Drought and the risk of hospital admissions and mortality in older adults in western USA from 2000 to 2013: a retrospective study

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Summary

Background Occurrence, severity, and geographic extent of droughts are anticipated to increase under climate change, but the health consequences of drought conditions are unknown. We estimate risks of cardiovascular-related and respiratory-related hospital admission and mortality associated with drought conditions for the elderly population in western USA.

Methods For this retrospective study, we analysed the 2000 to 2013 data from the US Drought Monitor for 618 counties in the western USA to identify full drought periods, non-drought periods, and worsening drought periods stratified by low severity and high severity. We used Medicare claims made between Jan 1, 2000, and Dec 31, 2013, to calculate daily rates of cardiovascular admissions, respiratory admissions, and deaths among adults aged 65 years or older. Using a two-stage hierarchical model, we estimated the percentage change in health risks when comparing drought with non-drought period days, controlling for daily weather and seasonal trends.

Findings On average, 2·1 million days were classified as non-drought periods and 0·6 million days were classified as drought periods. Compared with non-drought periods, respiratory admissions significantly decreased by –1·99% (95% posterior interval –3·56 to –0·38) during the full drought period, but not during worsening drought conditions. Mortality risk significantly increased by 1·55% (0·17 to 2·95) during the high-severity worsening drought period, but not the full drought or low-severity worsening drought periods. Cardiovascular admissions did not differ significantly during either full drought or worsening drought periods. In counties where drought occurred less frequently, we found risks for cardiovascular disease and mortality to increase during worsening drought conditions.

Interpretation Drought conditions increased risk of mortality during high-severity worsening drought, but decreased the risk of respiratory admissions during full drought periods among adults aged 65 years and older. Counties that previously had fewer drought events show larger risk for mortality and cardiovascular disease. This research describes an understudied environmental association with global health significance.

Funding The Yale Institute of Biospheric Studies, the National Institute of Environmental Health Sciences, the US Environmental Protection Agency.

Lancet Planet Health 2017; 1: e17–25

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Introduction

The UN refers to drought as "the most far reaching of all natural disasters".[1] In 2011–12, a pan-continental drought spanned 62% of the contiguous USA land area, exceeding the historical 99th percentile for drought size and affecting nearly 150 million people.[2] California is exiting an extreme drought that has been ongoing since 2013.[3] However, although health effects of some natural disasters (eg, heat waves and floods) are well studied,[4,5] little is known about drought, despite its global impact. Most drought and health research focuses on developing nations and indirect effects, such as vector-borne disease and malnutrition,[6] but an almost total absence of direct health effects research exists worldwide. So far, the study of drought and health has been hampered by the unique characteristics of drought, including gradual onset, persistence, large geographical extents, and difficulty assessing when one begins or ends.[7,8] Additionally, drought can be categorised as four distinct types: meteorological, agricultural, hydrological, and socio-economic.[7] The distinct drought types can create challenges in the estimation of human exposures and health effects because each type can potentially affect disease outcomes in a different way.

The biological mechanisms through which drought affects health are unknown. Several pathways are hypothesised. Drought might act on disease through secondary exposures, increasing airborne dust or wildfire smoke and modifying the maturation and dispersal of allergenic pollen and fungal spores.[9–11] Long-term drought has the potential to degrade the environment and affect community-level economic livelihood, inducing psychological stress.[12,13] Chronic stress will invoke behavioural and physiological response, including haemodynamic, endocrine, and immunological dysfunction that increase risk of cardiovascular and upper respiratory disease.[14,15] In extreme cases, this dysfunction can increase mortality. Community studies from Australia found associations

Research in context

Evidence before this study

We separately searched the PubMed and Google Scholar databases on Sept 23, 2013, using the search criteria "drought" AND "cardiovascular disease", "drought" AND "respiratory disease", "drought" AND "mortality" NOT "tree" NOT "plant" NOT "forest", "drought" AND "hospital", "drought" AND "United States" AND "health" for articles published in English, with no publication date exclusions. We did follow-up replicate searches on Nov 9, 2015, and Oct 3, 2016. We identified two systematic reviews and crosschecked their references. We did not identify any studies looking directly at the role of drought on cardiovascular or respiratory disease or all-cause mortality, or identify any observational studies investigating drought in North America or Europe. Existing epidemiological research was almost entirely restricted to the role of drought on mental health outcomes in Australia. Other scientific literature mainly focused on developing nations and the role of drought in crop loss, famine, and human migration, or the secondary role of drought on wildfires, dust, and vector-borne disease.

Added value of this study

We report the first evidence of associations between drought exposure and the risk of cardiovascular disease, respiratory disease, and all-cause mortality among the elderly. Using 2·7 million data days in 618 western US counties during a 14 year period, our study represents the largest investigation of drought and health for both population and geographical area. A decreased incidence of respiratory-related admissions was recorded during drought compared with non-drought periods, but not during worsening drought periods. For mortality, the high-severity periods of drought (but not low-severity or full drought periods) are associated with increased health risks compared with non-drought periods. In regions where drought occurred less frequently, we find both cardiovascular admissions and mortality to significantly increase during worsening drought compared with non-drought periods.

Implications of all the evidence

Our study contributes to the currently limited understanding that exposure to drought is associated with serious public health implications. With global drought severity and duration anticipated to increase under climate change, drought and health risks are of global concern. Several avenues of additional research are warranted, including the investigation of other population subgroups such as children and working age men in agricultural regions and the examination of alternative disease outcomes. Considering that drought is characterised by a gradual onset and persistent event, authorities should be aware of its health risks and assess the role preventive-care practitioners can have in mitigating health effects before a severe drought stage is achieved.

between drought and mental health, including increased deaths by suicide, in rural and agricultural populations.[16–18] Australian studies further identified drought severity to be an important exposure characteristic, with more severe drought associated with increased risk of adverse health outcomes.[17,18]

We estimated associations between drought periods and cardiovascular-related and respiratory-related hospital admissions and mortality in western USA across a 14 year period. Our exposure included full drought periods, plus a separate assessment focusing on the subset of days characterised by worsening drought of low severity and high severity. Our study participants are the elderly population; a subgroup with weakened immune response to environmental stressors.[19] We focus on western USA, a region with increased prevalence of drought conditions.[7] To our knowledge, this is the first study to investigate associations between drought and cardiovascular-related and respiratory-related health and all-cause mortality.

Methods

Study design and population

For this retrospective study, to calculate daily rates of cardiovascular and respiratory admissions, we acquired daily counts of hospital admissions based on fee for service Medicare claims made between Jan 1, 2000, and Dec 31, 2013, for beneficiaries aged 65 years or older living in 618 counties from 22 US states west of the Mississippi River. We categorised primary discharge diagnosis codes using the International Classification of Diseases, ninth revision (ICD-9). Cardiovascular admissions include acute and chronic rheumatic fever (ICD-9 classification code: 390–398); hypertensive disease (401–405); ischaemic heart disease (410–414); pulmonary circulation disease (415–417); other heart disease (420–429); cerebrovascular disease (430–438); diseases of arteries, arterioles, and capillaries (440–448); and diseases of veins and lymphatics (451–459). Respiratory admissions include acute respiratory infections (464–466), pneumonia and influenza (480–487), and chronic obstructive pulmonary disease (490–492). Data include county of residence. Mortality data are death certificate counts and provide no underlying causes.

The Medicare data for this study did not involve individual identifiers; therefore consent was not specifically obtained. The study was reviewed and exempted by the Yale Institutional Review Board Human Subjects Committee.

To determine drought status for the 618 counties, we analysed drought maps for 2000 to 2013, which are publicly available from the US Drought Monitor (USDM). These maps characterise weekly drought conditions using five severity categories: "abnormally dry", "moderate", "severe", "extreme", and "exceptional".[20]

We added a "no drought" category for areas and time periods not categorised as drought by USDM.

Procedures

We determined a blended drought metric to best represent exposure when established associations between drought type and disease are limited. This measure combines several drought metrics in an effort to represent broad drought conditions standardised across time and geography.[20] The USDM is a composite of five key indicators (Palmer Drought Severity Index, Climate Prediction Center Soil Moisture Model, US Geological Survey Weekly Streamflow, Standardized Precipitation Index, and Objective Drought Indicator Blends), local drought indicators (eg, snowpack and crop loss), and input from more than 350 expert observers across the country.[20] Although no gold standard exists for drought indices, the USDM is a robust measure to which other drought metrics are often compared.[21,22]

For each county, we assigned a daily USDM category equal to the value at the counties population-weighted centroid. Because USDM maps are published weekly, we assumed the same condition for each 7 day interval. The decision to apply a daily, as opposed to weekly model, was to control for daily acute confounders, including air pollution and weather, associated with hospital admission and mortality risk.[23,24] We acquired temperature and dew point data from the National Climactic Data Center. If a county contained more than one active weather station, the values were averaged.

We defined two drought conditions based on USDM values: full drought periods and non-drought periods. A full drought period was defined as a consecutive string of at least 150 days of "moderate", "severe", "extreme", or "exceptional" USDM conditions. A non-drought period was defined as a consecutive string of at least 150 days of "no drought" or "abnormally dry" USDM conditions. To determine the cutoff, we adjusted the non-drought and drought periods to 50, 75, 100, 150, and 200 days and assessed the variability of the USDM values within each of these blocks. We identified 150 days to represent the point when conditions were most consistently drought or non-drought values. Similarly, Hanigan and colleagues[17] found 5 months to be the optimum threshold for drought periods using the Hutchinson Drought Index. Although both non-drought and drought periods were at least 150 days, no limit was set regarding their duration.

Because several studies identified the importance of drought magnitude when assessing risk,[17,18] we investigated this trend by focusing on worsening drought stratified by severity. Worsening drought periods represent a subset of the full drought periods, where drought conditions are the same or worse than the previous day. We further separated these days into two categories: low severity (days of USDM "moderate" or "severe" conditions) and high severity (days of USDM "extreme" or "exceptional" conditions), representing the two highest USDM categories.

Days that fell in between a defined non-drought period or full drought period were considered transitional days and omitted from the analysis (14·8% of data). When assessing exposures and health effects, we compared the rate of health outcomes during days characterised as full drought periods or worsening drought periods of low-severity and high-severity with the rate of health outcomes during days of non-drought periods. Figure 1 presents an example of drought characterisation for Los Angeles County, CA, USA.

Statistical analysis

We calculated the ratio of non-drought period days to full drought period days in each county to estimate the county-level frequency of non-drought during our study. To ensure adequate statistical power in sparsely populated regions of the USA, we excluded those counties with less than 12 500 people (US Census 2010), less than a 1:1 ratio of non-drought to drought days (appendix pp 4–5), less than 50 days of weather data, less than 200 health events, and less than two unique seasons of drought occurrence.

See Online for appendix

We used two-stage hierarchical models to estimate county-level and overall associations between droughts and health risks. Individual models were fitted for each health outcome and drought exposure (full drought

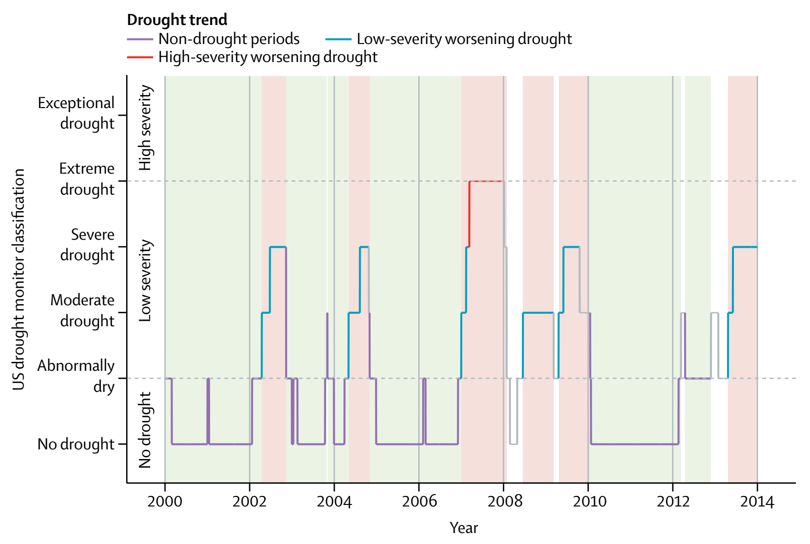

Figure 1: **2000–13 drought characterisation for Los Angeles County, CA**

We characterised drought using the US Drought Monitor for Los Angeles County, CA. For the first exposure metric, full drought periods are defined as 150 or more consecutive days of "moderate", "severe", "extreme", or "exceptional" drought conditions (pink shading). Non-drought periods are defined as 150 or more consecutive days of "no drought" or "abnormally dry" conditions (green shading or purple lines, or both). Days that are in between full drought and non-drought periods were regarded as transitional and omitted from the analysis (white shading). For the second exposure metric, days of worsening drought are defined as days included in the full drought periods with a drought condition that is the same or worse than the previous day. We stratified these worsening drought days into two categories: low severity (days of "moderate" or "severe" conditions [blue lines]) and high severity (days with "extreme" or "exceptional" drought conditions [red lines]). Days not meeting these or the previously defined transitional criteria were omitted from the analysis (grey lines).

	Drought assessment*		Worsening drought periods stratified by severity†		
	Non-drought periods	Full drought periods	Non-drought periods	Low-severity worsening drought periods	High-severity worsening drought periods
Number of counties‡	618	618	613	613	521
Days recorded					
Total‡	2 084 575	610 235	2 068 515	242 723	140 532
Mean per county (SD)	3373 (563)	987 (549)	3374 (565)	396 (299)	262 (211)
Cardiovascular admissions					
Total	4 367 366	1 350 276	2 280 593	221 001	157 452
Mean per county (SD)	7113 (18112)	2199 (8013)	7017 (11636)	680 (1359)	554 (1171)
Respiratory admissions					
Total	1 649 753	486 544	1 645 406	228 811	97 719
Mean per county (SD)	2727 (6601)	804 (2589)	2733 (6616)	380 (1731)	185 (555)
Mortality					
Total	3 448 744	1 100 922	3 442 061	525 790	219 223
Mean per county (SD)	5580 (12439)	1781 (5327)	5615 (12484)	858 (3538)	408 (1169)
Daily mean temperature (°C; IQR)	12·5 (5·2 to 20·9)	13·4 (5·4 to 22·2)	12·5 (5·2 to 20·9)	13·1 (5·3 to 21·7)	16·0 (7·8 to 25·6)
Daily mean dew point (°C; IQR)	5·9 (–1·3 to 13·8)	4·4 (–2·9 to 12·2)	5·9 (–1·3 to 13·8)	3·8 (–3·2 to 11·1)	6·5 (–1·8 to 15·7)
Daily mean $PM_{2·5}$§ (μg/m³; IQR)	9·7 (5·0 to 12·0)	9·4 (5·0 to 12·0)	9·7 (5·0 to 12·0)	9·5 (5·0 to 12·0)	9·3 (5·0 to 12·0)
Daily mean PM_{coarse}§ (μg/m³; IQR)	13·9 (6·0 to 18·0)	15·9 (7·0 to 21·3)	13·9 (6·0 to 18·0)	16·5 (7·4 to 22·0)	17·0 (7·0 to 23·0)

$PM_{2·5}$=fine particulate matter with a diameter of 2·5 μm or less. PM_{coarse}=coarse particulate matter with a diameter of 2·5–10 μm. *The drought assessment characterised non-drought periods as 150 or more consecutive days of "no drought" or "abnormally dry" conditions, whereas full drought periods were characterised as 150 or more consecutive days of "moderate", "severe", "extreme", or "exceptional" drought conditions. †Worsening drought assessments represent a subset of the days included in the full drought period, during which the drought conditions are the same or worse (ie, a more severe US Drought Monitor category) than the day before. Low-severity worsening drought period days are classified as "moderate" or "severe", whereas high-severity worsening drought days are classified as "extreme" or "exceptional" drought. ‡Number of counties and total days reflect mortality data. County counts for cardiovascular and respiratory admissions are reported in the appendix (p 8). §Fine and coarse particulate matter concentrations are estimated from 338 counties in the cardiovascular admissions cohort. The mortality (337 counties) and respiratory admission (257 counties) populations showed similar pollutant concentrations (results not reported).

Table: **Baseline environmental and health characteristics of older adults by county drought conditions, 2000–13**

periods; worsening drought periods stratified by severity). The first stage fits overdispersed Poisson models separately for each county and estimates the risk of a health event during drought days compared with non-drought days, adjusting for the total at-risk Medicare population by county, day, day of week, season, start season of the drought or non-drought condition, year, non-linear functions for daily temperature and dew point, and functions for the mean of the previous 3 days of daily temperature and dew point (appendix p 2).

The second stage model combines county-level effect estimates and their statistical uncertainty under a Bayesian framework to estimate overall associations between drought and health. The posterior interval (PI) combines intercounty and intracounty risk variability (appendix p 2) and a 95% PI can be interpreted as the Bayesian equivalent of a 95% CI.

We estimated the effect modification between the frequency of non-drought occurrence at the county-level and the risk of hospital admissions or mortality. In a second-stage model, a Bayesian hierarchical regression was fitted with the county-specific drought health effects and the county-specific ratios of non-drought days to full drought days (appendix p 2). Higher ratios reflect those counties with less frequent drought (appendix p 4). We also examined whether drought and health associations differ by county-level urban or rural designation, as defined by the Centers for Disease Control metropolitan or non-metropolitan classification. Model robustness was checked for the inclusion of transition days; doubling the minimum county inclusion cutoff to 400 health events and 100 days of weather data; and a 0·8:1 non-drought to drought day cutoff (694 [95·1%] of 730 eligible counties).

We assessed model sensitivity to air pollutants by adjusting for same day exposure to particulate matter with an aerodynamic diameter of more than 2·5 μm and less than or equal to 10 μm (PM_{coarse}) and fine particulate matter with a diameter of 2·5 μm or less ($PM_{2·5}$) in the full drought model using data from the US Environmental Protection Agency's (EPA) Air Quality System. Because the EPA does not measure PM_{coarse}, we estimated daily values by subtracting concentrations of $PM_{2·5}$ from concentrations of particulate matter with a diameter of 10 μm or more (PM_{10}) using co-located and nearby monitors (appendix p 3). Analysis was restricted to counties with more than 200 days of air pollution data and more than 200 health events (338 counties for cardiovascular admissions and mortality, and 257 counties for respiratory admissions). All analyses were done with R Statistical Software (version 3.01).

Role of the funding source

The funder of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report. The corresponding author had full access to all the data in the study and had final responsibility for the decision to submit for publication.

Results

Of 868 western US counties with 12 500 or more people, a total of 618 counties met our inclusion criteria for mortality, 614 for cardiovascular admissions and 605 for respiratory admissions during full drought periods. On average 2·1 million days were classified as non-drought periods and 0·6 million days as full drought periods (table). Health events ranged from 1·6 million respiratory and 4·4 million cardiovascular admissions during non-drought periods to 0·5 million respiratory and 1·4 million cardiovascular admissions during full drought periods (table). Of the 610 235 days characterised as a full drought period, 242 723 (39·8%) were low-severity worsening drought and 140 532 (23·0%) were high-severity worsening drought. Mean daily temperature was lowest during non-drought periods, but increased during low-severity and high-severity worsening droughts.

When compared with non-drought periods, worsening drought periods of high-severity showed a significant 1·55% (95% PI 0·17 to 2·95) increase in mortality risk (figure 2). No association was seen between mortality and low-severity worsening drought periods or full drought periods compared with non-drought periods. Cardiovascular admissions showed non-significant increases in risk during low-severity drought (1·41%, –1·49 to 4·40) and high-severity drought (2·54%, –1·04 to 6·26) compared with non-drought periods. During full drought periods, respiratory disease admissions showed a significant change of –1·99% (–3·56 to –0·38) compared with non-drought periods. However, cardiovascular admissions and mortality displayed little difference in risk between full drought and non-drought periods. Statistical models were robust to the inclusion of transition days, increases in minimum health events and weather day cutoffs, and lowering the non-drought to drought day ratio (results not shown).

California and the southwest showed decreased risk from mortality during drought periods compared with non-drought periods, whereas the eastern Great Plains and Pacific Northwest showed greater mortality risk from drought (figure 3).

Results from the second stage effect modification assessment showed that risks for mortality and cardiovascular admissions during drought periods compared with non-drought periods were significantly elevated in counties with less frequent drought (figure 4). A one-fold increase in the ratio of a county's non-drought period days to full drought period days (eg, going from 1:1 to 2:1) increased mortality risk during low-severity (0·31%, 95% PI 0·12–0·51) and high-severity (0·76%, 0·33–1·19) worsening drought periods and cardiovascular admissions risk during low-severity (0·72%, 0·15–1·30) and high-severity (1·32%, 0·45–2·21) worsening drought periods (appendix p 6).

Although health risks between urban and rural counties differed in magnitude, they were not significant. We estimated an increase in cardiovascular admissions of 4·25% (95% PI –1·32 to 10·13) during high-severity

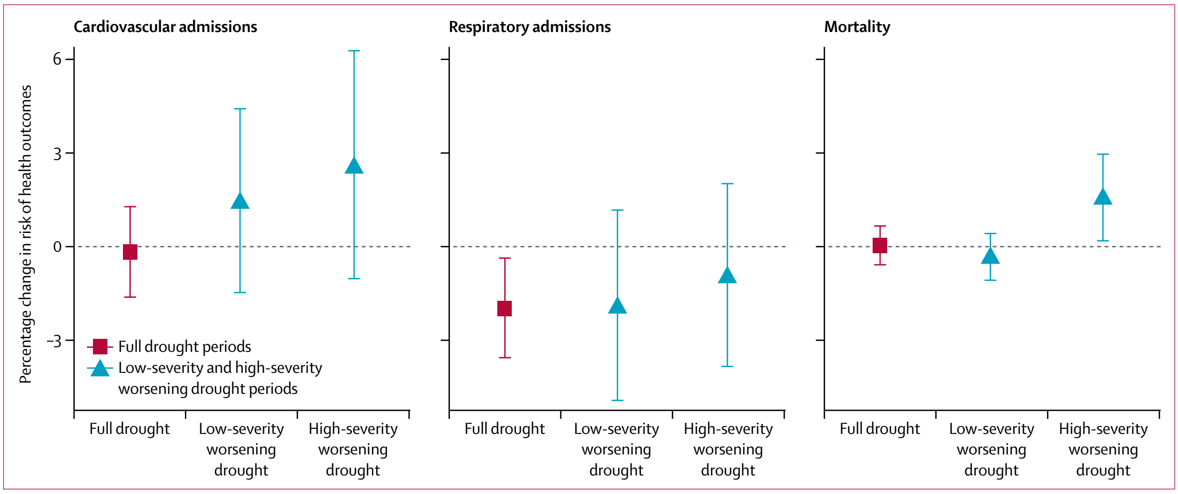

Figure 2: **Change in risk of health outcomes during full drought periods and low-severity and high-severity worsening drought periods compared with non-drought periods**

Estimates are for all 618 counties and error bars indicate 95% posterior intervals. We compared the rate of health outcomes during days characterised as full drought periods or worsening drought periods stratified by severity to the rate of health outcomes during days of non-drought periods.

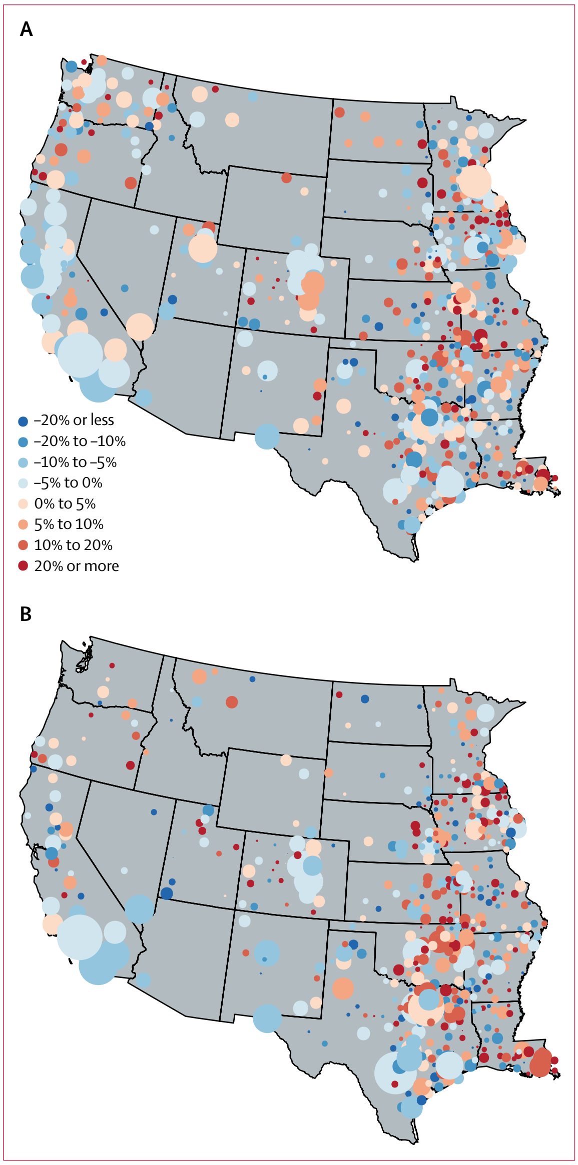

Figure 3: **County-level percentage change in risk of mortality during low-severity and high-severity worsening drought periods compared with non-drought periods**

(A) During low-severity worsening drought periods. (B) During high-severity worsening drought periods. Circles represent county-level effect estimates and larger sizes indicate higher certainty in our estimates.

worsening drought in urban counties and a –0·08% (–5·19 to 5·31) change for rural counties compared with non-drought periods. For mortality, we saw a 2·14% (–0·38 to 4·73) increased risk during high-severity drought days in rural counties, and a 0·49% (–0·96 to 1·96) increase in urban counties. Urbanicity did not modify the risk for respiratory admissions (appendix p 9).

In the 338 counties with available air pollution data, the mean PM_{coarse} concentration was 13·9 μg/m³ during non-drought periods, 16·5 μg/m³ during worsening drought of low severity, and 17·0 μg/m³ during worsening drought of high severity (table). $PM_{2·5}$ concentrations averaged 9·7 μg/m³ for non-drought periods and decreased during low-severity and high-severity worsening drought periods. Overall and county-specific estimates for drought risk were robust to inclusion of variables for $PM_{2·5}$ and PM_{coarse} (appendix pp 7,10).

Discussion

This study reveals a first-time association between drought exposure and health among a large and geographically diverse elderly population in the western USA during a 14 year period. Respiratory admission risk decreased during full drought periods compared with non-drought periods, but no significant differences in risk of cardiovascular admissions or mortality were seen between these periods. During periods of high-severity worsening drought, we found a significant increase in risk of mortality and a non-significant increase in risk of cardiovascular disease, compared with non-drought periods. In counties with less frequent drought, we found an increased risk for cardiovascular admissions and mortality. With 46·2 million adults aged 65 years and older in the USA, even minor variations in drought exposures can have major public health significance.

We found drought severity to have significant effects on health. The period when drought is getting both worse and more severe represents the most extreme meteorological deviation from normal conditions. This period is when the greatest risk for cardiovascular disease and mortality was identified and is broadly consistent with other research. A 15% increase in deaths by suicide among working age men was seen when the drought severity index rose from the first to third quartile,[17] whereas a 30 cm decrease in annual precipitation was associated with an 8% increase in suicide rates.[18] An association between drought severity and respiratory disease was not seen in this study.

A second finding was that geographical regions with low frequencies of drought have higher mortality and cardiovascular disease risks when drought events occur compared with counties with high frequencies of drought. The spatial heterogeneity of figure 3 might reflect this association because higher effect estimates cluster where drought occurs less frequently. In counties with less than 20% of days classified as drought periods (314 counties), a significant 4·4% change in mortality and a 9·3% change in cardiovascular admissions risk occurred during high-severity worsening drought periods compared with non-drought periods. With drought intensity and duration likely to increase in the southwest and central USA by the end of the 21st century,[25–27] geographical areas in which drought is currently rare will have more frequent exposures. This transition will initially put those populations at greater risk of adverse health. Although as drought becomes more common, we might observe population acclimatisation making future

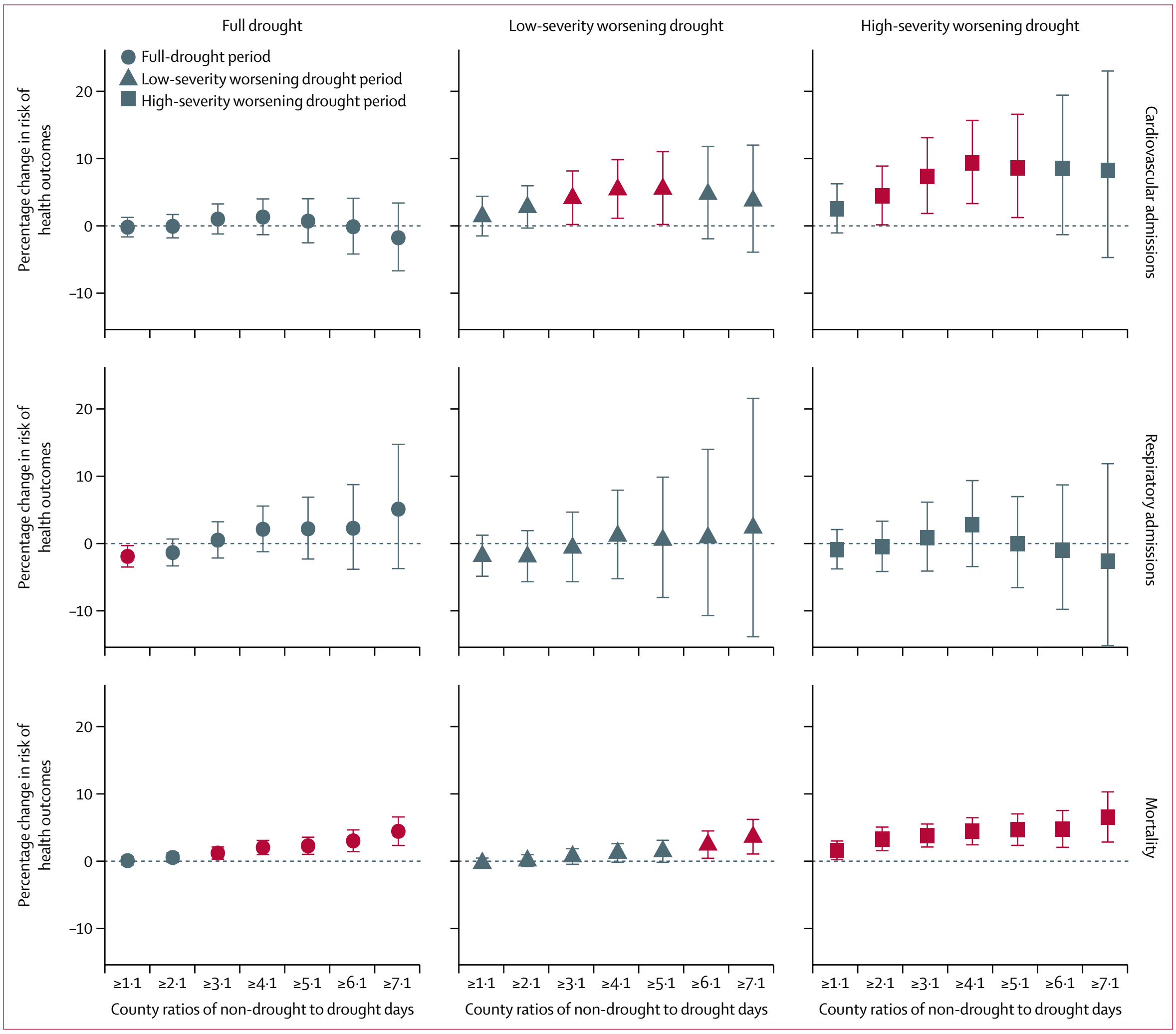

***Figure 4:* Percentage change in risk of health events for full drought and low-severity and high-severity worsening drought periods by county's ratio of non-drought period days to drought period days**

Vertical lines are 95% posterior intervals with red points denoting statistically significant effect estimates. Larger ratios of non-drought period days to full drought period days represent counties where drought is less common. The number of counties in each ratio is provided in the appendix (p 8).

health effects less pronounced, an outcome seen in studies of temperature and heat waves.[4,28]

Although the mechanisms between drought and health are not well defined, one potential explanation is that drought presents a chronic environmental exposure causing increased stress. Psychological stress from natural disasters has been associated with pathogenic processes, including long-term cardiovascular disease risk, myocardial ischaemia, active inflammatory response, and upper respiratory infection.[14,15,19] An Australian study[29] identified a 6·2% increase in mental distress during drought compared with non-drought events. Although our study cannot directly assess stress, we can capture stress-related outcomes in mortality and cardiovascular admissions. Crop loss in farming communities or rising food prices from drought present an economic burden on older farmers or elderly people with a fixed income. When drought causes loss of employment, it raises community poverty, increasing the psychological stressors among all residents and not just the working population.[13]

The pathophysiology of the effect of drought on respiratory disease is also not well understood; however, several plausible pathways might explain decreased risk during drought periods. Drought has a substantial role in the modification of ecological conditions that affect growth and transport of allergenic spores and pollen linked to respiratory infections, rhinitis, and asthma excerbations.[11] Rainfall-induced osmotic shock ruptures pollen grains to disperse allergen-carrying starch granules and paucimicronic particles.[11] Drought conditions are thought to suppress these exposure mechanisms and limit allergenic seasons, although conclusions have been mixed.[30,31] Although drought metrics provide a broad picture of present conditions; they do not have the specificity to assess individual weather events. Air pollution from drought-induced wildfire smoke and dust particulates are other potential pathways for affecting both cardiovascular and respiratory diseases, but linking them to drought has proven complex.[6,9,10] We found daily concentrations of dust (ie, PM_{coarse}) to be higher and $PM_{2·5}$ to be lower during drought compared with non-drought days, but health risks were robust to adjustment for air pollution.

Although not significant, we found the risk of mortality to be four times greater for rural than for urban counties during high-severity worsening drought periods. Research identified similar trends, with drought-related suicide and mental health outcomes being most severe among rural populations.[12,16,17,29] Drought type probably has a role in these trends; for example, rural regions would be more affected by agricultural drought than resource-diverse urban areas. Conversely, we found cardiovascular admission risk to be 4·3% greater in urban than in rural counties during high-severity worsening drought. A potential explanation is that decreased precipitation during drought might allow hazards linked to cardiovascular disease, such as road dust or combustion byproducts, to persist and recirculate in urban environments. Drought conditions might modify or concentrate $PM_{2·5}$ components into more toxic constituents, but this theory has not been tested.

The Medicare database is widely regarded as a valid and reliable measure for admissions, discharges, diagnoses, age, county of residence, and deaths. An estimated 98% of adults aged 65 years or older are enrolled in Medicare and 99% of deaths are captured.[32] Data limitations include the ongoing debate over the accuracy of entered ICD-9 codes and exclusion of those enrolled in Medicare Advantage.[32]

Several study limitations warrant further investigation. With pathways between drought and disease not fully understood, the most appropriate drought exposure metric is unknown and future investigation is needed. More than 150 drought indices exist, but none is designed for health-based purposes.[7,8] We selected the USDM because its algorithmic approach blends multiple drought indicators to create a consistent measure with minimised local uncertainties.[20] Alternative drought metrics, such as the Palmer Drought Severity Index, characterise some drought types with high specificity, but are limited with others.[33] For example, the Palmer Drought Severity Index effectively captures agricultural drought; however, it poorly describes long-term, winter, and high-elevation drought, while responding slowly to changing conditions.[7] Because our investigation spans 14 years and 22 states, an index must account for multiple drought risk factors across locations and times to avoid exposure bias. We hypothesise that drought and health are driven by cumulative effects rather than a single drought consequence and therefore the USDM best characterises aggregate drought exposures.

Other limitations lie in exposure and disease misclassification. Although our study of the western US Medicare population is large (8·6 million in 2013), we are restricted to a segment of the overall population, missing potential at-risk subgroups, including working-age men from agricultural regions.[16,17] Exposure misclassification might also exist within counties, notably at the margins of drought events, and as the US Sunbelt (eg, southern California, southern Nevada, Arizona, New Mexico, Texas, and Louisiana) increasingly attracts part-time residents, inconsistent population exposures might occur. Migration into a drought area might serve to underestimate risks because those individuals will have a shorter exposure period. For migration out of drought zones, it is unknown whether health risks would be immediately reduced or if lingering effects might be seen. Using 2013 as an example year, we found that only 3·6% of the Medicare population had moved across counties, so we anticipate a minimal effect on overall estimates of mortality and respiratory and cardiovascular admissions.

Although drought is a complex environmental exposure, it provides opportunity for preventive health-based interventions. Its gradual onset and persistent characteristics allow social and clinical interventions to be presented before an extreme drought stage is achieved. Interventions could include better communication of drought risks, so doctors and older patients predisposed to cardiovascular and respiratory disease have better awareness during extreme drought periods or concluding drought periods. Because rural counties have older populations than more urbanised counties, including more than 700 000 Medicare-eligible farmers,[34] providing community support to agricultural regions might alleviate some psychosocial risk factors from prolonged drought. With drought duration and intensity anticipated to increase in western USA,[26] preventive care could potentially have a crucial role in the reduction of adverse health effects, especially in areas with new and severe drought exposure.

Contributors

JDB and MLB conceived, designed, and developed the study, and drafted the initial manuscript. JDB, FD, RDP, and MLB acquired the drought, health, and environmental data. JDB, KE, RDP, and MLB were involved in the statistical analyses. All authors had a role in data interpretation and critical revisions of the final manuscript. MLB supervised the full project.

Declaration of interests

We declare no competing interests.

Acknowledgments

A Yale Institute for Biospheric Studies Donnelley Postdoctoral fellowship supported JDB. Additional funding was provided by the US Environmental Protection Agency (EPA): RD-83479801 (MLB, FD) and RD-83587101 (MLB); NIEHS R01ES019560 (MLB, FD, RDP), R01ES019587 (MLB), R01ES024332 (FD), R21ES020152 (MLB, RDP), R21ES021427 (MLB), and R21ES022585 (MLB, FD). This Article was developed under Assistance Agreement number RD-835871 awarded by the EPA to Yale University. It has not been formally reviewed by EPA. The views expressed in this document are solely those of the authors and do not necessarily reflect those of the EPA. EPA does not endorse any products or commercial services mentioned in this publication.

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