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BRIEF REPORT

A simple method for estimating excess mortality due to heat waves, as applied to the 2006 California heat wave

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Abstract
Objectives To characterize excess mortality during a major heat wave in California and its regions; to assess the validity of a simple method.
Methods We calculated mortality rate ratios for the heat-wave period, using a reference period of the same number of days from the same summer. We conducted alternative analyses and compared our results with those from a time-series model.
Results We estimated 655 excess deaths, a 6% increase (95% confidence interval, 3–9%), impacting varied geographic/climate regions. Alternate analyses supported model validity.
Conclusions California experienced excess heat-wave related mortality not restricted to high heat regions. As climate change is anticipated to increase heat events, public health efforts to monitor effects assume greater importance.

Keywords Climate change · Global warming · Heat wave · Mortality · Monitoring · Surveillance

The views expressed are those of the authors and may not necessarily represent the policies of the California Department of Public Health.

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Introduction

Global warming is predicted to cause more frequent heat waves and thus increase associated mortality risk, according to the Intergovernmental Panel on Climate Change (IPCC 2007). Public health and emergency preparedness agencies need data on mortality impact of heat waves to plan and evaluate the efficacy of public health interventions. However, analytic methods typically employed to estimate heat-associated deaths require specialized expertise and extensive data sources, complex statistical analysis, temperature data inputs, and numerous years' data, and are often beyond the capacity of health departments.

The present article proposes a simple method by which excess mortality may be estimated without complex calculations. Our goal was to develop an indicator for the mortality impact of heat-related climate change that could easily be adopted by state and other health departments.

This work is part of a collaborative effort by public health officials in several states to define indicators of health and environmental impacts of climate change, such as mortality, morbidity, air pollution, and adaptation responses, and is modeled after the Centers for Disease Control and Prevention's effort to create a nationwide tracking network to monitor exposures and health effects that may be related to environmental health hazards (McGeehin et al. 2004).

In 2006, residents of the continental United States, including the state of California, experienced the second hottest July on record (National Oceanic and Atmospheric Administration NWS 2007). An analysis of county coroner reports revealed 140 deaths in California specifically from heat stroke (Trent 2007). However, this figure would be expected to capture only a subset of the mortality impact, as deaths during heat waves can also occur among those susceptible due to pre-existing conditions such as cardiovascular or respiratory disease (Basu and Samet 2002), and the coroner's role is limited to investigation of unexpected and medically unattended deaths. Thus in the absence of an analysis of all causes of mortality, the full magnitude of the impact on the death rate was unknown. This analysis quantifies excess mortality in California from the 2006 heat wave, without requiring complex statistical modeling.

Methods

Records of all deaths for June–August of 2006 were obtained from the Electronic Data Registration System (EDRS) files of the California Center for Health Statistics, Office of Health Information and Research (Sacramento, CA). The EDRS system allows hospitals, coroners and others to make death reports directly through electronic data entry. These data then undergo quality checks prior to migration into the state master death data file. At the time EDRS was accessed, reporting was considered to be preliminary but virtually complete (Trent 2007).

To define a single exposure period across California's variable geography and to capture the broadest health effects of the heat wave, we chose 15 July–1 August, a period slightly longer than the span of days as identified by meteorological features, including record-breaking heat (16–26 July) (Blier 2007), and which corresponded to dates of heat-stroke deaths reported by California coroners (Trent 2007).

We also examined effects by geographic regions to understand if the impact was largely confined to the hottest areas of the state and to identify any other patterns by region. During the 2006 heat wave, the analysis of coroner reports found that 80% of heat-stroke deaths occurred in the Central Valley, a large agricultural valley in the center of the state with a hot summer climate, and in the southeast desert area east of Los Angeles and San Diego (Trent 2007). We evaluated the following six regions: the Central Valley, Southeast Desert, North Coast, North Central, Central Coast, and South Coast. These regions are based on California's 58 counties as related by geography, climate and population, and were defined for use in a previous analysis of hospitalizations and emergency room visits in the California heat wave, conducted by some of the same authors as this manuscript (Knowlton et al. 2009). Knowlton et al. also used the same heat-wave period as this analysis.

The expected number of deaths for the heat period was obtained by taking the sum of deaths from an equivalent set of reference days close in time to the heat period. We chose reference days with the same distribution of days of week, e.g. number of Mondays, Tuesdays, etc., as the heat-wave period: 8–14 July and 12–22 August; and excluded the Independence Day (4 July) holiday weekend. Thus, the reference period was chosen to maximize the comparability to the heat-wave period while being representative of normal summer conditions. We also excluded the week following the heat wave from the reference period to avoid comparison with a period in which deaths could be decreased because some very ill persons may have died prematurely during the heat wave (i.e. mortality displacement), and we also checked the data for a possible deficit of deaths during this week.

We examined rate ratios for number of total deaths during the heat wave versus reference period. The calculation of rate ratios (RR) would ordinarily involve estimates of person-time, but assuming that the population size remains constant over the summer, the number of persons cancels out of the numerator and denominator. Furthermore, for comparing heat wave and reference periods with equal numbers and distribution of days, the RR simplifies further to deaths in the heat-wave period (A_1) divided by deaths in the referent period (A_0): $\mathrm{RR} = A_1/A_0$. We calculated 95% confidence intervals using large sample statistics for person-time rate ratios (Rothman and Greenland 1998): $\exp([\ln(\mathrm{RR}) \pm 1.96\sqrt{(1/A_1 + 1/A_0)}])$. At the time of analysis, cause of death codes had not been assigned in the EDRS file, precluding sub-analyses by diagnosis or exclusions for reasons such as accidental causes of death.

We also examined several alternate time periods to see how results might vary under different assumptions. We looked at the meteorologically identified period (Blier 2007), as well as a period anticipated to represent the peak of heat effects, restricted to the days with the greatest concentration of heat-stroke deaths (22–27 July) (Trent 2007).

To test whether the reference period may have been unrepresentative and thus biased, we also conducted the analysis using deaths from the rest of the summer (June–August), adjusting rate ratios to avoid possible confounding by day of week by stratifying using the Mantel–Haenszel method (Rothman and Greenland 1998). Finally, to evaluate the validity of our method, we compared our results with those generated using time-series analysis, matching the nine counties (Fresno, Imperial, Kern, Merced, Sacramento, Los Angeles, San Bernardino, San Joaquin, and Stanislaus) and time period used in that analysis (Ostro et al. 2009).

Results

Total deaths for the heat-wave period numbered 11,610 versus an expected 10,955, representing an estimated 655 excess deaths, a statistically significant increase of 6%

(RR = 1.06; 95% confidence interval (CI), 1.03–1.09) (Table 1).

All regions showed excess mortality, although statistical significance at the 5% level was not achieved in all areas (Fig. 1). The Central Valley and Southeast Desert regions had excess mortality similar to and slightly above the statewide average, with 6 and 9% excess, respectively. However, the North Central and North Coast regions experienced the highest excess mortality, although confidence intervals were wide (North Central: RR = 1.15, 95% CI, 1.01–1.30; North Coast RR = 1.14, 95% CI, 1.01–1.28). The Central Coast region experienced the lowest excess mortality, with RR = 1.02 (95% CI, 0.96–1.08).

Analyses based on alternate, narrower time periods revealed more concentrated excesses. We estimated an 8% increase in deaths during the meteorologically defined period, and a 13% increase in deaths during the 6-day window of peak effects.

The alternative analysis conducted using the rest of the summer as a reference yielded similar estimates of excess deaths: 615 versus 655 in the original analysis. The time-series analysis also found consistent results, with estimates of excess mortality generated from different models and reference periods ranging from 160 to 397; our estimate was 327. The analysis of the week immediately following the heat wave found the same number of deaths as would be expected.

Discussion

Our analysis found a significant increase in the number of deaths occurring during the 2006 July heat wave in California. Analysis by region found effects were not restricted to specific high-temperature geographic regions, supporting the conceptualization of the heat wave as broadly statewide.

These findings by region are somewhat in contrast to previous morbidity findings related to the 2006 California heat wave (Knowlton et al. 2009). The Central Coast,

Table 1 Excess mortality during July 2006 heat wave, California

Model	Total deaths	Expected deaths[a]	Excess deaths	Rate ratios (95% confidence interval)
Main analyses[b]				
Heat-wave period: 15 July–1 August				
All California	11,610	10,955	655	1.06 (1.03–1.09)
California regions[c]				
Central Coast	2,011	1,974	37	1.02 (0.96–1.08)
Central Valley	2,017	1,904	113	1.06 (1.00–1.13)
North Central	529	460	69	1.15 (1.01–1.30)
North Coast	598	526	72	1.14 (1.01–1.28)
South Coast	5,092	4,845	247	1.05 (1.01–1.09)
Southeast Desert	1,346	1,231	115	1.09 (1.01–1.18)
Alternate analyses				
Meteorologically defined heat period: 16–26 July[b,d]	7,231	6,679	552	1.08 (1.05–1.12)
"Peak effects" heat period: 22–27 July[b,e]	4,117	3,651	466	1.13 (1.08–1.18)
Heat wave period 15 July–1 August[f] with full-summer reference period	11,610	10,995	615	1.06 (1.03–1.08)
Week following heat wave 2–8 August[b,g] with 16–22 August reference period	4,274	4,274	0	1.00 (0.96–1.04)

[a] Expected deaths = deaths per day during reference days × the number of days in the heat period

[b] Reference period matched for day of week

[c] Region counties: Central Coast (Alameda, Contra Costa, Monterey, San Benito, San Francisco, San Luis Obispo, San Mateo, Santa Clara, Santa Cruz); Central Valley (Amador, Calaveras, Fresno, Kern, Kings, Madera, Mariposa, Merced, Placer, Sacramento, San Joaquin, Stanislaus, Tulare, Tuolumne); North Central (Alpine, Butte, Colusa, El Dorado, Glenn, Lassen, Modoc, Mono, Nevada, Plumas, Shasta, Sierra, Siskiyou, Sutter, Tehama, Yolo, Yuba); North Coast (Del Norte, Humboldt, Lake, Marin, Mendocino, Napa, Solano, Sonoma, Trinity); South Coast (Los Angeles, Orange, San Diego, Santa Barbara, Ventura); and Southeast Desert/Inland Empire (Imperial, Inyo, Riverside, San Bernardino)

[d] Blier 2007

[e] Period restricted to the days with the greatest concentration of heat-stroke deaths (Trent 2007)

[f] Reference period adjusted for day of week using Mantel–Haenszel method

[g] Possible mortality displacement period

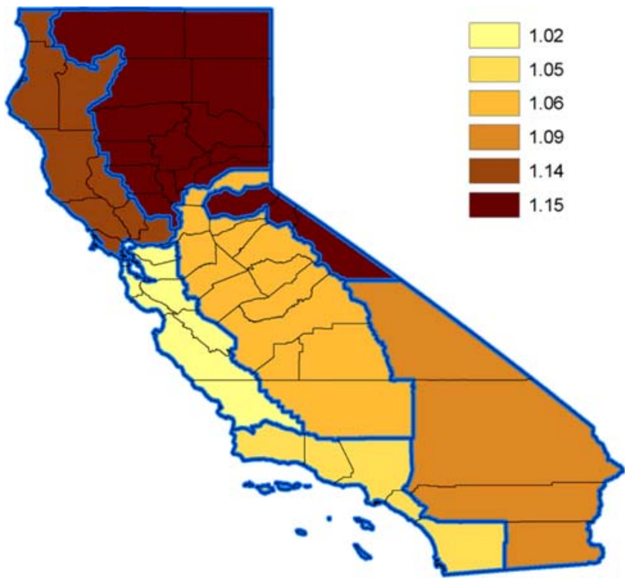

Fig. 1 Map of California regions showing RRs for excess mortality during the 15 July to 1 August, 2006 heat wave, compared with a reference period (July 8–14 and August 12–22, 2006). Regions (*clockwise from upper right*): North Central (includes two areas), Central Valley, Southeast Desert, South Coast, Central Coast, North Coast

which includes the San Francisco Bay Area counties and extends south to San Luis Obispo, despite the lowest mortality risk, experienced the highest excess of all regions for heat-related illness treated in hospital emergency rooms (Knowlton et al. 2009). Also in contrast to mortality, the region with the lowest excess risk for heat-related emergency department visits was the Southeast desert. Full exploration for reasons for these differences are beyond the scope of this analysis, but may be related to health care access and utilization patterns.

Although this type of approach will be sensitive to choice of reference period, our study's findings were supported by similar results obtained using an alternate, broader reference period, as well as the comparison with a more complex model. More narrowly defined heat periods displayed a sharper increase in excess deaths, but the broader period more completely captured the overall magnitude of impact. Also, our examination of the period immediately following the heat wave did not provide evidence of bias or error. Although not excluding this time period would not have changed our findings, it is unclear whether this resulted because the death rate had returned to normal, or the heat-wave effect persisted but was offset by a deficit from deaths displaced to the heat-wave period. In either case, this finding suggests that the identified excess was not simply a displacement of deaths. However, we would nevertheless recommend excluding and/or examining the post-heat time period separately in any analysis of this type.

Complex models have the advantage of advancing understanding of the dynamics between mortality and specific meteorological parameters. The work discussed earlier by Ostro et al. incorporated data on hourly measurements of relative humidity and ambient temperature for different locations in nine counties with data from 1999 to 2005. However, the data and computationally intensive nature of the analysis did not lend itself to an investigation of the overall statewide impact, which this analysis provides.

The validity of this simple period comparison approach is supported by analyses of the 1995 Chicago heat wave, where comparisons of initial results obtained by the Centers for Disease Control and Prevention (1995) were later confirmed using advanced time-series methods (Whitman et al. 1997) and regression models based on 16 years of data (Kaiser et al. 2007). Further, the 6% overall increase in deaths during the California 2006 heat wave is similar to that experienced in New York City (8% increase) (New York City Department of Health and Mental Hygiene 2006) and England/Wales (4% increase) (Office for National Statistics 2006).

All-cause mortality increased significantly in California during the 2006 heat wave, and this impact was several times greater than the number of deaths originally identified by coroners as directly caused by heat stroke. Our analysis provides evidence of a broad mortality impact not restricted to classic high heat regions, and which does not appear to track completely with morbidity outcomes. The availability of a simple approach to quantify health effects of heat events that is not dependent on elaborate statistical analyses or multi-year data may encourage more jurisdictions to conduct surveillance. Given the emergent science that predicts changes in global climate will most likely lead to more extreme heat events, efforts to monitor the health effects of extreme heat and promote adaptation strategies assume greater public health urgency.

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