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Research Article

Assessment of Drought Exposure to All-Cause Mortality in the Northern Rockies and Plains of the United States

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Abstract

Climate change is increasing the frequency, severity, and length of extreme events such as drought, heatwave, and wildfire. Drought is one of the more complex climate phenomena that changes regionally and temporally around the world and is likely to have a detrimental influence on human health. However, there is still a lack of research on the assessment of health risks associated with drought, particularly in the United States. The purpose of this study is to assess the risk ratio of monthly drought exposure to all-cause mortality in the Northern Rockies and Plains of the United States from 2000 to 2018. We applied two-stage time-series modeling approach to estimate the location-specific and overall risk ratio (RR) of all-cause mortality associated with the United States Drought Monitor (USDM) drought. In a general population, the all-cause mortality was positively associated with the severe drought (RR: 1.050, 95% Cr: 1.034 to 1.068). Our findings suggested that the elderly, both male and female were the most affected subgroups along with both metropolitan (urban) and non-metropolitan (rural) counties. These findings highlight the need for policymakers and communities to adopt more effective drought mitigation strategies in this region.

Key words: All-cause mortality; drought; risk ratio; human health; climate change;

Introduction

Extreme weather-related events such as heat waves, droughts, and wildfire are becoming more apparent and severe due to climate change, and they are expected to have a negatively impact on human health directly or indirectly through numerous pathways. These climatic risk events are associated with an increased risk of hospitalizations and mortality including cardiovascular, respiratory, mental health, renal disease [1-3], and continue to adversely affect economic and social development worldwide [4]. Moreover, it occurs concurrently and alters environmental risk factor such as air pollution level, increasing the risk of disease and mortality [5].

Drought is one of these climate risk occurrences that has an impact on a variety of sectors, including human health, human communities, natural resources, and ecosystems [6,7]. The severity and frequency have been risen dramatically as a result of climate change [8], and lead to less precipitation, higher temperature, and an increase in the risk of multiple diseases [9-15]. Despite the enormous public health concerns, the assessment of health risk associated with drought is frequently disregarded in the United States, particularly in regional contexts, to the best of our knowledge. Berman et al. showed that mortality risk in the western United States increased with less exposure to drought during worsening drought period. A subgroup, white population between the age 25-64 in the United States, had a positive association with short-term severe drought, but not in the general population [16]. A statistically significant association was not found in the general population of Nebraska, however, longer-term drought increased all-cause mortality in white individuals with aged 25 to 34 in metro counties and aged 45 to 54 in non-metro counties [17]. Recently, a large-scale climate region-level comprehensive assessment was conducted to evaluate the risk ratio of respiratory disease associated with drought exposure [9]. They discovered that drought has a considerable impact on the risk of respiratory death, although the magnitude and direction of the risk ratio varies between climate regions in the United States. A substantial amount of research has been undertaken outside of the United States by many researchers, and we link to a comprehensive review study that assesses the danger of extreme and climate exposure in public health consequences [18].

The majority of available research has shown that not all demographics (age, race, and sex) or geographics (rural and urban) are similarly affected negatively by drought exposure. Identifying the most vulnerable subpopulations is critical for public health officials and policymakers in order to establish an effective mitigation strategy to protect communities from such hazards. Multiple characteristics, such as socioeconomic status, education level, and healthcare facilities, may not be immediately quantifiable. Geographically, research have shown that rural and farming groups are more vulnerable to the negative effects of drought exposure [19]. According to the National Center for Health Statistics (NCHS) 2013 binary rural/urban categorization [21], approximately 88.3% of the counties in the Northern Rockies and Plains region were classified as rural. Because agriculture is the primary source of income in this region, residents are more exposed to outside activity and are expected to be more vulnerable to extreme climate occurrences, such as drought.

In this article, we aim to use two-stage time-series model to investigate the overall risk ratio of all-cause mortality associated with drought exposure in the Northern Rockies and Plains region of the United States. Our primary focus is to assess the health risks by the United States Drought Monitor (USDM) with the moderate and severe drought in this region. We assess risk in the entire population as well as subgroups stratified by age, sex, and urbanity. The findings of this study will be used to build effective drought mitigation methods for future management.

Materials and Methods

Health Data and Study Area

The mortality data can be requested from the Center for Disease Control and Prevention (CDC) from https://www.cdc.gov/nchs/nvss/nvss-restricted-data.htm. To access the health data, Data Use Agreement (DUA) and its related supporting materials should be submitted by all members for research purpose.

From January 2000 to December 2018, we obtained all-cause mortality data from the National Center for Health Statistics (NCHS). Using the data, we calculated monthly county-level death counts for all-cause mortality in the United States using International Classification of Diseases 10th revision (ICD-10 codes). These counts were stratified into four age groups (0-19, 20-39, 40-64, and above 65 years), three race groups (White, Black, and other than white and black), and sex (male and female). There are no other demographic variables available. The surveillance, epidemiology, and end results (SEER) program provided annual county-level population estimates by demographic variables (age, race, and sex), which were used in all months of each calendar year. For our study, we extracted all-cause mortality data for the Northern Rockies and Plains region (five states: Montana, Nebraska, North Dakota, South Dakota, and Wyoming) from the complete dataset. This region includes 291 counties (257 rural and 34 urban), with rural counties accounting for 88.3% of the total.

Drought Exposure Data

The USDM has been popularly used due to the robustness compared with other drought metrics [20, 24]. The USDM is a collaborative effort between the National Oceanic Atmospheric Administration (NOAA), the U.S. Department of Agriculture (USDA), and the National Drought Mitigation Center (NDMC) that has been providing weekly updates of drought conditions since 2000 [24]. Using a convergence of evidence approach, drought authors blend moisture deficits from across the hydrological cycle (i.e., precipitation, soil moisture, evaporation, etc) with drought reports from local experts to categorize drought conditions into one of six categories: wet to normal conditions (None), abnormally dry (D0), moderate (D1), severe (D2), extreme (D3), and exceptional (D4). We then reclassified USDM measures into monthly binary and three-level categories for this assessment.

A binary measure was estimated based on the frequencies of the drought status within a given month and county. ‘No drought’ was defined if the frequencies of no drought and D_0 condition in the week within a given month and county has more than the frequencies for all D_1 to D_4 conditions. Otherwise, it is labeled as a drought condition. The three-level categorical status is determined as (i) no drought in the binary measure; (ii) moderate drought (with binary drought condition and the sum of frequencies of D_1 and D_2 are greater than that of D_3 and D_4); and (iii) severe drought (with binary condition and the sum of frequencies of D_3 and D_4 are greater than that of D_1 and D_2).

Environmental and Other Data

The NCHS 2013 binary urban/rural classification codes were used to classify counties into metropolitan and non-metropolitan [21]. Metropolitan counties were divided into four categories of Large central metro, Large fringe metro, medium, and small metro based on population size. Non-metropolitan counties were further differentiated into two subcategories: micropolitan or noncore with population less than 50,000. In this article, we use the terms urban and rural interchangeably with metropolitan and non-metropolitan. Furthermore, monthly mean temperature anomaly was included from the NOAA’s Nclimgrid product at a 5km grid cell resolution [20]. We then calculated a monthly county level temperature anomaly using zonal averages of all grid cells falling inside a county boundary.

Statistical Modeling

Two-stage Model

We used a two-stage model to estimate county-level and overall risk ratio of all-cause mortality associated with drought exposure. In the first stage, a quasi-Poisson regression model was used to estimate location-specific risk ratio. We included cubic B-spline of months with 7 degrees of freedom to control long-term time and seasonal trend, second degree polynomial of anomaly temperature, and indicator variables to control calendar year effect. The drought exposure was used as three-level categorial variables (no drought, moderate, and severe). The values of logarithm for population size in each county were used an offset variable in the model.

In the second stage, we applied Bayesian meta regression model to estimate the overall risk ratio. Specifically, we combined county-specific risk ratio by a random effect Bayesian linear regression model to evaluate the overall risk ratio. We performed the entire analysis using two-stage model and stratified by age group, sex, and urbanicity. For all analysis, Statistical Analysis Software (SAS version 14.2) with PROC GLIMMIX and PROC MCMC procedures was used.

Results

Descriptive Statistics

Table 1 summarizes all-cause death counts in the Northern Rockies and Plains area from 2000 to 2018. The total number of all-cause deaths in this region was 813,121, with male having a higher mortality risk than female. The total number of deaths during the course of the study period was used to calculate the monthly mean death counts. Table 1 also shows that the observed and mean death counts increased substantially among the elderly population over 65, with females having higher mean death counts than males. Other age groups, on the other hand, followed an opposite pattern.

Table 1: Summary of all-cause death counts for study region during study period (2000-2018). N is the number of all-cause death county by each subgroup and SD indicates standard deviation.

Age group	**Male**			**Female**		
	N	Mean	SD	N	Mean	SD
Total	410,274	1799.45	149.86	402,847	1766.87	145.21
0-19	9589	42.06	7.99	6362	27.90	6.07
20-39	19,700	86.40	14.47	8796	38.58	7.69
40-64	91,311	400.49	46.57	56,337	247.09	31.29
+65	289,674	1270.05	115.15	331,352	1453.30	128.88

Figure 1 presents the distribution and the trajectory of percentage experiencing binary, moderate, and severe drought events in the Northern Rockies and Plains region. The percentage was calculated using the total number of drought events for binary, moderate, or severe in the counties over the study period and summarized by states (left panel) and year (right panel). We remind the readers that the binary drought events are further divided into either moderate or severe drought events. Various spatial and temporal patterns over the entire study period were identified within the same climate region (See Figure 1).

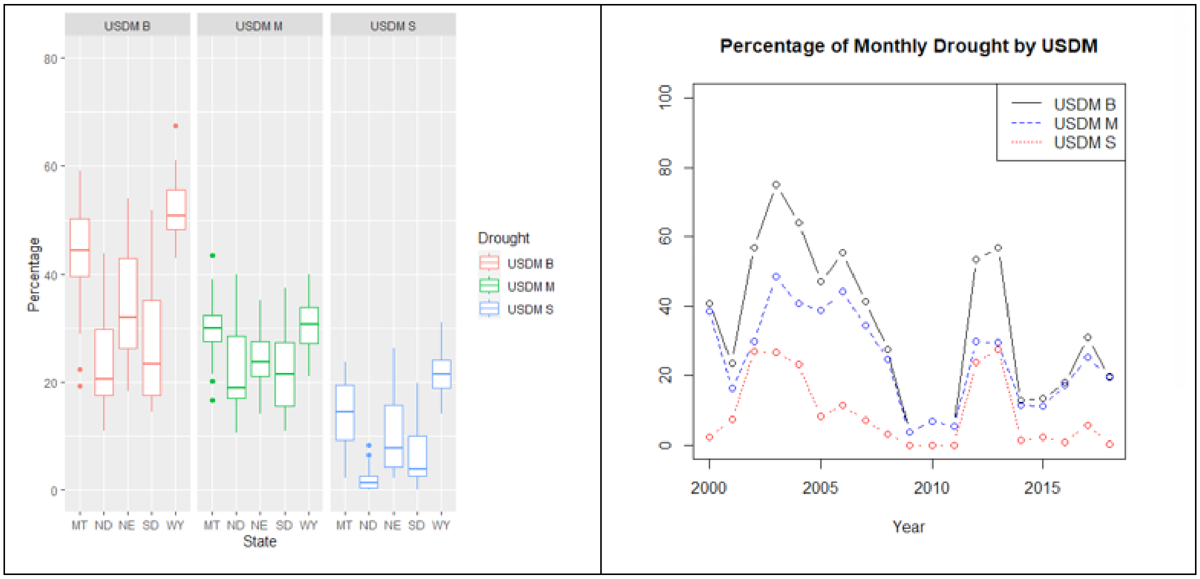

Figure 1: The percentage of months exposed to binary, moderate, and severe USDM drought in the Northern Rockies and Plains region by year 2000-2018. Abbreviations indicate states (MT: Montana, ND: North Dakota, NE: Nebraska, SD: South Dakota, WY: Wyoming). Abbreviations for the USDM drought (B: binary, M: moderate, S: severe).

Estimate Overall Risk Ratio

We conducted a Bayesian analysis and the posterior distribution is the main inference tool. The key quantity for interpretation is referred somewhat differently. Posterior mean and the 95% credible interval (Cr) are similar interpretation to an estimate and 95% confidence interval in classical statistics. Statistical significance is determined if the 95% Cr does not include the value of one.

Figure 2 shows the posterior means and their corresponding 95% Crs of the estimated overall risk ratios by USDM moderate and severe droughts. We see in Figure 2 that the overall risk ratio of severe drought over no drought is 1.050 (95% Cr: 1.034 to 1.068), indicating that severe drought increased the risk ratio 5.0% with experiencing the severe drought. Moderate drought had the risk ratio 1.009 (95% Cr: 0.999 to 1.018), however, this association is not statistically significant. These results indicate drought severity has negatively impact on all-cause mortality risk ratio in the Northern Rockies and Plains region.

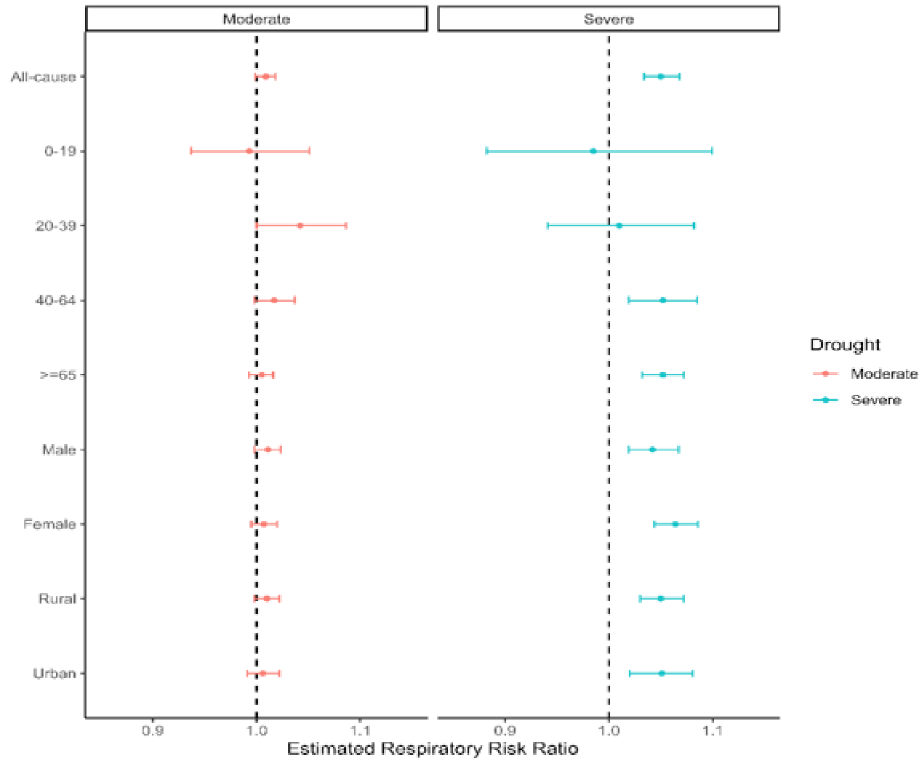

Figure 2: Overall risk ratio of the all-cause mortality risk ratios and their corresponding 95% Crs by general population and subgroups and drought types, moderate (left) and severe (right).

Stratification Analysis

We performed stratification analysis to investigate the effect of the drought exposures to all-cause mortality by subgroups. Figure 2 displays the estimated overall risk ratio and the 95% Crs stratified by age group, sex, and urbanicity. Statistically significant increased all-cause mortality risk ratio was identified in both age group 40-64 and over 65 years old by the USDM severe drought. The estimated risk ratios were 1.052, indicating that the risk ratio increased by 5.2% (95% Cr: 1.019 to 1.085 for the USDM moderate and 1.032 to 1.072 for the USDM severe). Age groups 0-19 and 20-44 were not identified as vulnerable subgroups by drought exposure.

Results by sex showed that both male and female were increased the risk ratio with experiencing the severe drought. However, female had greater risk ratio of 1.064 (95% Cr: 1.044 to 1.086) than the male 1.042 (95% Cr: 1.019 to 1.067) by the severe drought. While the moderate drought also increased the risk ratio, these were not statistically significant.

The increased risk ratios were identified in both urban and rural counties by the severe drought. The magnitudes of the estimated risk ratios 1.050 and 1.051 were similar in both counties. This demonstrates that the severe drought increased the all-cause mortality risk ratio about 5%.

Discussion and Conclusion

In this article, we investigate the risk ratio in all-cause mortality associated with the USDM drought exposure in the Northern Rockies and Plains region of the United States from 2000 to 2018. Our assessment will provide guidelines and implications for health impacts, as well as help in future risk management related to drought exposure. To estimate health impacts for the overall population and subpopulations stratified by age, gender, and urbanicity, we employed a commonly used two-stage time-series modeling approach.

The major findings were that the USDM severe drought exposure had negatively impact on the risk of all-cause mortality in the general population, while the moderate drought was most likely null effect. Our finding showed a similar assessment [7, 25, 26]. Severe drought can exacerbate the impacts on water resources, ecosystems, economies, and human societies directly or indirectly. This can provide an important message to reduce health risk by mitigating the effects of severe drought and implementing measures to build resilience against future drought events.

Our results showed that different sub-populations were affected differently by drought exposure. Mid-age (aged 40 to 64) and elderly (aged over 65) populations showed an increased risk ratio of all-cause mortality by the severe drought (Figure 2). Most of the existing studies also found that the elderly populations aged over 65 were the most affected subgroups associated with drought exposure, especially longer-term drought (Salvador et al, 2021; Lynch et al., 2020). This would be due to pre-existing health conditions, the higher baseline mortality rate, or longer stay in outdoor activity in this region. We found that the mid-age group increased the risk ratio (Figure 2). However, our finding was somewhat different from the other studies that these individuals were not susceptible to drought exposure [27, 17]. Both male and female individuals with severe drought had a significantly greater risk ratio of all-cause mortality, while female had a higher risk ratio than male (Figure 2). Other research showed that the severity of the drought had a greater negative impact, but it was either male or female [28, 27, 16]. We also discovered that both urban and rural counties were vulnerable to the effects of severe drought exposure. As stated in the study area section, 88.3% (257 out of 291) of the counties are rural communities in the Northern Rockies and Plains. Individuals in rural counties may face a shortage of health care services or facilities, malnutrition among younger and elderly populations (especially in under-developed countries) as well as increased job-related stress, due to geographical characteristics and principal source of income. While our data indicated urban counties were particularly hazardous places, we need to be cautious for this conclusion and generalization as it was based on only 34 counties.

We understand that there are more than 200 drought indices to determine the status of drought events [29], however, no research has been conducted to identify the differences of these drought indices linked to health risk assessment. The USDM and EDDI were used in climate region-level assessment and showed different pattern in certain climate regions of the United States [9]. Further research is needed to better understand these inconsistencies between drought indices in the same locations.

This study has several limitations. First, we adopted an ecological study design due to the nature of retrospective observational study. Our primary analysis was conducted by county-level aggregated data, rather than individual data in the study population. This potentially results in ecological fallacy. Second, we only looked at the USDM drought exposure. While the USDM is widely utilized, no time-scale such as 1, 3, 6, and 12 months are included. Previous research indicated that different drought indices with different time scales showed distinct patterns across NOAA climate regions [9]. More research, however, is required for further exploration. We remind readers that cumulative data analysis in time-series modeling would mask the overall effect. As shown in Figure 2, the percentage of monthly drought event by the USDM had different pattern in different time windows. More rigorous statistical method is needed to incorporate the heterogenous trends in assessing health risk associated with drought exposure. Finally, due to data availability, no meta-predictor was included in the second stage model. To improve our assessment, we can carefully evaluate the role of meta-predictors and their benefits in the model.

This information could be beneficial for public health practitioners in providing early warnings and communicating with high-risk populations. We expect that because climate change influences the severity and duration of drought occurrences, this information will be considered for future management.

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