HHS Public Access
Author manuscript
Lancet Planet Health. Author manuscript; available in PMC 2018 April 12.

Published in final edited form as:
Lancet Planet Health. 2017 April ; 1(1): e17–e25. doi:10.1016/S2542-5196(17)30002-5.

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

Jesse D Berman, PhD,
School of Forestry and Environmental Studies, Yale University, New Haven, CT

Keita Ebisu, PhD,
Office of Environmental Health Hazard Assessment, California Environmental Protection Agency, Oakland, CA

Roger D Peng, PhD,
Department of Biostatistics, Johns Hopkins Bloomberg School of Public Health, Baltimore, MD

Francesca Dominici, PhD, and
Department of Biostatistics, Harvard T.H Chan School of Public Health, Boston, MA

Michelle L Bell, PhD
School of Forestry and Environmental Studies, Yale University, New Haven, CT

Abstract

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 and respiratory-related hospitalization and mortality associated with drought conditions for the western U.S. elderly population.

Methods—For counties in the western U.S. (N=618) and for the period 2000 to 2013, we use data from the U.S. Drought Monitor to identify: 1) full drought periods; 2) non-drought periods; and 3) worsening drought periods stratified by low- and high-severity. We use Medicare claims to calculate daily rates of cardiovascular admissions, respiratory admissions, and deaths among adults 65 years or older. Using a two-stage hierarchical model, we estimated the percentage

---

Corresponding Author: Jesse D Berman, Yale School of Forestry and Environmental Studies, 195 Prospect Street, New Haven, CT 06511, Telephone: 203-432-9869, Fax: 203-436-9158, jesse.berman@yale.edu.

Authors Contributions
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.

change in health risks when comparing drought to non-drought period days controlling for daily weather and seasonal trends.

Findings—On average there were 2·1 million days and 0·6 million days classified as non-drought periods and drought periods, respectively. Compared to non-drought periods, respiratory admissions significantly decreased by −1·99% (95% posterior interval (PI): −3·56, −0·38) during the full drought period, but not during worsening drought conditions. Mortality risk significantly increased by 1·55% (95% PI: 0·17, 2·95) during the high-severity worsening drought period, but not the full drought period. Cardiovascular admissions did not differ significantly during either 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.

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

Introduction

The United Nations refers to drought as ‘the most far reaching of all natural disasters.’[1] In 2011–2012, a pan-continental drought spanned 62% of the contiguous U.S., exceeding the historical 99th percentile for drought size and affecting nearly 150 million people,[2] while California is exiting an extreme drought ongoing since 2013.[3] However while health effects of some natural disasters (heat waves, 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. To date, the study of drought and health has been hampered by the unique characteristics of drought including gradual onset, persistence, large geographic extents, and difficulty assessing when one begins or ends.[7,8] Additionally, drought can be categorized as four distinct types: meteorological, agricultural, hydrologic, and socio-economic.[7] This raises challenges in estimating human exposures and health effects, as drought type may potentially influence disease outcomes.

The biological mechanisms through which drought impacts health are unknown. Several pathways are hypothesized. Drought may 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 behavioral and physiological response, including hemodynamic, endocrine, and immunologic dysfunction that increase risk of cardiovascular and upper respiratory disease.[14,15] In extreme cases, this may increase mortality. Community studies from Australia found associations between drought and mental health, including increased suicides, among 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- and respiratory-related hospital admissions and mortality in 22 U.S. states, including 618 counties and across a 14-year period. Our exposure included full drought periods, plus a separate assessment focusing on the subset of days characterized by worsening drought of low- and high-severity. Our study participants are the elderly population; a subgroup with weakened immune response to environmental stressors.[19] We focus on the western U.S., a region with increased prevalence of drought conditions.[7] To the best of our knowledge, this is the first study to investigate associations between drought and cardiovascular- and respiratory-related health and all-cause mortality.

Methods

Study Population

Daily counts of hospital admissions were acquired from fee for service Medicare claims for beneficiaries aged ≥65 years from January 1, 2000 through December 31, 2013. Primary discharge diagnosis codes were categorized by International Classification of Diseases, Ninth revision (ICD-9). Cardiovascular admissions include acute and chronic rheumatic fever (390–398); hypertensive disease (401–405); ischemic 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 database is widely considered a valid and reliable measure for admissions, discharges, diagnoses, age, county of residence, and deaths. Among adults ≥65 years, it is estimated that 98% are enrolled in Medicare and 99% of deaths are captured.[20] Data limitations include ongoing debate over the accuracy of entered ICD-9 codes and exclusion of those enrolled in Medicare Advantage.[20] 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.

Study Area and Environmental Data

The study area considered 22 U.S. states west of the Mississippi River. Drought maps from 2000–2013 were acquired from the publicly available U.S. Drought Monitor (USDM), which characterizes weekly drought conditions using 5 severity categories: ‘Abnormally Dry,’ ‘Moderate,’ ‘Severe,’ ‘Extreme,’ and ‘Exceptional.’[21] We added a ‘No Drought’ category for areas and time periods not categorized as drought by USDM.

A blended drought metric was determined 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 standardized across time and geography.[21] The USDM is a composite of five key indicators (Palmer Drought Severity Index; CPC Soil Moisture Model; USGS Weekly Streamflow; Standardized Precipitation

Index; Objective Drought Indicator Blends), local drought indicators (e.g. snowpack, crop loss, etc.), and input from over 350 expert observers across the country.[21] While no 'gold standard' exists for drought indices, the USDM is a robust measure to which other drought metrics are often compared.[22,23]

For each county, we assigned a daily USDM category equal to the value at the counties population-weighted centroid. Since 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 hospitalization and mortality risk.[24,25] Temperature and dew point were acquired from the National Climactic Data Center and multiple within-county values were averaged.

Drought and Health Assessment

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 et al. (2012) found 5-months to be the optimal threshold for drought periods using the Hutchinson Drought Index.[17] While both non-drought and drought periods were at least 150-days, no limit was set regarding their duration.

Since 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: 1) low-severity, that is days of USDM 'moderate' or 'severe' conditions, and 2) high-severity, that is 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 analysis (14.8% of data). When assessing exposures and health effects, we compared the rate of health outcomes during days characterized as full drought periods or worsening drought periods of low- and high-severity to the rate of health outcomes during days of non-drought periods. Figure 1 presents an example of drought characterization for Los Angeles County, California.

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 region of the U.S., we excluded those counties with less than 12,500 people (U.S. Census 2010), <1:1 ratio non-drought to drought days (Figure S1; S2), <50 days of weather data, <200 health events, and <2 unique seasons of drought occurrence.

Two-stage hierarchical models were applied 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 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 to 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 (Methods S1).

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 inter- and intra-county risk variability (Methods S2) and a 95% PI can be interpreted as the Bayesian equivalent of a 95% confidence interval.

Effect Modification and Sensitivity Analysis

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 (Methods S2). Higher ratios reflect those counties experiencing less frequent drought (Figure S1). We also examined whether drought and health associations differ by county-level urban or rural designation, as defined by the Center for Disease Control metropolitan/nonmetropolitan classification. Model robustness was checked for: 1) inclusion of transition days; 2) doubling cutoffs for health events and weather days; 3) a 0.8:1 non-drought to drought day cutoff (94.5% eligible counties).

We assessed model sensitivity to air pollutants by adjusting for same day exposure to particulate matter with aerodynamic diameter >2·5μm and ≤10μm (PM_{coarse}) and fine particulate matter ($PM_{2·5}$) in the full drought model using data from EPA's Air Quality System. Since EPA does not measure PM_{coarse}, we estimated daily values by subtracting $PM_{2·5}$ from PM_{10} concentrations using co-located and nearby monitors (Methods S3, S4). Analysis was restricted to counties with >200 days of air pollution data and >200 health events (338 counties for cardiovascular admissions and mortality, and 257 counties for respiratory admissions). All analysis was performed with R Statistical Software (v. 3·01).

Role of Funding Source

The funders had no role in the project design, data collection, interpretation and analyses, in the manuscript composition, or in the publication decision. The authors had full access to the data and the corresponding author had final responsibility for manuscript submission.

Results

Of 868 western U.S. counties with ≥12,500 people, a total of 618, 614, and 605 counties met our inclusion criteria for mortality, cardiovascular admissions, and respiratory admissions during full drought periods, respectively. On average 2·1 million days were classified as non-drought periods and 0·6 million days as full drought periods (Table 1). 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. Of the days characterized as a full drought period, low-severity worsening drought and high-severity worsening drought comprised a 39·8% and 23·0% subset, respectively. Average daily temperature was lowest during non-drought periods, but increased during low- and high-severity worsening droughts.

When compared to non-drought periods, worsening drought periods of high-severity showed a statistically significant 1.55% (95% PI: 0·17, 2·95) increase in mortality risk (Figure 2). No association was observed between mortality and low-severity worsening drought periods. Cardiovascular admissions showed non-significant increases in risk of 1·41% (95% PI: -1·49, 4·40) during low-severity drought and 2·54% (95% PI: -1·04, 6·26%) during high-severity drought compared to non-drought periods. During full drought periods, respiratory disease admissions showed a statistically significant change of −1·99% (95% PI: −3·56, −0·38) compared to 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).

Figure 3 illustrates the spatial heterogeneity of county-level estimates for percent change in mortality during low- and high-severity worsening drought periods compared to non-drought periods. California and the Southwest showed decreased risk from mortality during drought conditions, while the eastern Great Plains and Pacific Northwest showed greater mortality risk from drought.

Results from the second stage effect modification assessment indicated that risks for mortality and cardiovascular admissions during drought periods compared to non-drought periods were significantly elevated in counties experiencing less frequent drought (Figure 4). A 1-fold increase in the ratio of a county's non-drought period days to full drought period days (e.g. going from 1:1 to 2:1) during low- and high-severity worsening drought periods increased the mortality risk by 0·31% (95% PI: 0·12, 0·51) and 0·76% (95% PI: 0·33, 1·19) and the cardiovascular admissions risk by 0·72% (95% PI: 0·15, 1·30) and 1·32% (95% PI: 0·45, 2·21, respectively (Figure S3).

While health risks between urban and rural counties differed in magnitude, they were not statistically significant. We estimated an increase in cardiovascular admissions of 4·25% (95% PI: −1·32, 10·13) during high-severity worsening drought in urban counties and a −0·08% (95% PI: −5·19, 5·31) change for rural counties compared to non-drought periods. For mortality, we observed a 2·14% (95% PI: −0·38, 4·73) increased risk during high-severity drought days in rural counties, and a 0·49% (95% PI: −0·96, 1·96) increase in urban counties. Urbanicity did not modify the risk for respiratory admissions (Table S2).

In the 338 counties with available air pollution data, the mean PM_{coarse} concentration was 13·9 μg/m^3 during non-drought periods and 16·5 and 17·0 μg/m^3 during worsening drought of low- and high-severity, respectively (Table 1). $PM_{2·5}$ concentrations averaged 9·7 μg/m^3 for non-drought periods and decreased for during low- 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} (Figure S4 and Table S3).

Discussion

This study reveals a first-time association between drought exposure and health among a large and geographically diverse western U.S. older adult population during a 14-year period. Respiratory risk decreased during full drought periods compared to non-drought periods, but had no significant association with cardiovascular admissions or mortality. During periods of more severe drought, we found increased risk of mortality and cardiovascular disease, although cardiovascular health effects were not statistically different from non-drought periods. In counties with less frequent drought, we observed increased risk for cardiovascular admissions and mortality. With a U.S. elderly population of 46.2 million, even minor variations in drought exposures can have major public health significance.

We found drought severity to have significant impacts on health. The period when drought is getting both worse and more severe represents the most extreme meteorological deviation from normal conditions. This is where the greatest risk for cardiovascular disease and mortality was identified and is broadly consistent with other research. A 15% increase in suicide deaths among working-age males was observed when the drought severity index rose from the 1st to 3rd quartile,[17] while a 30cm decrease in annual precipitation was associated with an 8% increase in suicide rates.[18] An association between drought severity and respiratory disease was not observed in this study.

A second finding was geographic regions experiencing low frequencies of drought have larger mortality and cardiovascular disease risks when drought events occur. The spatial heterogeneity of Figure 3 may reflect this association, as higher effect estimates cluster where drought less frequently occurs. In counties with less than 20% of days classified as drought periods (314 counties), there was a 4·4% change in mortality and a 9·3% change in cardiovascular admissions risk during high-severity worsening drought periods compared to non-drought periods. With drought intensity and duration likely to increase in the southwest and central U.S. by the end of the 21st century,[26–28] current ‘rare drought’ geographic areas will have more frequent exposures. This will initially put those populations at greater risk of adverse health. Although as drought becomes more common, we may observe population acclimatization making future health effects less pronounced, a phenomenon observed in studies of temperature and heat waves.[4,29]

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 ischemia, active inflammatory response, and upper respiratory infection.[14,15,19] An Australian study identified a 6·2% increase in mental distress during drought compared to non-drought events.[30] While our study cannot directly assess stress, we may capture stress related outcomes in mortality and cardiovascular admissions. Crop loss in farming communities or rising food prices from drought presents an economic burden on older farmers or elderly 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 drought's impact on respiratory disease is also not well understood; however, several plausible pathways may explain decreased risk during drought periods. Drought plays a strong role modifying ecological conditions that influence 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 particle.[11] Drought conditions may suppress these exposure mechanisms and limit allergenic seasons, although conclusions have been mixed.[31,32] While drought metrics provide a broad picture of current conditions; they lack the specificity to assess individual weather events. Air pollution from drought-induced wildfire smoke and dust particulates are other potential pathways for influencing both cardiovascular and respiratory disease, but sourcing them from drought has proven complex.[6,9,10] We found daily concentrations of dust (i.e. PM_{coarse}) to be higher and fine particulates ($PM_{2.5}$) to be lower during drought compared to non-drought days, but health risks were robust to adjustment for air pollution.

While not statistically significant, we found the risk of mortality to be 4-times greater for rural compared to 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.[12,16,17,30] Drought type likely plays a role, as rural regions would be more affected by agricultural drought, while a resource diverse urban area might see lesser effects. Conversely, we found cardiovascular admissions risk to be 4·3% greater in urban compared to rural counties during high-severity worsening drought. A potential explanation is that decreased precipitation during drought may allow hazards linked to cardiovascular disease, such as road dust or combustion byproducts, to persist and re-circulate in urban environments. It is possible that drought conditions modify or concentrate $PM_{2.5}$ components to more toxic constituents, but this has not been tested.

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. Over 150 drought indices exist, but none are 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 minimized local uncertainties.[21] Alternative drought metrics, such as the Palmer Drought Severity Index

(PDSI), characterize certain drought types with high specificity, but are limited with others.[33] For example, PDSI effectively captures agricultural drought; however, it poorly describes long-term, winter, and high-elevation drought, while responding slowly to changing conditions.[7] Since 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 hypothesize that drought and health is driven by cumulative impacts rather than a single drought consequence, therefore the USDM best characterizes aggregate drought exposures.

Other limitations lie in exposure and disease misclassification. Although our study of the western U.S. 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-males from agricultural regions.[16,17] Exposure misclassification may also exist within counties, notably at the margins of drought events, and as the U.S. Sunbelt increasingly attracts part-time residents there may be inconsistent population exposures. Migration into a drought area may serve to underestimate risks, as those individuals will be subjected to a shorter exposure period. For migration out of drought zones, it is unknown if health risks would be immediately reduced or if lingering effects are observed. Using 2013 as an example year, we identified only 3.6% of the Medicare population to have moved across counties, so we anticipate minimal impacts from migration on overall estimates.

While drought is a complex environmental exposure, it provides opportunity for preventative health-based interventions. Its gradual onset and persistent characteristics allow social and clinical interventions to be presented before an extreme drought stage is achieved. This may 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, respectively. Since rural counties have older populations, including over 700,000 Medicare eligible farmers,[34] providing community support to agricultural regions may alleviate some psychosocial risk factors from prolonged drought. With drought duration and intensity anticipated to increase in the western U.S.,[27] preventative care could potentially play a critical role reducing adverse health effects, especially in areas with new and severe drought exposure.

Acknowledgments

Funding: The Yale Institute of Biospheric Studies, the National Institute of Environmental Health Sciences, and the U.S. Environmental Protection Agency.

A Yale Institute for Biospheric Studies Donnelley Postdoctoral fellowship supported Dr. Berman. Additional funding was provided by the U.S. EPA RD-83479801 (Bell, Dominici) and RD-83587101 (Bell); NIEHS R01ES019560 (Bell, Dominici, Peng), R01ES019587 (Bell), R01ES024332 (Dominici), R21ES020152 (Bell, Peng), R21ES021427 (Bell), and R21ES022585 (Bell, Dominici).

References

1. [accessed Oct 5, 2015] UN-Water: Drought management. http://www.unwater.org/activities/multi-agency-featured-projects/drought-management/en/
2. Cook BI, Smerdon JE, Seager R, Cook ER. Pan-Continental Droughts in North America over the Last Millennium*. J Clim. 2013; 27:383–97.

3. [accessed Feb 10, 2017] US Drought Monitor - California. http://droughtmonitor.unl.edu/Home/StateDroughtMonitor.aspx?CA
4. Anderson GB, Bell ML. Heat Waves in the United States: Mortality Risk during Heat Waves and Effect Modification by Heat Wave Characteristics in 43 U.S. Communities. Environ Health Perspect. 2011; 119:210–8. [PubMed: 21084239]
5. Milly PCD, Wetherald RT, Dunne KA, Delworth TL. Increasing risk of great floods in a changing climate. Nature. 2002; 415:514–7. [PubMed: 11823857]
6. Stanke C, Kerac M, Prudhomme C, Medlock J, Murray V. Health Effects of Drought: a Systematic Review of the Evidence. PLoS Curr. 2013; doi: 10.1371/currents.dis.7a2cee9e980f91ad7697b570bcc4b004
7. Mishra AK, Singh VP. A review of drought concepts. J Hydrol. 2010; 391:202–16.
8. Heim RR. A Review of Twentieth-Century Drought Indices Used in the United States. Bull Am Meteorol Soc. 2002; 83:1149–65.
9. Smith LT, Aragão LEOC, Sabel CE, Nakaya T. Drought impacts on children's respiratory health in the Brazilian Amazon. Sci Rep. 2014; :4.doi: 10.1038/srep03726
10. Smoyer-Tomic KE, Klaver JDA, Soskolne CL, Spady DW. Health Consequences of Drought on the Canadian Prairies. EcoHealth. 2004; 1:SU144–SU154.
11. Knutsen AP, Bush RK, Demain JG, et al. Fungi and allergic lower respiratory tract diseases. J Allergy Clin Immunol. 2012; 129:280–91. [PubMed: 22284927]
12. OBrien LV, Berry HL, Coleman C, Hanigan IC. Drought as a mental health exposure. Environ Res. 2014; 131:181–7. [PubMed: 24727641]
13. Stain HJ, Kelly B, Carr VJ, Lewin TJ, Fitzgerald M, Fragar L. The psychological impact of chronic environmental adversity: Responding to prolonged drought. Soc Sci Med. 2011; 73:1593–9. [PubMed: 22005316]
14. Cohen S, Janicki-Deverts D, Doyle WJ, et al. Chronic stress, glucocorticoid receptor resistance, inflammation, and disease risk. Proc Natl Acad Sci. 2012; 109:5995–9. [PubMed: 22474371]
15. Pedersen A, Zachariae RDms, Bovbjerg DH. Influence of Psychological Stress on Upper Respiratory Infection-A Meta-Analysis of Prospective Studies. Psychosom Med. 2010; 72:823–32. [PubMed: 20716708]
16. Vins H, Bell J, Saha S, Hess JJ. The Mental Health Outcomes of Drought: A Systematic Review and Causal Process Diagram. Int J Environ Res Public Health. 2015; 12:13251–75. [PubMed: 26506367]
17. Hanigan IC, Butler CD, Kokic PN, Hutchinson MF. Suicide and drought in New South Wales, Australia, 1970–2007. Proc Natl Acad Sci. 2012; 109:13950–5. [PubMed: 22891347]
18. Nicholls N, Butler CD, Hanigan I. Inter-annual rainfall variations and suicide in New South Wales, Australia, 1964–2001. Int J Biometeorol. 2006; 50:139–43. [PubMed: 16235091]
19. Segerstrom SC, Miller GE. Psychological Stress and the Human Immune System: A Meta-Analytic Study of 30 Years of Inquiry. Psychol Bull. 2004; 130:601–30. [PubMed: 15250815]
20. Vernig, B. [accessed Jan 25, 2017] Strengths and Limitations of CMS Administrative Data in Research. Res Data Assist Cent. 2012. https://www.resdac.org/resconnect/articles/156
21. Svoboda M, LeComte D, Hayes M, et al. The Drought Monitor. Bull Am Meteorol Soc. 2002; 83:1181–90.
22. Park S, Im J, Jang E, Rhee J. Drought assessment and monitoring through blending of multi-sensor indices using machine learning approaches for different climate regions. Agric For Meteorol. 2016; 216:157–69.
23. Anderson MC, Hain C, Otkin J, et al. An Intercomparison of Drought Indicators Based on Thermal Remote Sensing and NLDAS-2 Simulations with U.S. Drought Monitor Classifications. J Hydrometeorol. 2013; 14:1035–56.
24. Bell ML, Ebisu K, Peng RD, et al. Seasonal and Regional Short-term Effects of Fine Particles on Hospital Admissions in 202 US Counties, 1999–2005. Am J Epidemiol. 2008; 168:1301–10. [PubMed: 18854492]

25. Ostro B, Broadwin R, Green S, Feng W-Y, Lipsett M. Fine Particulate Air Pollution and Mortality in Nine California Counties: Results from CALFINE. Environ Health Perspect. 2006; 114:29–33. [PubMed: 16393654]
26. Cook BI, Ault TR, Smerdon JE. Unprecedented 21st century drought risk in the American Southwest and Central Plains. Sci Adv. 2015; 1:e1400082. [PubMed: 26601131]
27. Stocker, T., Qin, D., Plattner, G., et al. IPCC, 2013: Summary for Policymakers. Cambridge, UK and NY, NY, USA: Cambridge University Press; 2013.
28. Wehner M, Easterling DR, Lawrimore JH, Heim RR, Vose RS, Santer BD. Projections of Future Drought in the Continental United States and Mexico. J Hydrometeorol. 2011; 12:1359–77.
29. Curriero FC, Heiner KS, Samet JM, Zeger SL, Strug L, Patz JA. Temperature and Mortality in 11 Cities of the Eastern United States. Am J Epidemiol. 2002; 155:80–7. [PubMed: 11772788]
30. Friel S, Berry H, Dinh H, O'Brien L, Walls HL. The impact of drought on the association between food security and mental health in a nationally representative Australian sample. BMC Public Health. 2014; 14:1102. [PubMed: 25341450]
31. Gehrig R. The influence of the hot and dry summer 2003 on the pollen season in Switzerland. Aerobiologia. 2006; 22:27–34.
32. Silverberg JI, Braunstein M, Lee-Wong M. Association between climate factors, pollen counts, and childhood hay fever prevalence in the United States. J Allergy Clin Immunol. 2015; 135:463–469. e5. [PubMed: 25304658]
33. Vicente-Serrano SM, Beguería S, Lorenzo-Lacruz J, et al. Performance of Drought Indices for Ecological, Agricultural, and Hydrological Applications. Earth Interact. 2012; 16:1–27.
34. National Agricultural Statistics Service. Farm Demographics: US Farmers by Gender, Age, Race Ethnicity, and More. U.S. Department of Agriculture; 2014.

Research in Context Panel

Evidence before this study

We separately searched the PubMed and Google Scholar databases in September 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' with no publication date exclusions. Replicated follow-up searches were performed in November 2015 and October 2016. Two systematic reviews were identified and references crosschecked. We did not identify any studies looking directly at the role of drought on cardiovascular or respiratory-disease or all-cause mortality, nor did we identify 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 literature primarily 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 U.S. counties during a 14-year period, our study represents the largest investigation of drought and health for both population and geographic area. A decreased incidence of respiratory-related admissions was observed during drought compared to 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 to non-drought periods. In regions where drought less frequently occurred, we find both cardiovascular admissions and mortality to significantly increase during worsening drought compared to 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, including children and working age-males in agricultural regions, and the examination of alternative disease outcomes. Since drought is characterized by a gradual onset and persistent event, authorities should be aware of the health risks, as preventative care practitioners can play a role in mitigating health effects before a severe drought stage is achieved.

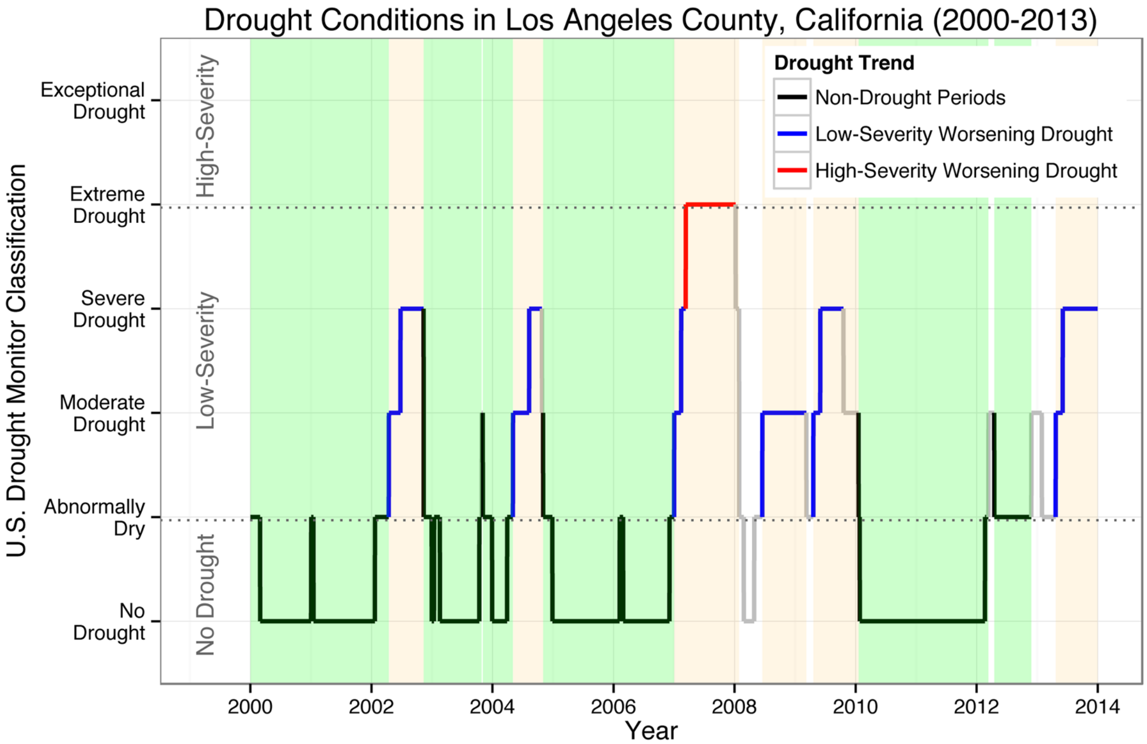


Figure 1.

Drought characterization using the U.S. Drought Monitor (USDM) for Los Angeles County, California.

For the first exposure metric, full drought periods are defined as ≥150 consecutive days of ‘moderate,’ ‘severe,’ ‘extreme,’ or ‘exceptional’ drought conditions (tan shading). Non-drought periods are defined as ≥150 consecutive days of ‘no drought’ or ‘abnormally dry’ conditions (green shading and/or black lines). Days that are in between full drought and non-drought periods were considered transitional and omitted from analysis (white shading).

For the second exposure metric, days of worsening drought are defined as days included into the full drought periods having a drought condition that is the same or worse than the previous day. We stratify these worsening drought days into two categories: 1) Low-severity, that is, days of ‘moderate’ or ‘severe’ conditions (blue lines); and 2) high-severity, that is days with ‘extreme’ or ‘exceptional’ drought conditions (red lines). Days not meeting these or the previously defined transitional criteria were omitted from analysis (gray lines).

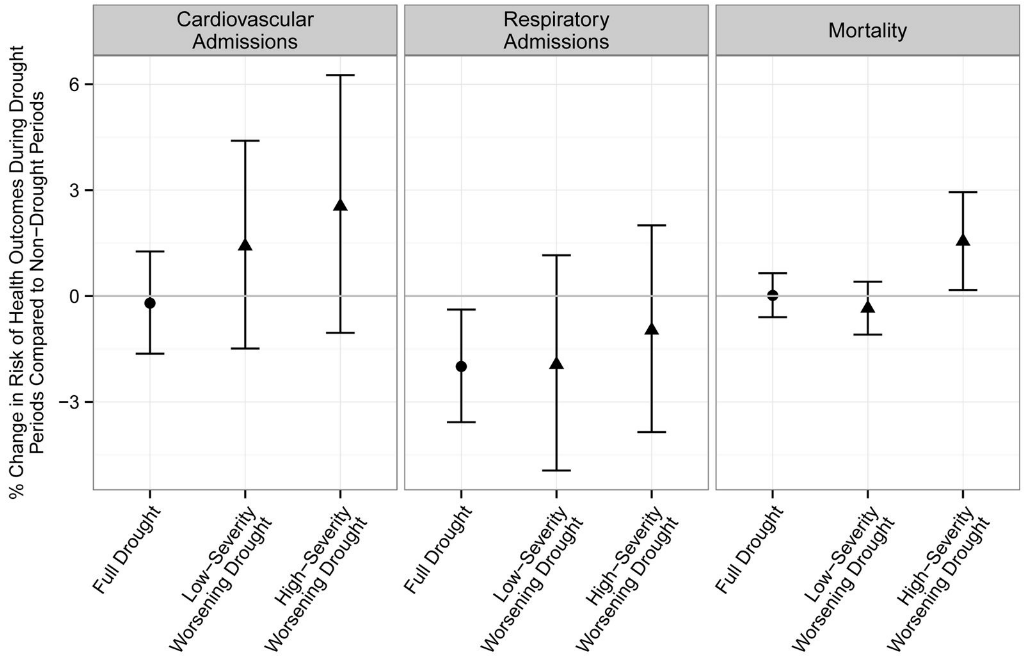
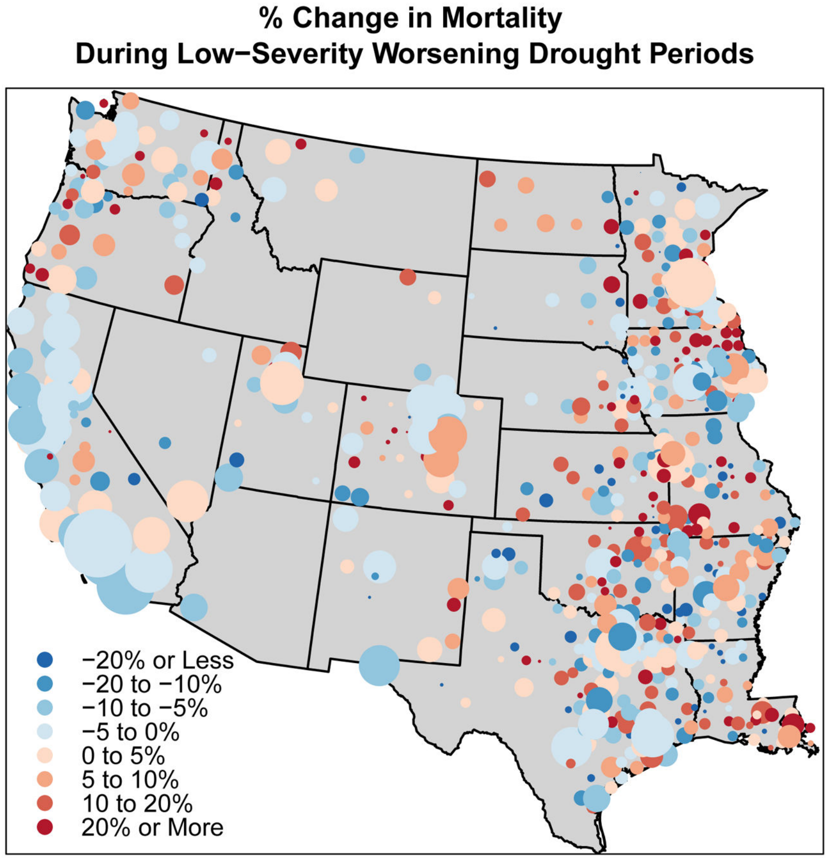


Figure 2.

Percent change in risk of health outcomes during full drought periods (circles) and low- and high-severity worsening drought periods (triangles) compared to 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 characterized as full drought periods or worsening drought periods stratified by severity to the rate of health outcomes during days of non-drought periods.


% Change in Mortality
During Low−Severity Worsening Drought Periods
−20% or Less
−20 to −10%
−10 to −5%
−5 to 0%
0 to 5%
5 to 10%
10 to 20%
20% or More

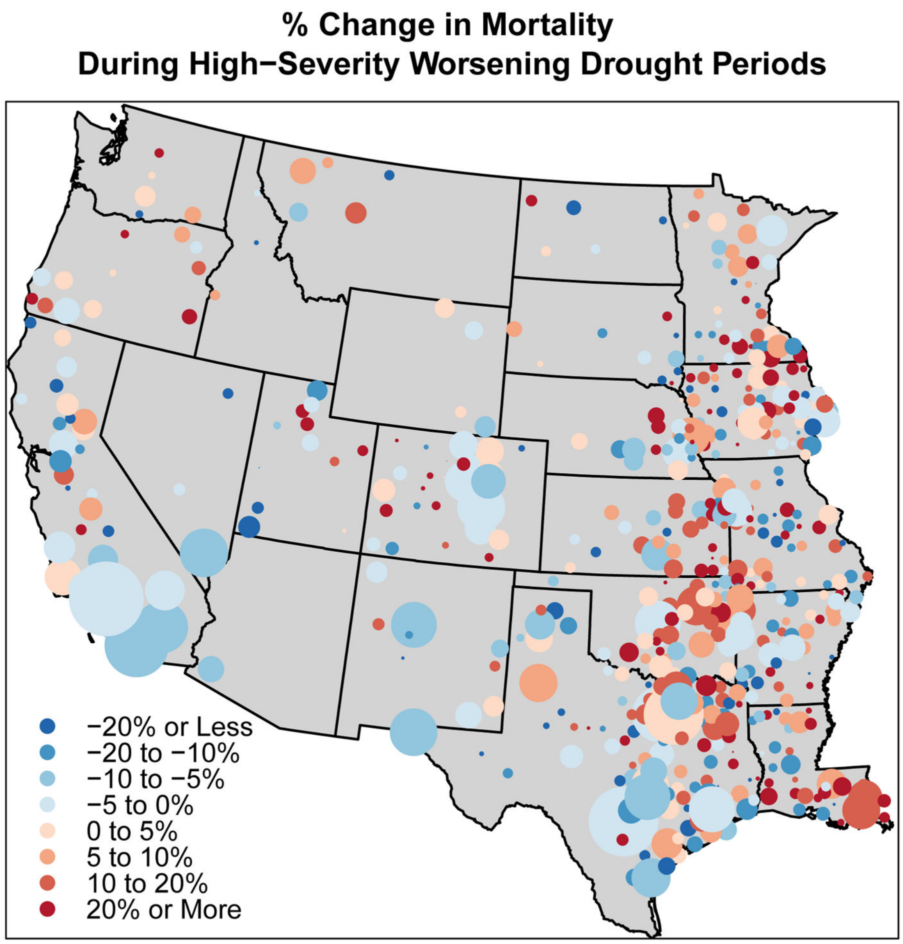


Figure 3.

County-level percent change in risk of mortality during low- and high-severity worsening drought periods compared to non-drought periods

Circles represent county-level effect estimates and larger sizes indicate higher certainty in our estimates.

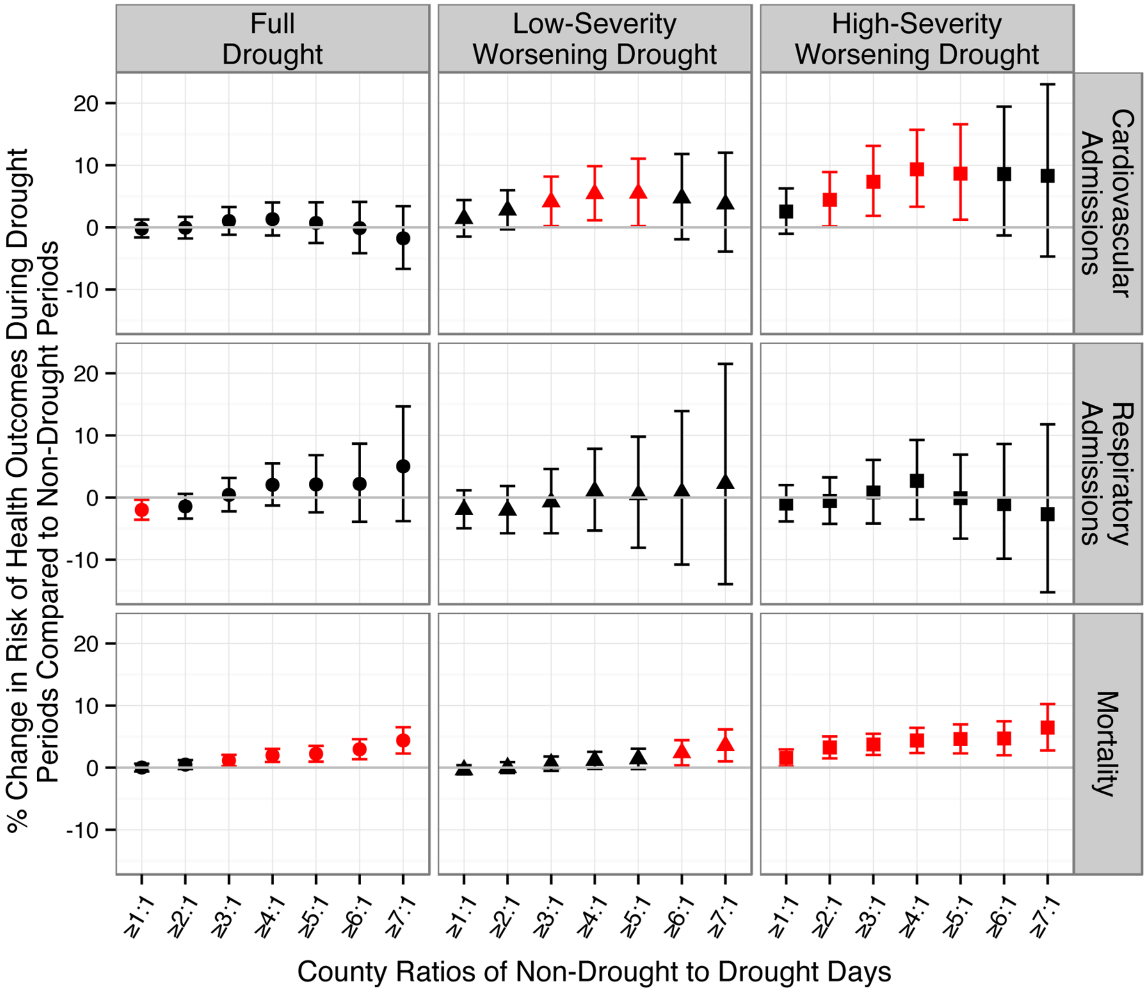


Figure 4.

Percent change in risk of health event for full drought and low- 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 Table S1.

Table 1

Baseline environmental and health characteristics of older adults by county drought conditions, 2000–2013.

	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
Total Days* (Mean per County)	2,084,575 (3,373)	610,235 (987)	2,068,515 (3,374)	242,723 (396)	140,532 (262)
Total Cardiovascular Admissions (Mean per County)	4,367,366 (7,113)	1,350,276 (2,199)	2,280,593 (7,017)	221,001 (680)	157,452 (554)
Total Respiratory Admissions (Mean per County)	1,649,753 (2,727)	486,544 (804)	1,645,406 (2,733)	228,811 (380)	97,719 (185)
Mortality (Mean per County)	3,448,744 (5,580)	1,100,922 (1,781)	3,442,061 (5,615)	525,790 (858)	219,223 (408)
Daily Mean Temperature (°C) (IQR)**	12·5 (5·2, 20·9)	13·4 (5,4, 22·2)	12·5 (5·2, 20·9)	13·1 (5·3, 21·7)	16·0 (7·8, 25·6)
Daily Mean Dew Point (°C) (IQR)	5·9 (−1·3, 13·8)	4·4 (−2·9, 12·2)	5·9 (−1·3, 13·8)	3·8 (−3·2, 11·1)	6·5 (−1·8, 15·7)
Daily Mean $PM_{2·5}$ (μg/m^3) (IQR)§	9·7 (5·0, 12·0)	9·4 (5·0, 12·0)	9·7 (5·0, 12·0)	9·5 (5·0, 12·0)	9·3 (5·0, 12·0)
Daily Mean PM_{coarse} (μg/m^3) (IQR)	13·9 (6·0, 18·0)	15·9 (7·0, 21·3)	13·9 (6·0, 18·0)	16·5 (7·4, 22·0)	17·0 (7·0, 23·0)

† The drought assessment characterized non-drought periods as ≥150 consecutive days of 'no drought' or 'abnormally dry' conditions, while full drought periods were ≥150 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, where the drought conditions are the same or worse (i.e., a more severe USDM category) than the day before. Low-severity worsening drought period days are classified as 'moderate' or 'severe,' while high-severity worsening drought days are classified as 'extreme' or 'exceptional' drought.

* Number of counties and total days reflect mortality data. Included counties had ≥12,500 total population; ≥50 days of temperature and dew point temperature data; ≥1:1 ratio of non-drought period days to drought period days; and ≥2 unique seasons of drought occurrence. The worsening drought category stratified by severity represents a subset of the full drought conditions; therefore fewer counties met our inclusion criteria. County counts for cardiovascular and respiratory admissions are reported in Table S2.

** IQR (Interquartile Range) represents the 25^{th} and 75^{th} percentile of the distribution.

§ Fine and coarse particulate matter concentrations are estimated from 338 counties in the cardiovascular admissions cohort. The mortality (337 counties) and respiratory admissions (257 counties) populations showed similar pollutant concentrations (results not reported).