poisson regression, which assumes that the conditional distribution of suicide counts in each district d during growing season g is Poisson:

$$y_{dg} = \tilde{}Poisson(u_{dg})$$

The model is expressed by the equation:

$$u_{dg} = \exp(\propto + \beta X\, SPEI_{dg} + \sigma_d + \rho_r + \tau_y + \pi_{yr} + \theta_f + \delta X_{dg} + \ln(tdeaths_{dg}))$$

where.

u_{dg} is the number of suicides in each district d in growing season g.

SPEI is the Standardized Precipitation Evapotranspiration Index for each district d in each growing season g.

σ_d are district fixed effects.

ρ_r are region fixed effects.

τ_y are year fixed effects (to control for secular trends in suicide rates).

π_{yr} is an interaction term between region and year (to allow trends in suicide to vary by region).

θ_f is an indicator variable for sampling frame (i.e., 2001-03, 2004–2013).

X_{dg} are basic demographic covariates (age, sex) at the district-growing season level.

$tdeaths_{dg}$ is the total number of deaths in each district d in growing season g.

The effect of extremes in water availability may vary by region or demographic factors. We tested if our effects differed by these factors by including interaction terms between 1) region and SPEI, 2) sex and SPEI, and 3) age and SPEI. We tested interactions with Wald tests. In instances where we found significant interactions, we included the interaction in our model, and also included an additional parameter to allow for differential secular trends for demographic factors (e.g., age X year).

2.4. Sensitivity analyses

We performed additional analyses to assess the robustness of our results. Our main analysis estimated the effect of changes in water availability on the corresponding change in suicide within the same time period (June–March), and we performed additional analyses to test whether water availability preceded suicide. First, we excluded deaths (both suicides and total deaths) occurring during the first two months of the growing season (i.e., June and July), because these deaths may be attributable to the conditions of the preceding growing season. Thus, these analyses estimate the effect of water availability between June and March on deaths occurring between August and March. Second, we estimated effects with 1 and 2 month time lags. This analysis was conducted by summing total death and suicide counts during a time period that was one month (July–April) and two months (August–May) later than the growing season, and then estimating the lagged effect of water availability during the growing season (June–March) on suicides between July and April (1 month lag) and August to May (2 month lag). Third, we assessed the cumulative effect of water availability over the preceding two years by including both current year and past year SPEI values in the same model.

We used total deaths as the offset, and a key assumption is that, within districts, water availability does not substantially affect non-suicide death counts. While specific causes of death might be affected by water availability in India (e.g., snake bites, malaria), an increase or decrease in these other types of death will only lead to bias if total death counts are affected. We tested this assumption by estimating the relation between water availability and non-suicide deaths.

We also conducted two falsification tests to examine if our main analysis might be biased (Prasad and Jena, 2013). First, we identified a related type of death that should not be affected by water availability, deaths from unintentional injuries. These deaths were predominantly due to road traffic accidents (35%) and falls (29%), which we believe should not be affected by long-term water availability over an entire growing season. Second, we estimated the effect of water availability on suicide in urban areas, which encompassed 340 districts in our sample. In both analyses, finding an association between water availability and our outcome suggests that our main analysis may be biased, whereas finding no association provides evidence that our assumptions may be reasonable. We estimated these associations with the same models used in our main analysis, namely, a fixed effects model that adjusted for age, sex, year, region, district, and sampling frame, and allowed trends to differ by region (year X region).

3. Results

There were 249,786 deaths and 9456 suicides that occurred during the growing season among adults aged 15 and older living in rural India in our study population. The most common modes of suicide were poisoning (40%), hanging or strangulation (37%), and burning (10%). Table 1 shows that the percent of deaths due to suicide was highest among those aged 15 to 40 and people living in rural areas, and that suicide rates were almost as high in women as men (male-to-female suicide ratio = 1.1). There was substantial variation in the percent of

Table 1
Characteristics of suicide deaths, Million Deaths Study, India, 2001–2013.

	Suicide deaths	Total deaths	Percent of deaths due to suicide
Age			
0 to 15	268	110017	0.2
15 to 40	9380	72873	12.9
40 or older	4518	399083	1.1
Sex			
Male	8154	327151	2.5
Female	5743	255052	2.3
Location			
Urban	2350	123555	1.9
Rural	11816	458711	2.6
Time of year			
Growing season (June 1 - March 31)	11547	491472	2.3
Non-growing season (April 1- May 31)	2527	87490	2.9

deaths due to suicide by district, which was highest in the South (Fig. 1).

There were differences in water availability between districts, and water availability changed substantially during wet and dry years (Fig. 2). Extremely wet conditions were more common than extremely dry conditions (Fig. 3): on average, each year 1.7% of districts experienced extreme or exceptionally dry conditions, and 6.6% experienced extreme or exceptionally wet conditions. There were notable fluctuations in water availability by year, and there were also fluctuations in the percent of deaths due to suicide (Fig. 4).

In analyses restricted to deaths in rural areas and occurring during the growing season, models that adjusted for district, year, sample frame, sex, age, region, and allowed for secular trends in suicide by region (year X region), we found that the percent of deaths due to suicide increased during growing seasons with extremes in water availability (Table 2). The predicted percent of deaths due to suicide increased from 6.1 (95% CI: 5.9, 6.3) during normal growing seasons to 7.2 (95% CI: 6.5, 8.0) during extremely wet growing seasons, which corresponded to a relative increase of 18.7 percent (95% CI: 6.2, 31.2) and an absolute increase of 1.1 percentage points (95% CI: 0.4, 1.9). The predicted percent of deaths due to suicide also increased slightly during extremely dry conditions (6.3; 95% CI: 5.0, 7.6), which corresponded to a relative increase of 3.6 percent (95% CI: −17.9, 25.0) and an absolute increase of 0.2 percentage points (95% CI: −1.1, 1.5) compared to normal conditions. However, effect estimates were imprecise and included the null.

In fully adjusted models, we found substantial variation in effects by age ($p = 0.01$) but not region ($p = 0.32$) or sex ($p = 0.78$). Therefore, in additional models we allowed effects to vary by age by including a product term between age and SPEI and allowing these effects to vary by year (age X year). Among adults aged 15 to 40, extremely wet conditions corresponded to a relative increase of 15.5 percent (95% CI: 1.9, 29.2) and an absolute increase of 1.9 percentage points (95% CI: 0.3, 3.5) compared to normal growing conditions. However, extremely dry conditions did not correspond to an increase in suicide. Among adults aged 40 and older, extremely wet conditions corresponded to a relative increase of 25.5 percent (95% CI: 4.4, 46.6) and an absolute increase of 0.3 percentage points (95% CI: 0.0, 0.5) compared to normal conditions, and extremely dry conditions corresponded to a relative increase of 42.8 percent (95% CI: 1.4, 84.1) and an absolute increase of 0.4 percentage points (95% CI: 0.0, 0.9). The much larger absolute differences observed among those aged 15 to 40 compared to those 40 and older reflect the much higher percent of suicide deaths among this younger age group (12.9%) compared to the older age group (1.1%), as shown in Table 1.

In sensitivity analyses assessing temporality, we found very similar

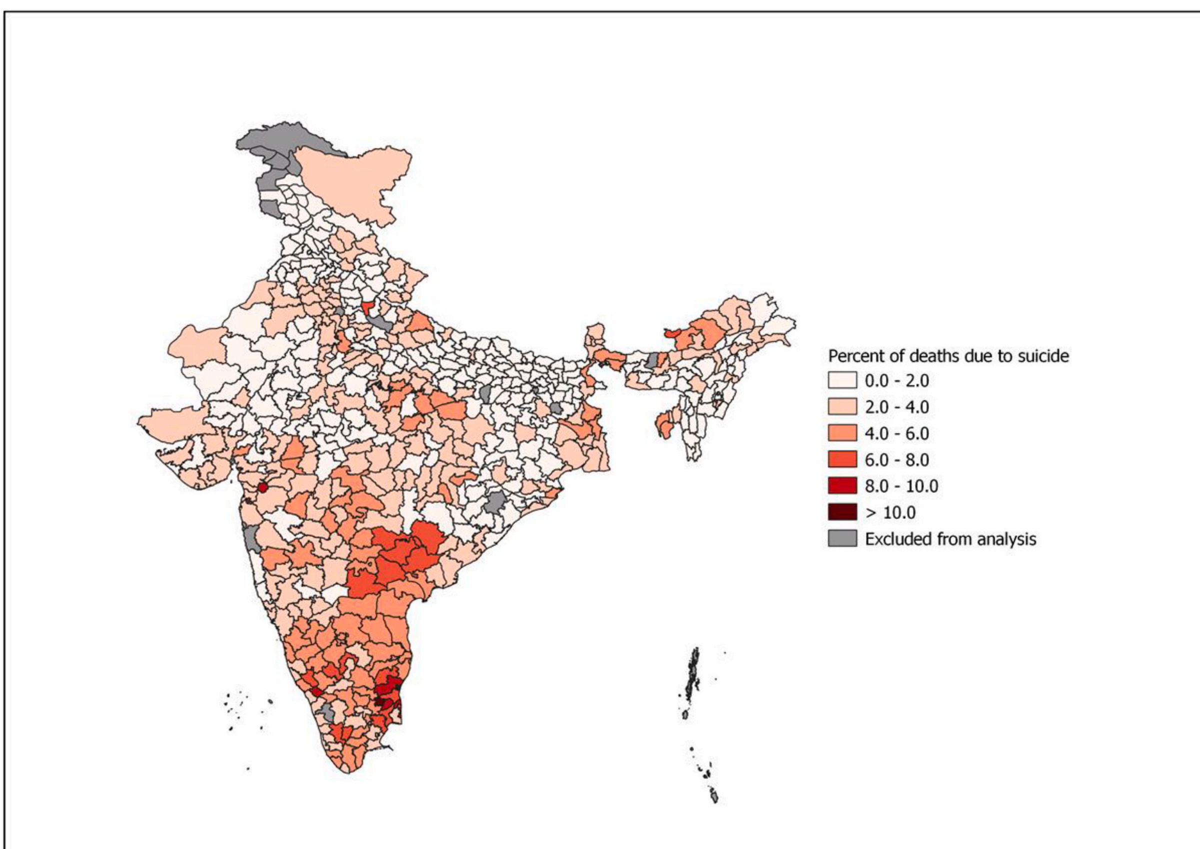

Fig. 1. Percent of deaths due to suicide by district, Million Deaths Study, India, 2001–2013. Note: Districts excluded from analysis include: i) those that were composed solely of urban areas (n = 16), ii) island territories (n = 3), and iii) districts that had data sources that could not be successfully linked (n = 6).

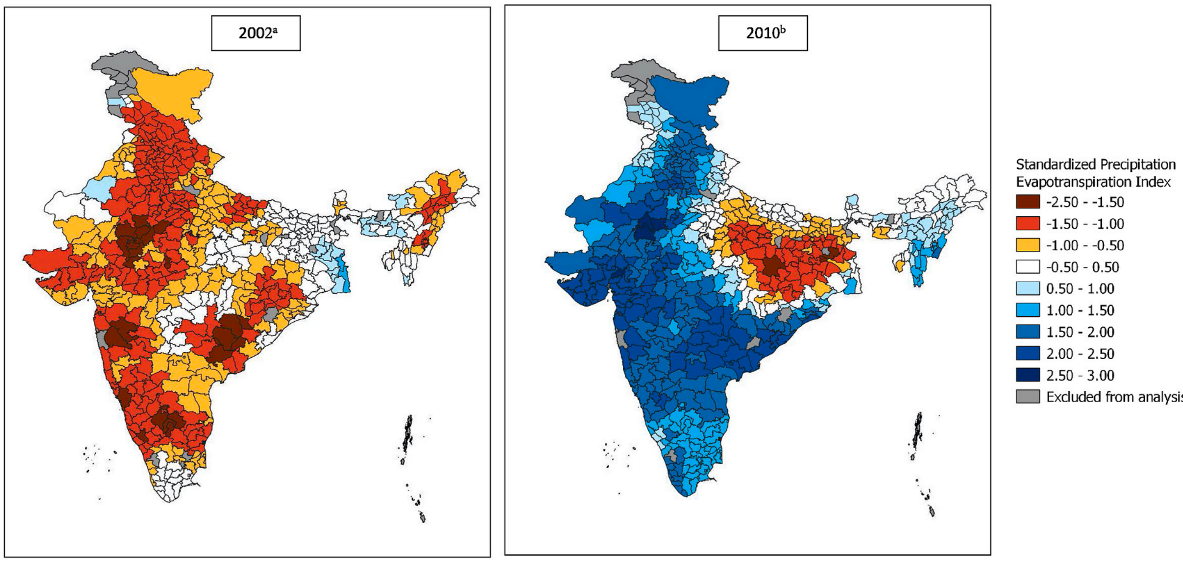

Fig. 2. Standardized Precipitation Evapotranspiration Index (SPEI) values during a dry (2002) and wet year (2010). [a]10-month average SPEI values from June 1, 2002 to March 31, 2003. [b]10-month average SPEI values from June 1, 2010 to March 31, 2011. Notes: 1. Negative values (orange or red) indicate dry conditions, and positive values (blue) indicate wet conditions. 2. Districts excluded from analysis include: i) those that were composed solely of urban areas (n = 16), ii) island territories (n = 3), and iii) districts that had data sources that could not be successfully linked (n = 6). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

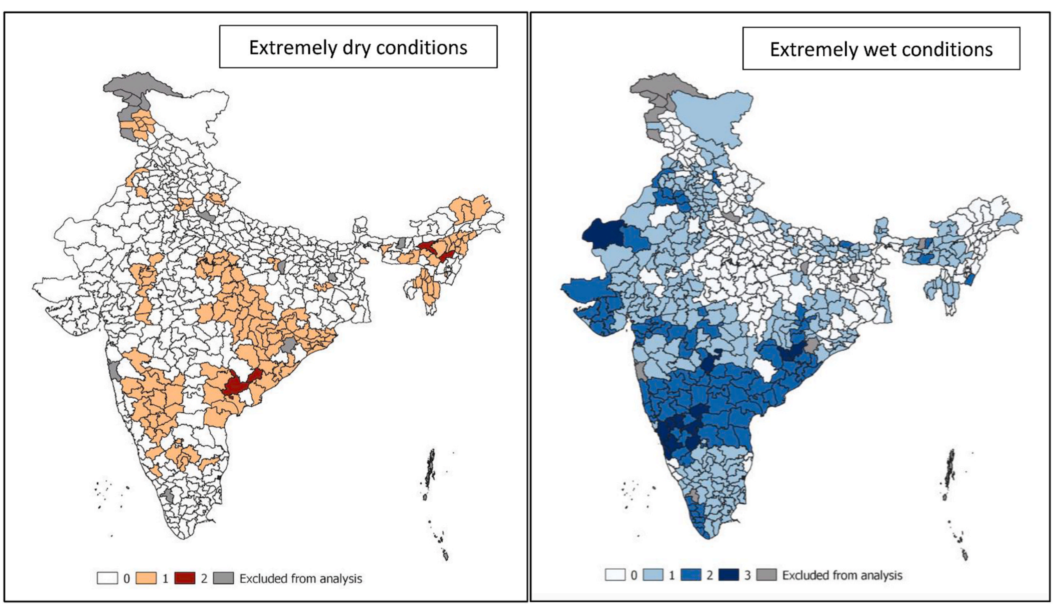

Fig. 3. Frequency of extremely dry (SPEI ≤ -1.6) and extremely wet (SPEI ≥ 1.6) conditions from 2001 to 2013. Note: Districts excluded from analysis include: i) those that were composed solely of urban areas (n = 16), ii) island territories (n = 3), and iii) districts that had data sources that could not be successfully linked (n = 6).

effect estimates to our main results when we excluded deaths occurring at the beginning of the growing season (Appendix 2), and when we added a one or two month time lag between water availability and suicide (Appendix 3 & 4). However, we did not find an association between extremes in water availability and suicide when we modeled the cumulative effect of past and current year (Appendix 5), indicating that water availability in the current year, but not preceding year, may be most relevant for suicide. Our analysis estimating the relation between water availability and non-suicide deaths found slight changes in non-suicide deaths (Appendix 6). The largest change was among adults aged 15 to 40 during extremely wet conditions, where suicide deaths decreased by 4.5 percent (95% CI: −6.3, −2.7) relative to normal conditions. These results indicate that non-suicide deaths are only slightly affected by water availability, and thus provides evidence that total deaths is an appropriate offset.

Our falsification tests were supportive of the conclusions from our primary analysis (Appendix 7 & 8). First, we did not find strong evidence that our negative control, unintentional injury deaths, was associated with a relative increase in either extremely dry conditions (relative change = 2.3; 95% CI: −9.5, 14.1) or extremely wet conditions (relative change = 4.9; 95% CI: −2.3, 12.0) compared to normal conditions. Second, we did not find evidence of an effect of either extremely dry conditions (relative change = −16.3; 95% CI: −50.5, 18.0) or extremely wet conditions (relative change = 29.6; 95% CI: −2.3, 61.6) compared

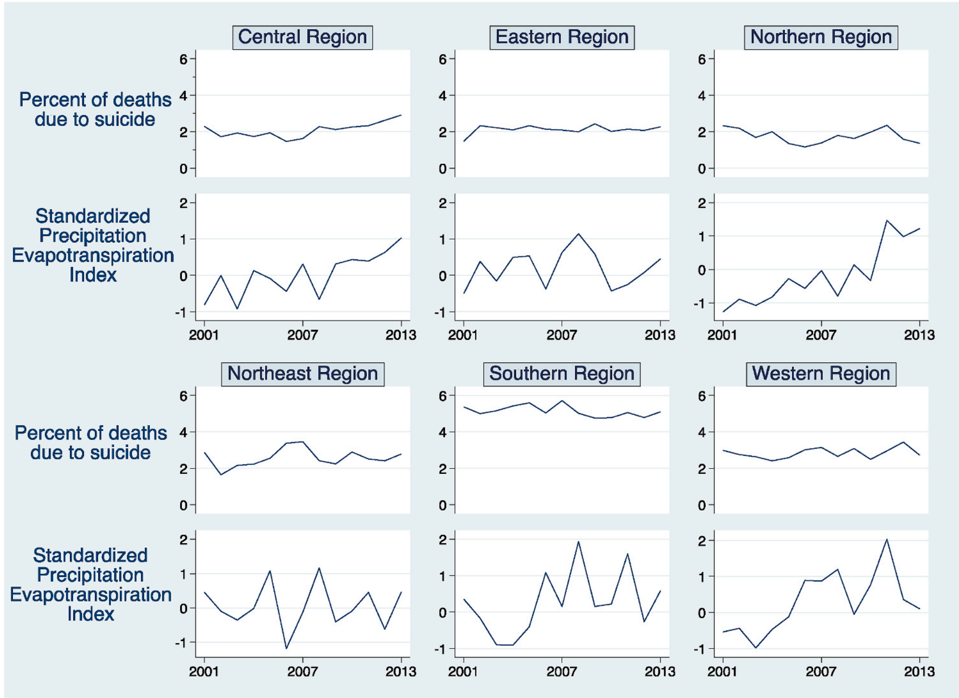

Fig. 4. Percent of deaths due to suicide and average Standardized Precipitation Evapotranspiration Index (SPEI) values by region, 2001 to 2013. Notes: 1. Years span from June 1 to March 31st of the following year, 2. Standardized Precipitation Evapotranspiration Index (SPEI) values above 0 denote wet conditions, and values below 0 denote dry conditions.

Table 2
Percent of deaths due to suicide (95% CI) as a result of extremes in water availability, as measured by the Standardized Precipitation Evapotranspiration Index (SPEI), rural India, 2001–2013.

	Normal (−1.6> SPEI <1.6)	Extremely dry (SPEI ≤ −1.6)			Extremely wet (SPEI ≥ 1.6)		
	Predicted % of deaths due to suicide	Predicted % of deaths due to suicide	Percent change from normal conditions	Absolute change from normal conditions	Predicted % of deaths due to suicide	Percent change from normal conditions	Absolute change from normal conditions
Main effects							
Adjusted for district[a]	2.8 (2.7, 2.9)	2.8 (2.2, 3.4)	0.3 (−22.5, 23.2)	0.0 (−0.6, 0.6)	3.0 (2.7, 3.3)	8.0 (−3.3, 19.3)	0.2 (−0.1, 0.5)
Fully adjusted[b]	6.1 (5.9, 6.3)	6.3 (5.0, 7.6)	3.6 (−17.9, 25.0)	0.2 (−1.1, 1.5)	7.2 (6.5, 8.0)	18.7 (6.2, 31.2)	1.1 (0.4, 1.9)
By age							
Aged 15 to 40[c]	12.1 (11.8, 12.5)	10.4 (7.7, 13.1)	−14.7 (−37.1, 7.7)	−1.8 (−4.5, 0.9)	14.0 (12.5, 15.6)	15.5 (1.9, 29.2)	1.9 (0.3, 3.5)
Aged 40 or older[c]	1.0 (1.0, 1.1)	1.4 (1.0, 1.9)	42.8 (1.4, 84.1)	0.4 (0.0, 0.9)	1.3 (1.1, 1.5)	25.5 (4.4, 46.6)	0.3 (0.0, 0.5)

[a] Includes fixed effect for district.
[b] Model controlled for year, sampling frame, age, sex, and region; included an interaction term between region and year (region X year); and a fixed effect for district.
[c] Model controlled for year, sampling frame, age, sex, and region; included interaction terms between SPEI and age (age X SPEI) and region and year (region X year); and a fixed effect for district.

to normal conditions in urban areas, although our analysis is likely underpowered to detect a difference; only 340 district had urban areas, and the sample size in urban areas was about a quarter of the size of rural areas (Table 1).

4. Discussion

We found extremes in water availability – especially extremely wet conditions – associated with an increase in the percent of deaths due to suicide among adults living in rural areas. Our study adds to a broad and robust literature on the health effects of weather extremes (Green et al., 2019), which are projected to increase due to climate change (Coumou and Rahmstorf, 2012).

Research investigating water availability and mental health has focused almost exclusively on drought (Hanigan et al., 1970–2007; Stain et al., 2011; O'Brien et al., 2014; Sena et al., 2014), and drought as a cause of suicide within India has dominated public discourse (McCarthy, 2016; Bhalla, 2017; Schilling, 2018; Karve and Ghosh, 2019; Kakondkarl, 2017). To our knowledge, no studies before ours have investigated the link between suicide and water availability at both extremes. We found, perhaps surprisingly, extremely wet conditions more strongly associated with suicide than extremely dry conditions. Our results were robust to a number of sensitivity analyses.

We found substantial variation in the effect of water availability by age, with adults aged 15 to 40 experiencing the largest percentage point increase in suicide deaths as a result of extremely wet conditions. We are not aware of research that has investigated the mental health effects of water availability among different age groups, and thus this is an underexplored area of research. Younger people in rural areas may be particularly susceptible to water extremes due to the migration of young adults with better mental health to urban areas (i.e., the healthy migrant effect), which has been postulated as a mechanism in other settings such as China (Gu et al., 2013), or cohort effects, such that people born during different time periods have a different risk profile for suicide (Stockard and O'Brien, 2002). Future research could investigate potential reasons for this heterogeneity.

While our study could not investigate potential mechanisms, very wet conditions could be especially damaging to crops because of limited means to mitigate conditions: while extreme drought might be offset by irrigation, extremely wet conditions – such as flooding or torrential rain – may result in conditions that are less easily mitigated and more devasting to crops. Excess soil moisture is linked with crop loss in the US (Rosenzweig et al., 2002), and research from India finds extreme wetness associated with diminished crop yields (Singh et al., 2011; Auffhammer et al., 2012). However, these Indian studies find extreme dryness associated with larger reductions in crop yield than extremely wet conditions (Singh et al., 2011; Auffhammer et al., 2012), although we found a stronger association between wet conditions and suicide. This difference could be due to additional mechanisms linking extremely wet conditions with suicide (e.g., cloud cover (Schneider et al., 2020; Kadotani et al., 2014), temperature (Page et al., 2007; Likhvar et al., 2011; Kim et al., 2011, 2016; Burke et al., 2018; Schneider et al., 2020)), or extremely wet conditions could truly be more damaging to crops, but the extant literature from India is incomplete; this literature used rainfall as a proxy for drought and flood, which is a less accurate measure of water availability than measures (such as the SPEI) that integrate temperature (Aadhar and Mishra, 2017b).

Extremes in water availability may affect suicide by impacting crop production, and thus investigating the link between crop yield and suicide would provide support for this mechanism. Regrettably, we were not able to investigate crop yield, or factors related to crop yield (e.g., irrigation, crop types) directly; although crop yield data by district is publicly available, district boundaries changed over time, which precludes a longitudinal analysis between crop yield and suicide. Our study overcame this challenge by collecting suicide counts in districts that were consistently defined over time, and then linking these consistently defined districts to granular, geographical data on water availability. Thus, while our approach allows a longitudinal analysis of changes in water availability over time, it does not allow linkages with other data sources collected at the district level that could complement our main analysis.

Climate projections indicate extreme weather will increase in South Asia. Projections show the frequency of years with extremely high and extremely low rainfall will increase, and seasonal variation in rainfall will be amplified, with precipitation decreasing by 30% in the dry season and increasing by 30% in the wet season (The World Bank, 2013). These predictions portend even more challenging growing conditions in the coming years and potentially even more suicides attributable to extremes in water availability. Indian governmental responses to extremes in water availability (specifically drought) have been criticized as reactive and ineffective (Choudhury and Sindhi, 2017), and these projections highlight that a comprehensive governmental strategy to ameliorate the effects of water availability extremes is urgently needed. Our findings indicate public health and governmental monitoring and response to adverse growing conditions within India should encompass exceptionally wet conditions.

Our study has a number of strengths. First, we leveraged a unique population-based data source with stringent methods for ascertaining cause of death. Prior studies rely on suicide counts collected by the NCRB, which substantially under-counts suicide (Patel et al., 2012). Second, we used an approach that controls for district-level differences in suicide rates with fixed effects regression. Suicide rates vary substantially by district, and by controlling for these differences, our study can provide accurate estimates of the effect of water availability on suicide. Third, we measured water availability with a validated scale, measured at the district level, which provides an accurate picture of growing conditions at local levels. Fourth, research investigating water availability and mental health has focused almost exclusively on drought (Hanigan et al., 2012; Stain et al., 2011; O'Brien et al., 2014; Sena et al., 2014), and we investigated effects at both extremes.

Our study has limitations. First, because suicide was rare and our study aggregated deaths to small geographical areas, our assessment of effect heterogeneity by sex, region, and age may have been underpowered to detect differences. Relatedly, we could not investigate heterogeneity by more than two age categories due to the sparseness of suicide data. Second, because of limited demographic indicators collected by the MDS, we were not able to investigate effects among specific demographic groups that may be most affected by water availability, such as the poor or farmers. Third, there may be residual confounding of our effect estimates due to unmeasured time-varying characteristics of districts (e.g., economic downturns), as well as bias due to spillover effects from adjacent districts. Fourth, while we found compelling evidence that extremely wet conditions may affect suicide, our conclusions for extremely dry conditions were more ambiguous due to small effect estimates and wide confidence intervals. Finally, because we used the percent of total deaths due to suicide as the outcome, we cannot completely rule out the potential for confounding due to extreme growing conditions affecting other types of death, such as deaths due to malaria or snakebites. While our sensitivity analysis did not find non-suicide deaths strongly related to changes in water availability, we cannot rule this out as a source of residual confounding. Future research that replicates our findings and investigates effects with population denominators and for specific demographic groups, especially among different age groups, would be a welcome addition to the literature.

In summary, we found extremes in water availability, especially extremely wet conditions, associated with an increase in deaths due to suicide. Within India, exceptionally wet growing conditions should be considered an important population-level risk factor for suicide in public health and governmental interventions that aim to address these preventable deaths.

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CRediT author statement

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.envres.2020.109969.

References

Aadhar, S., Mishra, V., 2017a. High-resolution near real-time drought monitoring in South Asia. Figshare. https://figshare.com/articles/High-resolution_near_real-time_drought_monitoring_in_South_Asia/5165401/1.
Aadhar, S., Mishra, V., 2017b. High-resolution near real-time drought monitoring in South Asia. Scientific Data 4.
Auffhammer, M., Ramanathan, V., Vincent, J.R., 2012. Climate change, the monsoon, and rice yield in India. Climatic Change 111 (2), 411–424.
Bertrand, M., Duflo, E., Mullainathan, S., 2004. How much should we trust difference-in-differences estimates? Q. J. Econ. 119 (1), 249–275.
Bhalla, N., 2017. Hit by Drought and Debt, Indian Farmers Protest with Human Skulls and Rats. Thomson Reuters Foundation. Published. https://www.reuters.com/article/us-india-farmers-suicides/hit-by-drought-and-debt-indian-farmers-protest-with-human-skulls-and-rats-idUSKBN16Y1O8. (Accessed 23 October 2019).
Burke, M., González, F., Baylis, P., et al., 2018. Higher temperatures increase suicide rates in the United States and Mexico. Nat. Clim. Change 8, 723–729.
Carleton, T.A., 2017. Crop-damaging temperatures increase suicide rates in India. Proc. Natl. Acad. Sci. U. S. A 114 (33), 8746–8751.
Causes of Death in India, 2004-2006. New Delhi, India: Office of the Registrar General.
Causes of Death in India, 2001-2003, 2009. Office of the Registrar General & Ministry of Home Affairs, New Delhi, India.
Choudhury, P.R., Sindhi, S., 2017. Improving the drought resilience of the small farmer agroecosystem. Econ. Polit. Wkly. 52 (32), 41–46.
Coumou, D., Rahmstorf, S., 2012. A decade of weather extremes. Nat. Clim. Change 2, 491–496.
Das, S., 2018. Unfounded assumptions in linking crop-damaging temperature and suicide in India. Proc. Natl. Acad. Sci. U. S. A 115 (2), E116.
Green, H., Bailey, J., Schwarz, L., Vanos, J., Ebi, K., Benmarhnia, T., 2019. Impact of heat on mortality and morbidity in low and middle income countries: a review of the epidemiological evidence and considerations for future research. Environ. Res. 171, 80–91.
Gu, L., Xie, J., Long, J., et al., 2013. Epidemiology of major depressive disorder in mainland China: a systematic review. PloS One 8 (6), e65356.
Hanigan, I.C., Butler, C.D., Kokic, P.N., Hutchinson, M.F., 2012. Suicide and drought in new South wales, Australia, 1970-2007. Proc. Natl. Acad. Sci. U. S. A 109 (35), 13950–13955.
India State-Level Disease Burden Initiative Suicide Collaborators, 2018. Gender differentials and state variations in suicide deaths in India: the Global Burden of Disease Study 1990-2016. Lancet Publ. Health 3 (10), e478–e489.
Jha, P., Gajalakshmi, V., Gupta, P.C., et al., 2006. Prospective study of one million deaths in India: rationale, design, and validation results. PLoS Med. 3 (2), e18.
Jha, P., Kumar, D., Dikshit, R., et al., 2019. Automated versus physician assignment of cause of death for verbal autopsies: randomized trial of 9374 deaths in 117 villages in India. BMC Med. 17 (1), 116.
Kadotani, H., Nagai, Y., Sozu, T., 2014. Railway suicide attempts are associated with amount of sunlight in recent days. J. Affect. Disord. 152–154, 162–168.
Kakondkarl, P., 2017. Farmer Suicides up 42% between 2014 & 2015. The Times of India. Published. http://timesofindia.indiatimes.com/india/farmer-suicides-up-42-between-2014-2015/articleshow/56363591.cms. (Accessed 23 October 2019).
Karve, A., Ghosh, A., 2019. The 'angriest' State in India Is Plagued by Suicides and Drought. Published. https://www.bloomberg.com/news/features/2019-04-16/the-angriest-state-in-india-is-plagued-by-suicides-and-drought. (Accessed 23 October 2019).
Kim, Y., Kim, H., Kim, D.S., 2011. Association between daily environmental temperature and suicide mortality in Korea (2001-2005). Psychiatr. Res. 186 (2–3), 390–396.
Kim, Y., Kim, H., Honda, Y., et al., 2016. Suicide and ambient temperature in east asian countries: a time-stratified case-crossover analysis. Environ. Health Perspect. 124 (1), 75–80.
Likhvar, V., Honda, Y., Ono, M., 2011. Relation between temperature and suicide mortality in Japan in the presence of other confounding factors using time-series analysis with a semiparametric approach. Environ. Health Prev. Med. 16, 36–43.
McCarthy, J., 2016. Amid India's drought crisis, suicides increase among farmers deep in debt. National Public Radio. Published. http://www.npr.org/2016/05/15/478114654/amid-india-s-drought-crisis-suicides-increase-among-farmers-deep-in-debt. (Accessed 23 October 2019).
Ministry of Agriculture & Farmer Welfare, 2015. Pocketbook of Agricultural Statistics. Government of India, New Delhi, India.
Mishra, S., 2006. Farmers' suicide in Maharashtra. Econ. Polit. Wkly. 41 (16), 1538–1545.
Mohanty, B.B., 2005. 'We are like the living dead': farmer suicides in Maharashtra, western India. J. Peasant Stud. 32 (2), 243–276.
Murari, K.K., Jayaraman, T., Swaminathan, M., 2018. Climate change and agricultural suicides in India. Proc. Natl. Acad. Sci. U. S. A 115 (2), E115.
National Crime Records Bureau, 2016. Accidental Deaths & Suicides in India 2015. Ministry of Home Affairs, New Delhi, India.
Office of the registrar general & census commissioner. Census data 2001/metadata. Accessed March 24, 2020.
O'Brien, L.V., Berry, H.L., Coleman, C., Hanigan, I.C., 2014. Drought as a mental health exposure. Environ. Res. 131, 181–187.
Page, L.A., Hajat, S., Kovats, R.S., 2007. Relationship between daily suicide counts and temperature in England and Wales. Br. J. Psychiatr. 191, 106–112.
Patel, V., Ramasundarahettige, C., Vijayakumar, L., et al., 2012. Suicide mortality in India: a nationally representative survey. Lancet 379 (9834), 2343–2351.
Prasad, V., Jena, A.B., 2013. Prespecified falsification end points: can they validate true observational associations? J. Am. Med. Assoc. 309 (3), 241–242.
Rosenzweig, C., Tubiello, F.N., Goldberg, R., Mills, E., Bloomfield, J., 2002. Increased crop damage in the US from excess precipitation under climate change. Global Environ. Change 12, 197–202.
Schilling, M.K., 2018. India's drought is killing crops—and pushing people to suicide. Published. https://www.newsweek.com/2018/08/24/india-drought-suicides-climate-change-farmers-skulls-heat-disaster-1072699.html. (Accessed 23 October 2019).
Schneider, A., Hampel, R., Ladwig, K.H., et al., 2020. Impact of meteorological parameters on suicide mortality rates: a case-crossover analysis in Southern Germany (1990-2006). Sci. Total Environ. 707, 136053.
Sena, A., Barcellos, C., Freitas, C., Corvalan, C., 2014. Managing the health impacts of drought in Brazil. Int. J. Environ. Res. Publ. Health 11 (10), 10737–10751.
Singh, A., Phadke, V.S., Patwardhan, A., 2011. Impact of drought and flood on Indian food grain production. In: Attri, S., Rathore, L., Sivakumar, M., Dash, S. (Eds.), Challenges and Opportunities in Agrometeorology. Springer, Berlin, Heidelberg.
Stain, H.J., Kelly, B., Carr, V.J., Lewin, T.J., Fitzgerald, M., Fragar, L., 2011. The psychological impact of chronic environmental adversity: responding to prolonged drought. Soc. Sci. Med. 73 (11), 1593–1599.
Stockard, J., O'Brien, R.M., 2002. Cohort effects on suicide rates: international variations. Am. Socio. Rev. 67 (6), 854–872.
Svoboda, M., LeComte, D., Hayes, M., et al., 2002. The drought monitor. Bull. Am. Meteorol. Soc. 83 (8), 1181–1190.
The World Bank, 2013. Turn Down the Heat: Climate Extremes, Regional Impacts, and the Case for Resilience. World Bank, Washington, DC.
Vicente-Serrano, S.M., Begueria, S., Lopez-Moreno, J.I., 2010. A multiscalar drought index sensitive to global warming: the standardized precipitation evapotranspiration index. J. Clim. 23, 1696–1718.
Vicente-Serrano, S.M., Begueria, S., Lorenzo-Lacruz, J., et al., 2012. Performance of drought indices for ecological, agricultural, and hydrological applications. Earth Interact. 16, 1–27.
Wang, H., He, B., Zhang, Y., Huang, L., Chen, Z., Liu, J., 2018. Response of ecosystem productivity to dry/wet conditions indicated by different drought indices. Sci. Total Environ. 612, 347–357.
World Health Organization, 2012. Verbal Autopsy Standards: 2012 WHO Verbal Autopsy Instrument. World Health Organization, Geneva.
Zhang, Y., You, Q., Lin, H., Chen, C., 2015. Analysis of dry/wet conditions in the Gan River Basin, China, and their association with large-scale atmospheric circulation. Global Planet. Change 133, 309–317.