Int J Biometeorol (1998) 42:44–50

ORIGINAL ARTICLE

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A comparative analysis of heat waves and associated mortality in St. Louis, Missouri – 1980 and 1995

Received: 12 August 1997 / Revised: 12 January 1998 / Accepted: 13 February 1998

Abstract This research investigates heat-related mortality during the 1980 and 1995 heat waves in St. Louis, Missouri. St. Louis has a long history of extreme summer weather, and heat-related mortality is a public health concern. Heat waves are defined as days with apparent temperatures exceeding 40.6°C (105°F). The study uses a multivariate analysis to investigate the relationship between mortality and heat wave intensity, duration, and timing within the summer season. The heat wave of 1980 was more severe and had higher associated mortality than that of 1995. To learn if changing population characteristics, in addition to weather conditions, contributed to this difference, changes in population vulnerability between 1980 and 1995 are evaluated under simulated heat wave conditions. The findings show that St. Louis remains at risk of heat wave mortality. In addition, there is evidence that vulnerability has increased despite increased air-conditioning penetration and public health interventions.

Key words Heat waves · Heat-related mortality · St. Louis

Introduction

Heat waves have been responsible for thousands of deaths in the United States, such as during the summers of 1988 and 1995. Extreme temperatures not only trigger heatstroke, but also exacerbate many pre-existing health problems, leading to sizeable elevated mortality rates. Past research has shown that prolonged heat waves and those occurring earlier in the summer season, when the population has not become acclimatized to hot weather, are most dangerous (Kilbourne 1989; Kalkstein 1991; Kalkstein and Smoyer 1993). Although weather conditions are the source of exposure, population vulnerability is an important component of heat wave mortality risk. Risk factors include old age and low income, while access to air-conditioning is a protective factor (Jones et al. 1982; Kilbourne 1989; Smoyer 1996). Heat wave impacts are greatest in urban areas, where reduced vegetation and the concentration of brick, steel, and asphalt lead to higher temperatures, particularly at night (Landsberg 1981; Oke 1981).

St. Louis, Missouri has a long history of extreme summer weather and associated high mortality. Located in the central United States, St. Louis frequently experiences hot and humid maritime tropical (mT) air masses originating in the Gulf of Mexico. Much of the city's housing stock is red brick, contributing to urban heat island effects. Exacerbating the problems stemming from the city's heat-retaining physical environment are socioeconomic stresses on the population associated with the rising unemployment and poverty rates that have occurred since the 1970s.

In 1980, St. Louis experienced one of its worst heat waves on record, resulting in many excess deaths. During the heat wave that broke temperature records and caused hundreds of deaths in the upper Midwest in July 1995, St. Louis received only residual effects and had minimal mortality. The worst of the 1995 heat wave bypassed the area (Kunkel et al. 1996; Livezey and Tinker 1996); yet given the city's location and housing stock, it is probable that St. Louis will experience another severe heat wave with high mortality. What magnitude of a public health problem might be expected if St. Louis were to experience another heat wave comparable to that of 1980? Are the residents of St. Louis at higher or lower risk than they were in 1980? Most heat wave/mortality research focuses on either the characteristics of the weather event or of the population for a given heat wave year. Changes in population vulnerability over time have not been afforded sufficient attention. The purposes of this study, therefore, are to compare (1) the weather conditions in St. Louis during 1980 and 1995; (2) the association between heat waves and mortality for the two years; and (3) the vulnerability of the population in 1980 to that in 1995.

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Methods

Many methods exist for characterizing the weather and designating a heat wave. Apparent temperature, also known as the heat index, provides a measure of perceived temperature according to air temperature and relative humidity. The index incorporates human physiology and the body's ability to dissipate heat. Apparent temperature can be simply calculated from readily available weather data using an equation derived from Steadman's table of air temperature and dew point temperature (Steadman 1979) as follows:

$$AT=2.719+0.994\,T_a+0.016\,(T_d)^2 \qquad (1)$$

where AT = apparent temperature, T_a = maximum air temperature, and T_d = maximum dew point temperature (°C). The derivation of the equation is discussed in Kalkstein and Valimont (1986).

For the period 1 June–31 August for 1980 and 1995, days with an AT >40.6°C were classified as heat wave days. Although this value is arbitrary, it was chosen to correspond with United States National Weather Service heat wave warnings, which are issued when the AT exceeds 40.6°C (105°F). Above this level, the risk of heat-related illness increases substantially (NOAA 1985). Days when AT was equal to or below 40.6°C were categorized as non-heat wave days. In addition to AT, measures of heat wave duration (Duration) and of the timing of the heat wave within the summer season (Time) were used in the analysis to investigate the association between mortality and prolonged and early heat waves for the 2 years. Because the timing of non-heat wave days within the summer season is unlikely to be a health determinant, the timing variable was multiplied by Duration and used as an interaction term (Duration * Time), resulting in a value of zero for the variable on non-heat wave days.

The Missouri Department of Health provided the mortality data, which are derived from death certificates. Mortality from many different causes increases during heat waves (Ellis et al. 1975; Kilbourne 1989), and no consistent definition of heat-related deaths has been established in the United States (Centers for Disease Control 1995). All causes of death, therefore, were used in this analysis because using only deaths classified as heat-related would underestimate heat wave impacts. The research presented here was limited to persons over 64 years of age because the elderly are disproportionately at risk of heat wave mortality. In concurrent research analyzing all age groups, relationships were weaker for the population under 65. Base population sizes for the elderly for 1980 were obtained from US census data. The number of elderly in 1995 was derived by multiplying the percentage of persons older than 64 years, given in the 1990 US census, by estimates for the total population for 1995.[1] Mortality estimates for 1980 are thus more reliable than those for 1995.

The independent variable, the number of elderly deaths per day, is discrete rather than continuous and is positively skewed for both years, particularly for 1980. Therefore, a Poisson regression procedure, which is appropriate for count data (Lovett and Flowerdew 1989), was used to model the relationship between daily mortality and heat wave conditions:

$$D_j=\exp\{\ln(E_j)+\beta_0+\beta_1X_1+\beta_2X_2+\beta_3X_2X_3\} \qquad (2)$$

where D_j is predicted elderly deaths per day, and E_j is exposure (population size for a given year). The regression procedure accounts for the main effects of the heat wave variables AT and Duration (X_1 and X_2 respectively), as well as the interaction between heat wave duration and timing in the summer season (X_2X_3).

A series of nested multivariate models were analyzed separately for 1980 and 1995. The models for each year can be compared using twice the difference in the log likelihood [referred to as –2(Change) hereafter], which has a X^2 distribution with degrees of freedom equal to the change in the number of parameters between subsequent models (Agresti 1990). The null hypothesis is that the more parsimonious model provides an equivalent fit. When –2(Change) exceeds the X^2 critical value, the null hypothesis can be rejected, and the preceding nested model should be accepted.

The next step was to evaluate changes in population vulnerability between 1980 and 1995. Heat wave conditions in 1995 were less extreme than those in 1980, hindering comparison of population responses to heat waves for the two summers. To standardize for meteorological differences, after selection of the best models for each year, two additional sets of models were run to simulate the effects of a severe heat wave on the 1995 population. In the first set of models, elderly deaths were estimated using 1980 weather data and the 1980 model parameters, with the exposure term adjusted for 1995 population size. The results indicate potential mortality impacts during a severe heat wave if the population were to respond in the same manner as in 1980. The second set of models also uses 1980 weather data to simulate a severe heat wave, but substitutes 1995 model parameters to estimate mortality responses based on the relationship modeled for the 1995 population. Estimates from the two sets of models were then compared to evaluate evidence of changing population vulnerability between 1980 and 1995.

Heat wave description

The summer of 1980 had higher temperatures, more days with AT >40.6°C, and longer-lasting heat waves than did 1995. These conditions occurred earlier in the summer season in 1980 than in 1995 (Table 1). For example, the temperature in July 1980 was 3.6°C above the 30-year normal, but mean temperatures were only slightly above normal in July 1995. The mean temperature during August was 3.5°C above normal for both years. In 1980, the first extended run of heat wave days began on 4 July and persisted for 13 days (Fig. 1), while in 1995 the first heat wave began on 12 July and only remained for 5 days (Fig. 2). The July heat waves of 1980 and 1995 were different in intensity and duration, yet the upper air patterns were similar. For both years, a cut-off high was present over the central United States, trapping hot and humid

Table 1 Summer weather and mortality in St. Louis, 1980 and 1995. Standard deviations given in parentheses, where relevant. Temperature data from NOAA (1980, 1995)

	1980	1995
Maximum temperature	41.7°C	38.3°C
Number of heat wave days	31	18
Longest heat wave duration (days)	13	9
Average June temperature *Departure from 30-year normal*	24.2°C *+0.3*	24.2°C *+0.1*
Average July temperature *Departure from 30-year normal*	29.4°C *+3.6*	27.4°C *+0.8*
Average August temperature *Departure from 30-year normal*	28.6°C *+3.5*	28.8°C *+3.5*
Average number of deaths *all days*	20.91 (8.90)	13.16 (3.76)
Average number of elderly deaths *all days*	14.61 (6.91)	9.07 (3.31)
Average elderly mortality rate (per 10,000) *heat wave days*	2.36 (1.20)	1.65 (0.52)
Average elderly mortality rate (per 10,000) *non-heat wave days*	1.56 (0.45)	1.46 (0.55)

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[1] St. Louis 1995 population estimates were obtained from the Claritas Corporation.

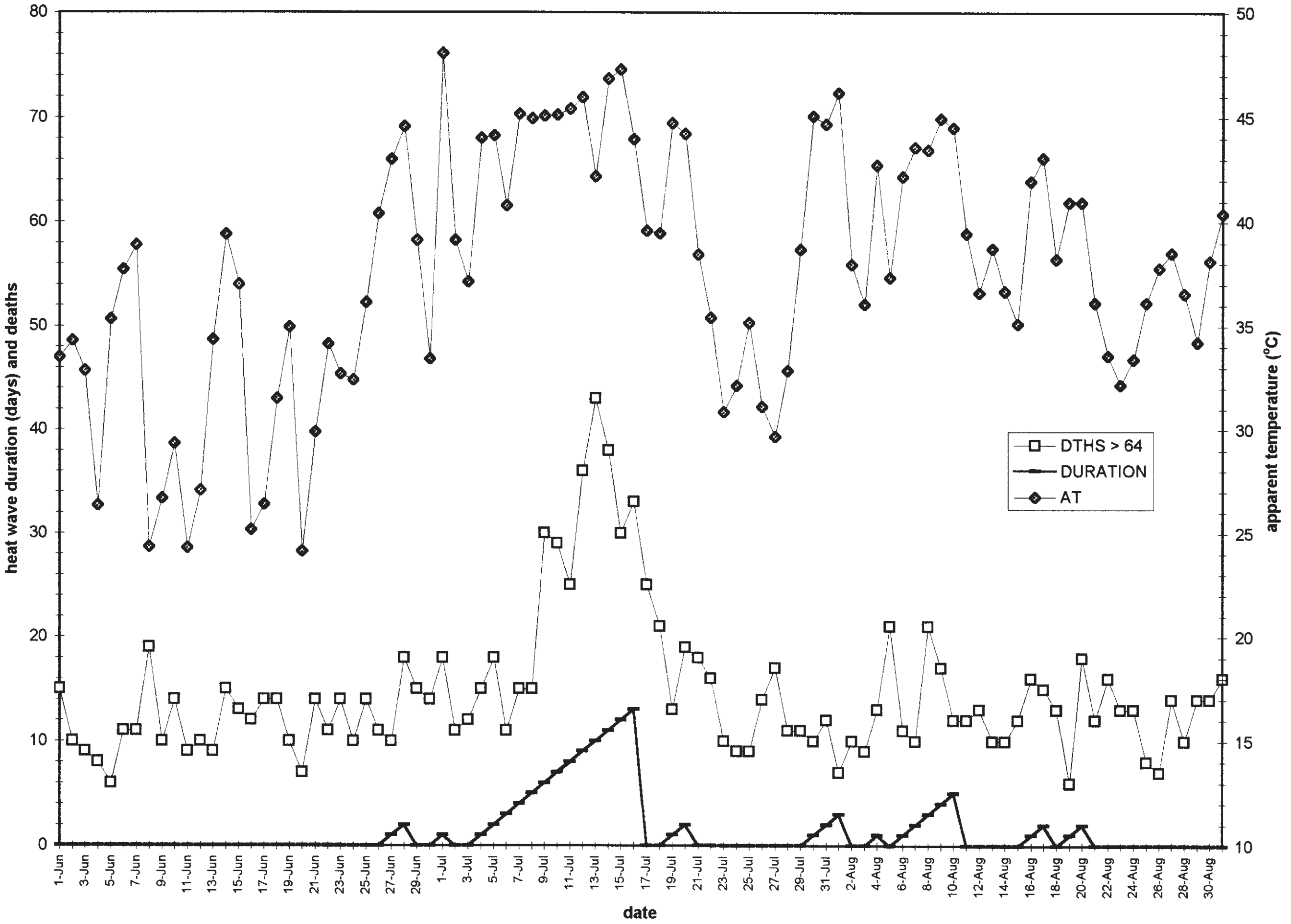

Fig. 1 Apparent temperature (*AT*), heat wave duration, and elderly mortality in St. Louis, 1 June–31 August 1980. *DTHS*>64 = number of elderly deaths

mT air over the central states. During 1980, the upper-level ridge persisted over the region longer than in 1995 (NOAA 1980, 1995).

Mortality responses differed for the two summers. In 1980, mortality peaked on the 10th day of the first heat wave, which was also the longest of the summer (Fig. 1). In 1995, the largest number of heat wave deaths occurred in July as well, during the 4th day of the first heat wave, even though the summer's longest heat wave occurred in August. The number of deaths did not increase during the prolonged August heat wave, but instead dropped below the summer average of 13 deaths per day (Fig. 2). Thus, although August of 1995 was hotter than July of 1995, the summer's heat wave impacts occurred primarily in July. The timing of the majority of heat wave deaths corresponds with the findings of past research, which has attributed the larger number of deaths early in the season to a combination of the most susceptible individuals succumbing to the first heat wave (sometimes called pre-shifted mortality) and to short-term acclimatization to heat wave conditions (Kilbourne 1980; Kalkstein and Smoyer 1993).

Model results

Despite the differences in the 1980 and 1995 heat waves, the same variables, Duration and Time, provide the best model fit for both years, as shown by the low value of –2(Change) in comparison to the critical value of X^2 (Model 2; Tables 2, 3). The coefficients for both years' models are positive for Duration and negative for Duration * Time, indicating that prolonged heat waves and those occurring early in the summer season are associated with elevated mortality. On non-heat wave days, the model parameters are zero, resulting in estimates close to daily mean mortality.

Comparison of heat wave/mortality responses for the two years is complicated. For example, although the coefficients for the 1995 models are larger than for 1980, these results do not necessarily suggest that heat wave impacts were stronger in 1995 than in 1980. The standard errors illustrate that the point estimates for 1980 are more precise, indicating a better fitting model. Correlation between observed and predicted values shows that the 1980 model provides substantially more accurate estimates than the 1995 model, with r=0.811 for 1980 and r=0.305 for 1995. The superior fit of the 1980 model is probably a result of the more intense heat wave and higher mortality in 1980. During the summer of 1995, unmeasured non-meteorological factors appeared to have

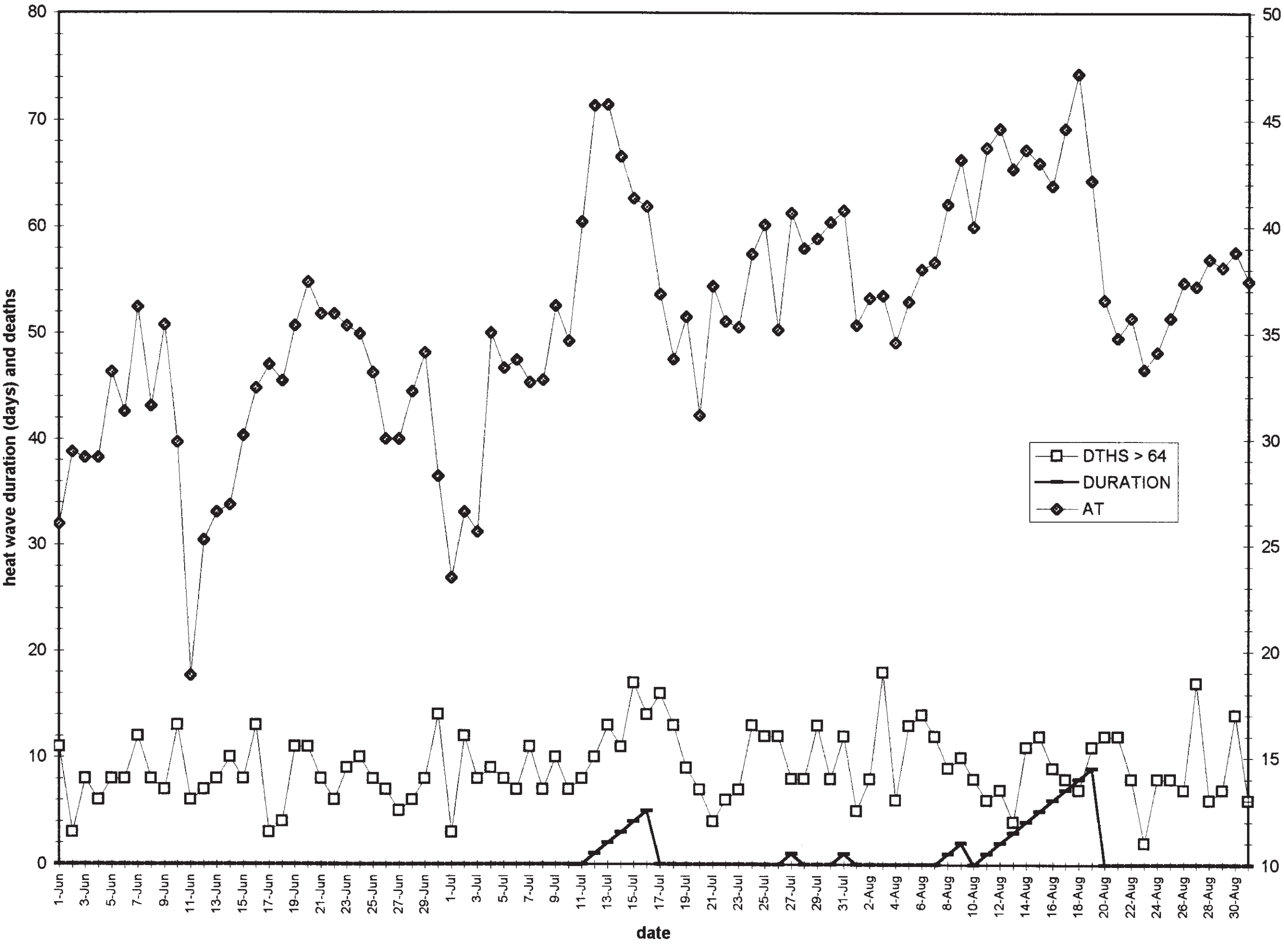

Fig. 2 Apparent temperature (*AT*), heat wave duration, and elderly mortality in St. Louis, 1 June–31 August 1995. *DTHS*> 64 = number of elderly deaths

Table 2 Regression Model Results, 1980. –2(Change) refers to difference in log likelihood from previous model unless indicated otherwise. Critical X^2 value for upper 5% of the distribution (values from Howell 1992). Best fitting model in boldface. *AT* Apparent temperature

Variable	COEF	SE	*Z*-score	*P*>|*Z*|	95% Conf. Int.	
Model 1						
Duration	0.2008	0.0465	4.315	0.000	0.1096	0.2921
Duration * Time	–0.0025	0.0011	–2.422	0.015	–0.0046	–0.0005
AT	0.0052	0.0058	0.897	0.370	–0.0062	0.0167
Constant	–8.9584	0.2148	–41.704	0.000	–9.3734	–8.5373
Log likelihood = –252.845	–2(Change) = n/a		Critical X^2 = n/a		*df* = n/a	
Model 2						
Duration	**0.2007**	**0.0468**	**4.287**	**0.000**	**0.1089**	**0.2924**
Duration * Time	**–0.0024**	**0.0010**	**–2.313**	**0.021**	**–0.0045**	**–0.0004**
Constant	**–8.7683**	**0.0324**	**–253.266**	**0.000**	**–8.8318**	**–8.7048**
Log likelihood = –253.249	**–2(Change) = 0.808**		**Critical X^2 = 3.84**		***df* = 1**	
Model 3						
Duration	0.0934	0.0070	13.294	0.000	0.0796	0.1072
Constant	–8.7791	0.0322	–273.062	0.000	–8.8421	–8.7161
Log likelihood = –256.065	–2(Change) = 5.632		Critical X^2 = 3.84		*df* = 1	
Model 4						
AT	0.0356	0.0048	7.427	0.000	0.0262	0.0451
Constant	–9.9710	0.1885	–59.900	0.000	–10.3405	–9.6016
Log likelihood = –300.489	–2(Change)[a] = 95.288		Critical X^2 = 5.99		*df* = 2	

[a] Change from Model 1

Table 3 Regression model results, 1995. –2(Change) refers to difference in log likelihood from previous model unless indicated otherwise. Critical X^2 value for upper 5% of the distribution (values from Howell 1992). Best fitting model in boldface. *AT* Apparent temperature

Variable	COEF	SE	*Z*-Score	*P*>|*Z*|	95% Conf. Int.	
Model 1						
Duration	0.2283	0.0951	2.400	0.016	0.0418	0.4147
Duration * Time	–0.0031	0.0013	–2.471	0.013	–0.0056	–0.0007
AT	0.0139	0.0080	–1.734	0.083	–0.0018	0.0296
Constant	–9.3157	0.2809	–33.163	0.000	–9.8662	–8.7651
Log likelihood = –233.552	–2(Change) = n/a		Critical X^2 = n/a		*df* = n/a	
Model 2						
Duration	**0.2746**	**0.0899**	**3.055**	**0.002**	**0.0984**	**0.4508**
Duration * Time	**–0.0035**	**0.0012**	**–2.800**	**0.005**	**–0.0059**	**–0.0010**
Constant	**–8.8320**	**0.0379**	**–233.118**	**0.000**	**–8.9063**	**–8.7577**
Log likelihood = –235.080	**–2(Change) = 3.056**		**Critical X^2 = 3.84**		***df* = 1**	
Model 3						
Duration	0.0233	0.0180	1.296	0.195	–0.0120	0.0586
Constant	–8.8225	0.0374	–235.779	0.000	–8.8958	–8.7492
Log likelihood = –238.716	–2(Change) = 7.356		Critical X^2 = 3.84		*df* = 1	
Model 4						
AT	0.0162	0.0065	2.482	0.013	0.0034	0.0289
Constant	–9.3859	0.2380	–39.430	0.000	–9.8524	–8.9193
Log likelihood = –236.412	–2(Change)[a] = 6.076		Critical X^2 = 5.99		*df* = 2	

[a] Change from Model 1

a greater influence on mortality than heat wave duration or timing. In addition, the population exposure term, which for 1995 is based on total population estimates adjusted by age structures that are 5 years out of date, may have affected model accuracy.

Differences are evident in the relationship between apparent temperature and mortality for the two years. In combination with Duration and Time (Model 1), AT is not a significant factor in heat wave mortality for 1980 (Table 2). The variable is significant at the 0.10 level for 1995, but removal of AT does not decrease model fit significantly (Table 3). When regressed alone with mortality for 1980 and 1995, AT is statistically significant for both years, although the model does not provide a satisfactory fit for 1980 (Model 4; Tables 2, 3). The 1980 model of AT and mortality reflects a non-linear relationship consistent with a threshold temperature response, above which mortality rates increase dramatically. This relationship has been noted in previous research (Kalkstein and Smoyer 1993) and will not be discussed here. For 1995, the model containing AT only (Model 4) narrowly exceeded the critical value of X^2 (Table 3), but the relatively low correlation (r=0.232) between observed elderly deaths and those predicted by Model 4 indicates that the Duration and Time model (Model 2) is preferable for 1995 as well as for 1980.

Heat wave simulation model results

The model simulations were used to estimate the number of deaths that would be expected in 1995 if weather conditions had been the same as in 1980 and if the population responded to heat wave conditions: (1) as it did in 1980 and (2) as it did in 1995. Under simulated 1980 heat wave conditions, the number of heat wave days for 1995 would increase from 18 to 31, the first heat wave would begin on 4 July, and the longest heat wave would last 13 days instead of 9 (Table 1). Both sets of the severe heat wave simulations used Model 2, which provided the best fit, along with 1980 values of Duration and Time, and either the 1980 or 1995 estimated variable coefficients as described previously. In addition to this step, differences in standard errors for the 1980 and 1995 models were taken into account by using the 95% confidence interval for each parameter estimate (Tables 2, 3) to select the values that would provide minimum and maximum mortality estimates. For example, based on the 1995 parameter estimates for Model 2 and weather data for 1980, *minimum* mortality values associated with a simulated heat wave were determined by:

$$D_j = \exp\{\ln(60448) - 8.9063 + 0.0984 * \mathrm{Duration} - 0.001 * \mathrm{Duration} * \mathrm{Time}\} \qquad (3)$$

with the exposure term ln(60448) reflecting the estimated 1995 elderly population. Maximum and minimum mortality values using the 95% confidence interval for the 1980 parameter coefficients were estimated similarly.

Model evaluation was limited to estimated mortality on heat wave days (actual or simulated), since estimates on non-heat wave days approximate mean daily mortality. To compensate for differences in heat wave onset, frequency, and duration, mortality for heat wave days observed in 1995 was compared to mortality for those simulated from 1980 data. According to the model simulations, between 319 and 822 deaths would be expected

Table 4 Estimated elderly mortality for simulated heat wave conditions. Average estimates derived from model coefficients; maximum and minimum estimates based on 95% confidence intervals for model coefficients (Table 2 and 3)

	Mean Daily Heat Wave Mortality	Total Heat Wave Mortality	Heat Wave Days
1995 weather data			
Observed deaths	9.94	179	18
1980 weather data			
1980 model parameters			
Average estimates	14.38	446	31
Minimum estimates	13.51	419	31
Maximum estimates	15.01	465	31
1995 model parameters			
Average estimates	15.51	481	31
Minimum estimates	10.29	319	31
Maximum estimates	26.51	822	31

during the summer of 1995 under 1980 weather conditions (Table 4). The larger number of heat wave days under simulated conditions (31 vs 18) does not fully account for the estimated increase of 140–643 deaths above the 179 heat wave deaths observed during the less severe summer of 1995. With the earlier onset and longer duration of hot weather under conditions analogous to 1980, estimated mean daily heat wave mortality also would increase above observed 1995 levels, even for the lowest model estimates (Table 4).

According to the model simulations, under severe heat wave conditions, both daily and total mortality would be expected to increase above levels observed in 1995. The population thus has *remained* vulnerable to heat wave conditions, but the more interesting question pertains to whether population vulnerability has *changed* since 1980. For the simulated heat wave models, higher mortality estimates using 1995 model parameters would indicate that vulnerability had increased, while higher estimates using 1980 parameters would suggest a decrease in vulnerability. The results show that for a simulated severe heat wave, mean daily mortality estimated with the 1995 model parameters is higher than mean mortality derived from 1980 parameters (Table 4). Based on a paired, two-sample difference of means *t*-test, this difference (15.51 vs 14.38) is significant at the 0.05 level. With the large standard errors of the 1995 parameter estimates, however, it is difficult to make definitive statements about changes in population vulnerability. For example, the maximum value of the mean mortality estimate using 1995 parameters is larger, while the minimum estimate is smaller, than analogous estimates using 1980 parameters (Table 4). Despite the low precision in the 1995 estimates, the results of the heat wave simulation models are more supportive of an increase than a decrease in population vulnerability since 1980.

Discussion

The identical structure of the best fitting models for 1980 and 1995 provides evidence that heat wave duration and timing were key factors in mortality for extreme as well as less severe heat waves. Past research documents this relationship (Kilbourne 1989; Kalkstein 1991; Kalkstein and Smoyer 1993). Although the summer of 1980 had more extreme conditions and higher mortality than the summer of 1995, the larger coefficients in the 1995 model raise questions about increased sensitivity to heat stress. Mortality estimates for 1995, based on simulated heat wave conditions, certainly do not support the hypothesis that population vulnerability has decreased, although the poor model fit and large confidence intervals in comparison with 1980 make the estimated number of deaths imprecise. But is there additional evidence of changing population sensitivity?

Several considerations are useful in assessing heat wave mortality vulnerability for a particular place. These include the demographic and socioeconomic composition of the population; housing type and access to air-conditioning; public health interventions for mitigating heat stress; and socioeconomic trends within the city and region that may influence the preceding factors. For example, an older, poorer population in substandard housing would indicate increased vulnerability, particularly in an area undergoing decline where health and social services are limited.

Census data show that the St. Louis population decreased by approximately 20% between 1980 and 1995, resulting in fewer deaths in 1995 (as reflected by the smaller exposure value in the 1995 model). Although the percentage of persons over 64 years decreased from 17.6% to 16.6% between 1980 and 1990, overall, the proportion of high-risk groups did not decrease. Notably, the percentage of residents over both 74 and 84 years increased from 7.6% to 8.2% and 1.7% to 2.1%, respectively (US Bureau of the Census 1980, 1990). These age groups comprise the “frail” elderly, who are at greater risk of mortality than the elderly population under 75. Also contributing to increased vulnerability is the rise in poverty rates from 21.8% to 24.6% between 1980 and 1995, as well as the rise in the proportion of elderly residents below the poverty line from 16.3% to 18.7% (US Bureau of the Census 1980, 1990).

Complicating the assessment of population vulnerability is the increase in air-conditioning from 64.1% in 1980 to 86.7% by 1991, the most recent year for which data are available (Current Housing Reports 1980, 1991). It is unclear how increased poverty rates, in combination with increased air-conditioning rates, are related to heat wave mortality risk. For example, high energy costs and fixed low incomes, which are common among the elderly, may discourage air-conditioning operation among owners. St. Louis newspapers have documented cases of heatstroke deaths of elderly residents who owned functional air-conditioning units that were not in use at the time of death. As an extension of the study presented here, research is currently under way investigating the differential effects of poverty and air-conditioning rates.

Public awareness of heat wave mortality risk and prevention efforts have improved over the study period. In response to the epidemic of heat-related deaths during the 1980 heat wave, the St. Louis public health department initiated a heat wave mortality prevention program involving a heat wave/health watch warning system, education about heat wave risks, operation of cooling shelters, and distribution of air-conditioners to high-risk individuals. The success of these efforts has not been evaluated formally, and should be viewed in the larger context of resources available to the city.

Regional and city socioeconomic trends have not been favorable for St. Louis residents. The city of St. Louis is particularly susceptible to population and employment fluctuations because it is a municipal county, constrained by fixed boundaries that prevent it from collecting taxes from more affluent suburban residents (except for those affected by the city's earnings tax). For example, the number of employees in the metropolitan area fell 5.3%, and in the city decreased by 29.3%, between 1982 and 1992 (US Bureau of the Census 1982, 1992). In addition, the large population loss in the city is indicative of an area in economic decline. Many people remaining in the city are elderly and low-income, putting a strain on city-provided social services.

In conclusion, on the one hand, the wider availability of air-conditioning and heat wave mortality prevention programs should help to decrease vulnerability in St. Louis. On the other, the population using these resources appears to be at greater risk with regard to age and income. Proposed cuts in the safety net at the national level, through policies concerning health care, social security, and income and housing assistance, may have serious impacts on population vulnerability during heat waves. These trends may be felt not just in St. Louis, but also in other US cities undergoing decline. Preventative measures, including increased surveillance and weather/health watch warning systems could help to offset population vulnerability. These programs show great potential in cities such as St. Louis and Philadelphia, but their effectiveness in reducing heat-related mortality has not yet been evaluated.

The recurrence of severe heat wave conditions in St. Louis is likely given the region's location. While the findings of this research are inconclusive about changes in population vulnerability since 1980, they do suggest that St. Louis residents continue to be at risk, despite higher air-conditioning rates and public health prevention efforts. In the event of another heat wave comparable to that of July 1980, St. Louis could face a sizeable death toll.

Acknowledgements This research was funded in part by the Association of American Geographers and the University of Minnesota Center on Aging. The author would like to thank Prof. Connie H. Weil of the University of Minnesota and Dr. Peter Schultz of the Pennsylvania State University, in addition to the anonymous reviewers, for their helpful comments on this manuscript. The mortality data used in this research were handled in accordance with Institutional Review Board human subjects research protocol.

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