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ORIGINAL PAPER

# The impact of heat waves on mortality and years of life lost in a dry region of Iran (Kerman) during 2005–2017

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## Abstract
The present study was conducted to compare the impact of heat waves on mortality and years of life lost (YLL) in Kerman, Iran during the years 2005–2017. Daily mean temperature in a combination of intensity and duration were used in order to define heat waves (90, 95, and 98th percentile and ≥ 2, 3, and 4 consecutive days). YLL was calculated according to Iran's life table and by considering the discount rate. In order to investigate the impact of heat waves in different lags and its cumulative effect on mortality and YLL, Poisson and linear models within distributed lag nonlinear models were used respectively. A maximum lag of 14 days was considered. The best model was selected based on AIC (Akaike Information Criteria). The model was adjusted for air pollutants, public holidays, days of the week, and humidity. The average daily mortality and YLL were 10.54 ± 4.31 deaths and 175.58 ± 91.39 years respectively. They were higher in men and in heat waves matching a definition of above the 98th temperature percentile and ≥ 3 days, than others. Except heat waves defined as the 98th percentile and ≥ 4 days, the impact of heat waves on mortality and YLL were the highest at lag 0. The cumulative relative risk of total mortality was significantly higher in heat waves above the 95 and 98th percentiles. The cumulative effect of heat waves on total YLL was significantly higher only above the 98th percentile. Men over 65 years old were the most vulnerable and had the highest mortality and YLL. Heat waves with temperatures above the 98th percentile that lasted at least 2 or 3 consecutive days had a significant effect in increasing both total YLL and mortality in Kerman, Iran.

**Keywords** Heat wave · Mortality · Years of life lost · Iran

## Introduction

Recently, studies have shown the hazardous impact of high ambient temperatures on health. Various studies have shown that heat can cause different types of mortality including cardiovascular, respiratory, and trauma deaths (Aboubakri et al. 2018; Dadbakhsh et al. 2017; Kalankesh et al. 2015; Khanjani and Bahrampour 2013; Sharafkhani et al. 2017a, b; Yi and Chan 2015). High temperatures can also increase heart rate and body temperature, cause thermal stress (Ravandi et al. 2016), and increase hospitalization (Michelozzi et al. 2009).

Heat waves, which are the result of heat continuity for a certain period, have recently been addressed by researchers and health authorities (Gasparrini and Armstrong 2011). The hazardous impact of heat waves, especially increase in mortality, has raised concern, because following global warming the frequency of these waves has increased in parts of Asia, Europe, and Australia (Lee et al. 2016; Song et al. 2018). A multi-country study has shown that if societies do not adapt to climate change, heatwave-related mortality will increase in the future (Guo et al. 2018). The definition of heat wave is different in different references. Many studies have defined it based on a combination of temperature intensity and duration (Xu et al. 2016). These studies have shown that extended and severe heat waves can increase mortality considerably. Other studies (Lee et al. 2016), have shown that as temperature and duration raise, the negative effects became more pronounced.

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A systematic review study conducted by Xu et al. (2016) showed that depending on temperature threshold and duration, the impact of heat waves on mortality was different.

Most previous studies in the field of temperature and health have used death and disability as the outcome and have not considered the burden of disease or years of life lost (YLL) (Yang et al. 2015). YLL is a measure of disease burden that uses life expectancy and gives more weight to deaths that happen among younger people, compared to crude mortality rates that weigh all deaths equally (Huang et al. 2012). Most of the studies in this field have used the YLL as an indicator of burden (Baccini et al. 2013; Luan et al. 2017). Yang et al. showed that cold and heat had a significant effect on YLL from non-accidental deaths in both men and women (Yang et al. 2015). Although many studies have been conducted in the field of temperature and YLL, but relatively few studies have considered cold or heat waves and YLL. Huang et al. defined heat waves as temperature above the 99th percentile in at least 2 consecutive days, and reported that it led to a significant increase in YLL (Huang et al. 2012).

It is necessary to evaluate the impact of heat waves on mortality in different areas, and establish a warning system for extreme temperatures according to available evidence (Luan et al. 2017; Tong et al. 2014). Ambient temperature is very different in different parts of Iran, and few studies have been conducted on the relation between heat waves and mortality or YLL in this country. This is the first study assessing the impact of heat waves on mortality and YLL in Iran by using various definitions of heat waves.

# Methods

## Data and area under study

Kerman city has a population of about 740,000 people and is located in Kerman province in southeastern Iran. It is located at 56° 52′ 30″–57° 07′ 30″ E and 30° 07′ 30″–30° 22′ 30″ N and on a flat plain with an altitude of 1754 m. Its climate is dry with hot summers and cold winters. Its air temperature varies from about − 8 to 37 °C throughout the year (Atapour 2015; Hamzeh et al. 2011).

In this study, meteorological and mortality data were obtained from the Iran Meteorological Organization and Health Deputy of Kerman University of Medical Sciences respectively, from January 2005 to March 2017. Data on ambient air pollutants were obtained from the Kerman Department of Environment.

## Heat wave definition

There is no standard definition for a heat wave. Previous studies have provided various definitions according to intensity and duration (Lee et al. 2016; Song et al. 2018). Also, various studies have shown that one parameter is not enough to define heat waves in different regions. Nonetheless, many studies have shown that mean daily temperature is a more important predictor for mortality than the minimum or maximum daily temperature for defining heat waves (Xu et al. 2018; Xu et al. 2016; Xu and Tong 2017). In the present study, the AIC in models using daily mean temperature was less than those using minimum or maximum daily temperature, as well. Therefore, a combination of severity and duration of mean daily temperature was used to define heat waves in this study. In accordance with the overall review, we had on heat wave definitions; we selected different cut-offs in order to show the impact of heatwaves based on different cut-offs on mortality and years of life loss. Nine definitions of a heat wave have been listed in Table 1. Nine binary variables were constructed, in which code 1 was assigned to heat waves and 0 to non-heat waves.

## Years of life loss

One component of Burden of Disease (BoD), the years of life lost due to premature death, was used in this study. This

**Table 1** Definition of heat waves

| Heat wave | Definition | |
|---|---|---|
| | Percentile | Duration of high temperature |
| HW1 | ≥ 90th percentile of temperature | ≥ 2 consecutive days |
| HW2 | | ≥ 3 consecutive days |
| HW3 | | ≥ 4 consecutive days |
| HW4 | ≥ 95th percentile of temperature | ≥ 2 consecutive days |
| HW5 | | ≥ 3consecutive days |
| HW6 | | ≥ 4 consecutive days |
| HW7 | ≥ 98th percentile of temperature | ≥ 2 consecutive days |
| HW8 | | ≥ 3 consecutive days |
| HW9 | | ≥ 4 consecutive days |

indicator was calculated for deaths due to all causes for the *i*th age group and for the $g^{th}$ sex group through Eq. 1.Where *N* and *L* are the number of deaths and standard life expectancy, respectively. Iran's life table was used in order to acquire life expectancy for different age and sex groups. The 0.03 is the constant discount rate and is a standard value for these calculations (Mathers et al. 2001).The total amount of YLL for each day was calculated using Eq. 2.

$$\mathrm{YLL_{ig}} = \frac{N_{ig}}{0.03}\left(1 - e^{-0.03 L_{\mathrm{ig}}}\right) \quad (1)$$

$$\mathrm{YLL}_t = \sum_{i=0}^{n} \mathrm{YLL_{ig}} \quad (2)$$

The YLL was calculated for women, men, the ≥ 65, and < 65 age groups.

### Statistical analysis

The cumulative effects of heat wave on mortality and YLL were investigated using distributed lag non-linear models (DLNM) (Gasparrini 2011). Selection of the best model was based on the Akaike information criterion (AIC). Air pollutants including $SO_2$, $O_3$, and $PM_{10}$, days of the week, public vacations, and daily average relative humidity remained as potential confounders in the final model. GLM and Poisson models were used to investigate the relation between heat wave and mortality. Linear models were used in order to assess their impact on YLL. The two abovementioned models are shown in Eqs. 3 and 4, respectively.

$$\begin{aligned}\log(Y_t) = \alpha &+ \mathrm{CbHW_{tl}} + \mathrm{NS}\,(\mathrm{SO_2}, 3) + \mathrm{NS}\,(\mathrm{PM_{10}}, 3) \\ &+ \mathrm{NS}\,(\mathrm{O_3}, 3) + \mathrm{NS}\,(\mathrm{Humidity}, 3) \\ &+ NS\,(\mathrm{Time}, 5{*}year) + \mathrm{DOW} + \ \mathrm{Holiday} \\ &+ \varepsilon_t \end{aligned} \quad (3)$$

$$\begin{aligned}\mathrm{YLL}_t = \alpha &+ \mathrm{CbHW_{tl}} + \mathrm{NS}\,(\mathrm{SO_2}, 3) + \mathrm{NS}\,(\mathrm{PM_{10}}, 3) \\ &+ \mathrm{NS}\,(\mathrm{O_3}, 3) + \mathrm{NS}\,(\mathrm{Humidity}, 3) \\ &+ \mathrm{NS}\,(\mathrm{Time}, 5{*}year) \ + \mathrm{DOW} + \ \mathrm{Holiday} \\ &+ \varepsilon_t \end{aligned} \quad (4)$$

In these equations, $Y_t$ and $\mathrm{YLL}_t$ are the number of deaths and the years of life lost on day *t*, respectively. HW is the main exposure variable (heat wave) at time *t*, $\alpha$ is the intercept, and Cb is the cross-basis function in DLNM that shows a heat wave at day *t* and lag time l and is a matrix. There were 14 lags (days) modeled in this study. NS and $\varepsilon_t$ are the natural spline function and the residual at time *t*, respectively. Considering the possible delay effects, the maximum lag time of 14 was considered. According to the lowest AIC, the degree of freedom equal to 3 was selected for the natural spline. The time variable with a degree of freedom equal to 5 per year, was entered into the model in order to control the trend and seasonal effects. The degree of freedom of 5 was also selected based on the lowest AIC. In these models, DOW and Holiday are the days of the week and the public holidays, respectively. Holiday was introduced as a binary variable into the model. The DOW variable is a qualitative variable with seven categories and Friday (the weekend in Muslim countries) was considered as the reference.

In addition to the above analysis, one-way ANOVA was used to compare the mean daily mortality and YLL in various definitions of heat waves.

The analysis were performed using Excel 2013, SPSS 21 and R software version 3.3.2.

## Results

### Descriptive information

The average daily temperature was 17.32 ± 8.87 °C. The 90th, 95th, and 98th percentiles, that were used to define the heat waves, were 28.4, 30, and 31.10 °C, respectively. The average of minimum, maximum, mean daily temperature, and mean daily humidity along with other characteristics of mortality and years of life lost by age and sex groups are shown in Table 2. There were about 46,200 deaths during the course of the study, all of which were entered into the analysis. The average daily death was 10.54 ± 4.31 deaths, which happened more in men (6.2 ± 3.05). Also, the average daily YLL was 175.58 (± 91.39) years in the population, and was more for men than women (99.83 versus 75.75).

### Heat waves

Table 3 shows the types of heat wave and their characteristics based on their definition. The longest heat wave based on the 90th, 95th, and 98th percentiles occurred on June 3, 2008; June 26, 2006; and July 4, 2016 and lasted for 25, 16, and 7 consecutive days, respectively. The average duration (days) that each heat wave lasted, the average daily number of deaths, and years of life lost during the heat wave days are shown in Table 3. The mean daily mortality in HW5, HW7, and HW8 were significantly more than HW1, HW2, and HW3. There was also a significant difference between the mean of YLL on HW7 and HW8 with HW1, HW2, and HW3. There was no significant difference between the other heat waves in terms of YLL or mortality.

**Table 2** Summary of daily meteorological variables, mortality, and years of life lost in Kerman, Iran (2005–2017)

| | | Mean (SD) | Minimum | Maximum | Percentile | | |
|---|---|---|---|---|---|---|---|
| | | | | | 25 | 50 | 75 |
| Meteorological factors | Minimum temperature(°C) | 7.93 (8.23) | − 20.80 | 26.60 | 1.60 | 9.00 | 14.40 |
| | Maximum temperature(°C) | 25.63 (9.11) | − 2.80 | 41.00 | 18.50 | 26.80 | 33.40 |
| | Average temperature(°C) | 17.32 (8.87) | − 8.50 | 32.90 | 9.90 | 18.10 | 25.00 |
| | Average humidity (%) | 31.28 (17.63) | 5.50 | 97.38 | 18.00 | 25.88 | 40.13 |
| Mortality | Male | 6.2 (3.05) | 0.00 | 21.00 | 4.00 | 6.00 | 8.00 |
| | Female | 4.3 (2.42) | 0.00 | 15.00 | 3.00 | 4.00 | 6.00 |
| | < 65 | 5.43(2.92) | 0.00 | 20.00 | 3.00 | 5.00 | 7.00 |
| | ≥ 65 | 5.13 (2.67) | 0.00 | 15.00 | 3.00 | 5.00 | 7.00 |
| | Total | 10.54 (4.31) | 0.00 | 32.00 | 8.00 | 10.00 | 13.00 |
| YLL | Male | 99.83 (56.46) | 0.00 | 383.15 | 59.74 | 94.25 | 133.20 |
| | Female | 75.75 (69.14) | 0.00 | 525.50 | 33.68 | 59.63 | 94.50 |
| | < 65 | 124.74 (69.62) | 0.00 | 528.24 | 74.45 | 117.05 | 166.01 |
| | ≥ 65 | 37.64 (20.63) | 0.00 | 123.48 | 23.23 | 35.80 | 50.18 |
| | Total | 175.58 (91.39) | 0.00 | 674.36 | 114.54 | 163.56 | 220.98 |

## The relation between heat wave and mortality

The added effect of heat wave on mortality in different lags (up to lag 14) has been shown in Fig. 1.The relative risk of death in lag 0 is the highest except for HW9, which is the 98th percentile and at least 4 consecutive days heat waves. However, in the 98th percentile after the decrease of relative risk until lag 3, it increased until lag 8, and this increase continued a few more days for heat waves that lasted at least 4 consecutive days (HW9). Table 4 presents the cumulative relative risk up to lag 14 for different heat wave definitions and age and sex groups. Total mortality was significantly higher on heat wave days than non-heat waves during the 95th and 98th percentile heat waves. No significant effect was observed

**Table 3** Different definitions of heat waves and their characteristics

| Heat wave | Definition | | Number | Average duration in days, mean (SD) | Mortality | | YLL | |
|---|---|---|---|---|---|---|---|---|
| | Percentile | Duration | | | Mean (CI 95%) | *p* value** | Mean (CI 95%) | *p* value** |
| HW1 | ≥ 90th percentile | ≥ 2 consecutive days | 51 | 8.29 (6.38) | 9.8 (9.39, 10.22) | 0.001 | 155.95 (148.39, 163.51) | 0.029 |
| HW2 | | ≥ 3 consecutive days | 43 | 9.47 (6.28) | 9.77 (9.35, 10.2) | | 155.21 (147.47, 162.96) | |
| HW3 | | ≥ 4 consecutive days | 36 | 10.72 (6.11) | 9.77 (9.33, 10.21) | | 155.16 (147.22, 163.1) | |
| HW4 | ≥ 95th percentile | ≥ 2 consecutive days | 42 | 5.10 (3.43) | 10.46 (9.87, 11.06) | | 165.24 (154.18, 176.31) | |
| HW5 | | ≥ 3consecutive days | 32 | 6.06 (3.40) | 10.57* (9.93, 11.2) | | 166.86 (155, 178.72) | |
| HW6 | | ≥ 4 consecutive days | 24 | 7.08 (3.35) | 10.48 (9.78, 11.17) | | 167.01 (154, 180.03) | |
| HW7 | ≥ 98th percentile | ≥ 2 consecutive days | 20 | 3.65 (1.57) | 11.37* (10.46, 12.28) | | 178.95* (160.62, 197.28) | |
| HW8 | | ≥ 3 consecutive days | 15 | 4.2 (1.42) | 11.49* (10.5, 12.49) | | 180.51* (160.47, 200.56) | |
| HW9 | | ≥ 4 consecutive days | 8 | 5.25 (1.16) | 10.88 (9.86, 11.9) | | 176.02 (152.6, 199.43) | |

*Significantly different with the HW1, HW2, and HW3

***p* value was based on ANOVA

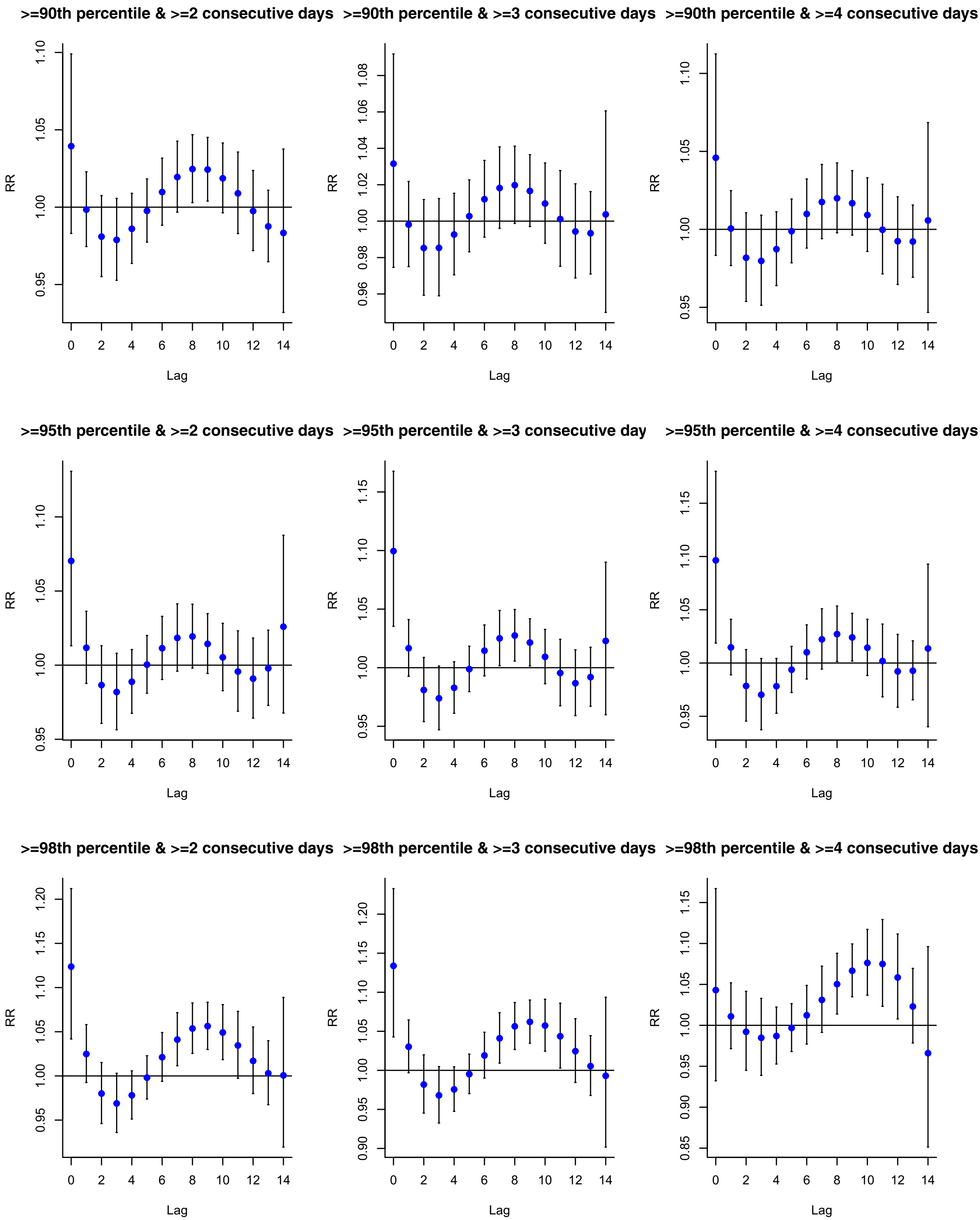


**Fig. 1** Relative risk of mortality due to heat waves at different lag times and different heat wave definitions

in the 90th percentile heat waves. Also, no significant effect was observed in the under 65-year age group except for HW7 (98 percentile for at least 2 consecutive days). Generally, the risk of death due to heat waves was higher for men over 65

**Table 4** Cumulative effect (relative risk and 95% confidence interval) of heat waves on mortality by different age and sex groups in Kerman, Iran (2005–2017)

| Heat wave | Definition | | Sex | | Age group | | Age-sex groups | | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Percentile | Duration | Male | Female | < 65 | ≥ 65 | Male and < 65 | Male and ≥ 65 | Female and < 65 | Female and ≥ 65 | |
| HW1 | 90 | ≥ 2 days | 1.086 (0.964, 1.223) | 1.02 (0.882, 1.180) | 1.013 (0.891, 1.151) | 1.101 (0.965, 1.256) | 1.018 (0.870, 1.192) | 1.174 (0.979, 1.409) | 1.009 (0.806, 1.262) | 1.019 (0.841, 1.235) | 1.054 (0.962 1.156) |
| HW2 | | ≥ 3 days | 1.104 (0.978, 1.246) | 1.021 (0.880, 1.184) | 1.029 (0.903, 1.172) | 1.103 (0.964, 1.262) | 1.043 (0.889, 1.224) | 1.185 (0.984, 1.427) | 1.02 (0.812, 1.281) | 1.013 (0.833, 1.232) | 1.065 (0.97, 1.17) |
| HW3 | | ≥ 4 days | 1.101 (0.975, 1.242) | 1.008 (0.869, 1.168) | 1.036 (0.909, 1.180) | 1.077 (0.942, 1.233) | 1.06 (0.904, 1.244) | 1.149 (0.954, 1.384) | 1.009 (0.804, 1.268) | 0.997 (0.820, 1.212) | 1.057 (0.962, 1.161) |
| HW4 | 95 | ≥ 2 days | 1.185* (1.015, 1.385) | 1.05 (0.866, 1.274) | 1.064 (0.900, 1.257) | 1.183 (0.993, 1.410) | 1.085 (0.885, 1.329) | 1.331* (1.045, 1.696) | 1.06 (0.788, 1.425) | 1.035 (0.802, 1.336) | 1.122 (0.994, 1.266) |
| HW5 | | ≥ 3 days | 1.215* (1.036, 1.425) | 1.071 (0.878, 1.307) | 1.113 (0.938, 1.320) | 1.188 (0.991, 1.423) | 1.144 (0.930, 1.408) | 1.308* (1.019, 1.679) | 1.077 (0.794, 1.459) | 1.059 (0.814, 1.379) | 1.151* (1.016, 1.303) |
| HW6 | | ≥ 4 days | 1.219* (1.036, 1.434) | 1.026 (0.838, 1.255) | 1.073 (0.902, 1.276) | 1.195* (1.001, 1.436) | 1.097 (0.887, 1.356) | 1.391* (1.080, 1.793) | 1.044 (0.768, 1.419) | 1.004 (0.768, 1.313) | 1.131 (0.997, 1.283) |
| HW7 | 98 | ≥ 2 days | 1.609* (1.239, 2.090) | 1.146 (0.828, 1.587) | 1.344* (1.015, 1.779) | 1.43* (1.064, 1.920) | 1.397 (0.989, 1.972) | 1.891* (1.264, 2.829) | 1.314 (0.804, 2.149) | 1.015 (0.656, 1.569) | 1.399* (1.141, 1.715) |
| HW8 | | ≥ 3 days | 1.587* (1.203, 2.093) | 1.28 (0.909, 1.802) | 1.302 (0.967, 1.753) | 1.579* (1.157, 2.155) | 1.268 (0.879, 1.829) | 2.085* (1.362, 3.191) | 1.447 (0.862, 2.430) | 1.124 (0.711, 1.779) | 1.448* (1.168, 1.795) |
| HW9 | | ≥ 4 days | 1.673* (1.192, 2.346) | 1.179 (0.781, 1.779) | 1.389 (0.968, 1.993) | 1.418 (0.972, 2.069) | 1.449 (0.923, 2.274) | 1.922* (1.145, 3.224) | 1.367 (0.734, 2.547) | 1.011 (0.581, 1.761) | 1.434* (1.105, 1.861) |

* The asterisk indicates statistical significance ($p < 0.05$)

than any other subgroup, and they were significantly affected by the 95th and 98th percentile heat waves.* The asterisk indicates statistical significance (p<0.05)

## The relationship between heat waves and YLL

Figure 2 shows the mean difference of YLL between heat wave and non-heat wave days at different lag times. Although a similar pattern with mortality (Fig. 1) was seen in term of effect size, but it was different in terms of significance at different lags. The mean difference of YLL was significant only at the 8th and 9th lags, in the 98th percentile (Fig.2). Table 5 shows the cumulative mean difference of YLL up to lag 14. The cumulative effects of heat waves on total daily YLL were significant only at the 98th percentile. Similar to mortality, men (especially men over 65) had higher YLL than women. The mean difference of YLL was significant only for the upper 65-age group at HW8.* The asterisk indicates statistical significance (p<0.05)

The cumulative effects of heat waves on both mortality and YLL were also assessed up to lag 7. Generally, the results showed the same pattern as lag 14, but the estimations were lower in some cases.

**Discussion** The results of this study showed that heat waves above of the 98th percentile and for at least 3 consecutive days caused the greatest daily mortality and YLL. There was also a significant effect in the 98th percentile heat waves that lasted for 2 and 3 days on both mortality and YLL. Men especially over 65, were more vulnerable than women. Although the impact of heat waves on these two outcomes had almost the same pattern in different lags, but they were different in terms of significance.

Our study is the first to examine the cumulative effects of heat waves on YLL in Iran. There are few studies about the relation between heat waves and YLLs. Egondi et al. (2015) examined the added effects of heat wave on years of life lost (YLL) due to all-cause mortality among the urban poor population of Nairobi. They found that heat waves do not have a clear effect in lags 0–14, but its effect becomes significant at longer lags, and heat waves defined by the 98th percentile had a significant effect on YLL at lags 18 and 19. This pattern was similar to our results that the effect was more evident in longer lags (after day 6). Huang et al. examined the added effects of heat waves on YLL due to premature cardiovascular deaths in Brisbane, Australia, and showed that there was a significant effect in all three heat waves (>=2, 3, and 4 consecutive days). However, these authors only used the 99th percentile to define heat waves (Huang et al. 2012).

Li et al. (2017) explored the impact of temporal variations on the temperature-YLL relation before and after the 2013 heat waves in a southern China city. They showed that the

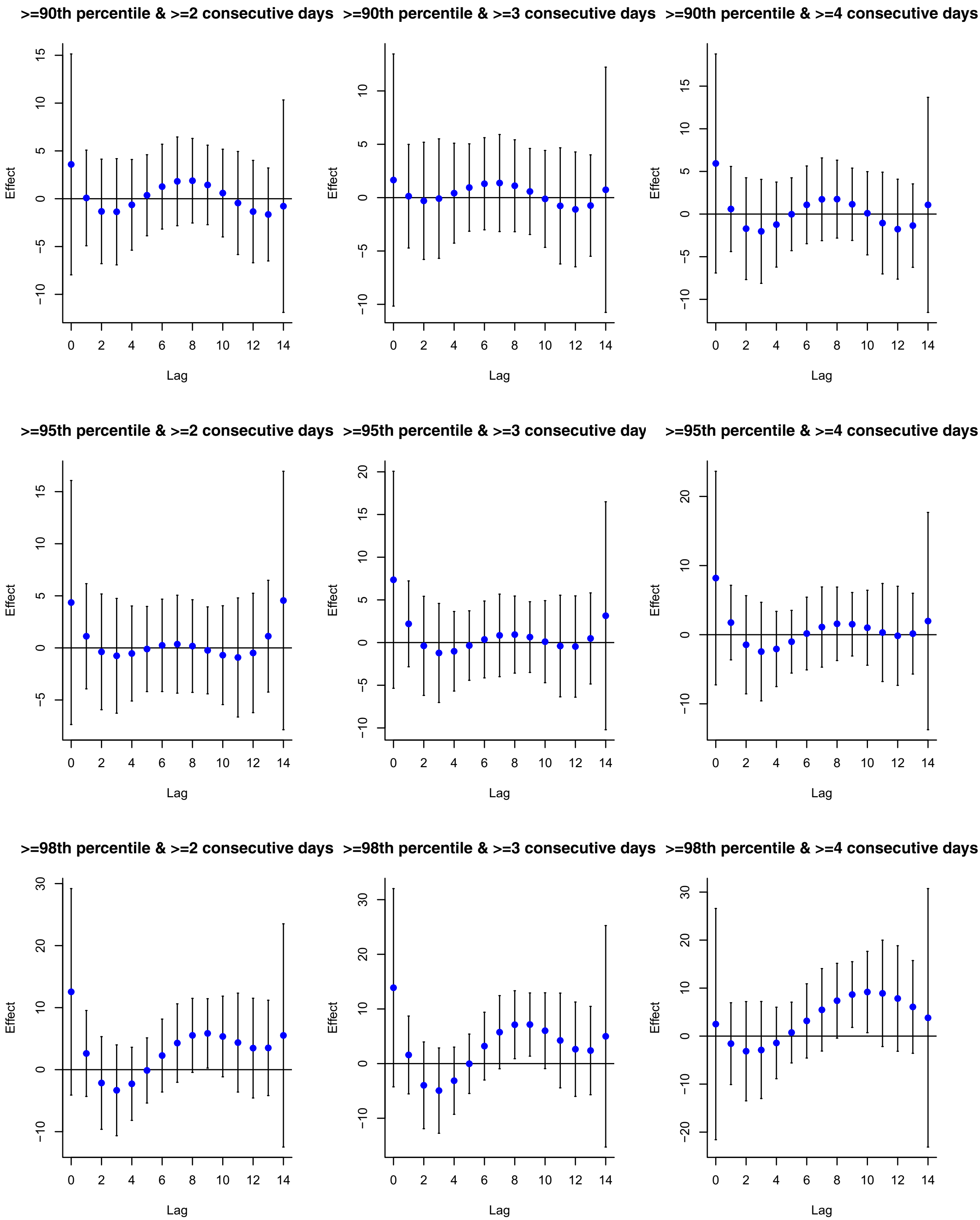


**Fig. 2** Mean difference of years of life lost between heat wave and non heat wave days, at different lag times and different heat wave definitions

trend in heat-related YLL was steeper in period II (after the heat wave) than period I (before the heat wave). They also showed that heat had its greatest effect on YLL, on the first days. Similar to this study, Yang et al. (2015) examined the

**Table 5** Cumulative effect (mean difference and 95% confidence interval) of heat waves on years of life lost by different age and sex groups in Kerman, Iran (2005–2017)

| Heat wave | Definition | | Sex | | Age group | | Age-sex groups | | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Percentile | Duration | Male | Female | < 65 | ≥ 65 | Male and < 65 | Male and ≥ 65 | Female and < 65 | Female and ≥ 65 | |
| HW1 | 90 | ≥ 2 days | 6.034 (− 8.582, 20.649) | − 2.545 (− 14.535, 9.446) | 5.799 (− 12.088, 23.685) | 2.512 (− 3.018, 8.041) | 2.8 (− 11.238, 16.839) | 2.569 (− 1.396, 6.534) | 2.998 (− 7.164, 13.160) | − 0.057 (− 3.837, 3.722) | 3.489 (− 15.985, 22.962) |
| HW2 | | ≥3 days | 7.864 (− 7.021, 22.748) | − 2.736 (− 14.948, 9.475) | 7.41 (− 10.804, 25.624) | 2.627 (− 3.007, 8.260) | 4.599 (− 9.697, 18.896) | 2.716 (− 1.324, 6.756) | 2.811 (− 7.538, 13.159) | − 0.09 (− 3.939, 3.759) | 5.127 (− 14.705, 24.960) |
| HW3 | | ≥4 days | 7.604 (− 7.231, 22.440) | − 3.353 (− 15.528, 8.822) | 7.618 (− 10.544, 25.779) | 1.671 (− 3.949, 7.291) | 5.108 (− 9.146, 19.361) | 1.941 (− 2.087, 5.970) | 2.51 (− 7.809, 12.829) | − 0.27 (− 4.108, 3.568) | 4.251 (− 15.522, 24.025) |
| HW4 | 95 | ≥2 days | 11.364 (− 8.283, 31.010) | − 3.556 (− 19.671, 12.558) | 10.097 (− 13.939, 34.132) | 4.751 (− 2.671, 12.174) | 6.403 (− 12.462, 25.268) | 4.306 (− 1.024, 9.636) | 3.693 (− 9.962, 17.349) | 0.445 (− 4.631, 5.521) | 7.808 (− 18.365, 33.980) |
| HW5 | | ≥3 days | 15.519 (− 4.697, 35.736) | − 3.301 (− 19.889, 13.287) | 14.144 (− 10.594, 38.882) | 5.536 (− 2.101, 13.173) | 10.34 (− 9.078, 29.759) | 4.551 (− 0.931, 10.034) | 3.803 (− 10.254, 17.861) | 0.984 (− 4.240, 6.209) | 12.218 (− 14.717, 39.153) |
| HW6 | | ≥4 days | 12.121 (− 8.318, 32.559) | − 1.527 (− 18.292, 15.238) | 9.266 (− 15.746, 34.278) | 5.732 (− 1.993, 13.456) | 6.315 (− 13.311, 25.941) | 5.612* (0.070, 11.154) | 2.951 (− 11.251, 17.154) | 0.119 (− 5.164, 5.403) | 10.594 (− 16.635, 37.823) |
| HW7 | 98 | ≥2 days | 38.363* (5.028, 71.698) | 9.07 (− 18.315, 36.454) | 39.27 (− 1.542, 80.082) | 10.908 (− 1.701, 23.516) | 26.802 (− 5.234, 58.838) | 10.923* (1.883, 19.963) | 12.468 (− 10.738, 35.675) | − 0.015 (− 8.640, 8.609) | 47.433* (3.009, 91.856) |
| HW8 | | ≥ 3 days | 31.189 (− 3.948, 66.326) | 15.696 (− 13.159, 44.550) | 34.797 (− 8.211, 77.805) | 14.432* (1.150, 27.714) | 18.234 (− 15.532, 51.999) | 12.559* (3.033, 22.084) | 16.563 (− 7.880, 41.006) | 1.873 (− 7.215, 10.961) | 46.885* (0.083, 93.688) |
| HW9 | | ≥4 days | 42.772* (0.199, 85.346) | 11.904 (− 23.094, 46.901) | 47.657 (− 4.457, 99.770) | 8.068 (− 8.057, 24.192) | 33.082 (− 7.814, 73.978) | 9.071 (− 2.510, 20.651) | 14.575 (− 15.073, 44.222) | − 1.003 (− 12.021, 10.015) | 54.676 (− 2.055, 111.406) |

* The asterisk indicates statistical significance ($p < 0.05$)

impact of temperature on YLL in Guangzhou, China and reported that heat shows its effects on YLL mainly on the first days and the effect was stronger on the elderly than others.

Few studies have been done about the relation between heat wave and mortality in Iran, but there are studies from other countries. A study conducted to assess the impact of heat waves under various definitions by Zhang et al. in China showed that women were more vulnerable than men, and older age groups were more vulnerable than young and middle-aged people in terms of daily non-accidental death; for instance, there was an increased RR of 1.45 (95% CI 1.21, 1.74) for male mortality, 1.84 (95% CI 1.54, 2.20) for female mortality, and 1.40 (95% CI 1.09, 1.80) for mortality under 65 years, and 1.71 (95% CI 1.47, 2.00) for mortality ≥ 65 years (Zhang et al. 2017). Other studies that have examined the impact of heat waves on mortality in the USA, China, and South Korea have examined this effect in several communities, and showed that women and elderly people are more vulnerable than men and young individuals (Anderson and Bell 2009; Goggins et al. 2012; Son et al. 2012).

Vulnerability of the elderly to temperature has been shown in studies from China and Thailand. These studies have used DLNM packages and various lag time analysis (Guo et al. 2012; Li et al. 2016, 2015). Various factors can explain why elders are more vulnerable to die from high temperatures. For example, as age increases, the body's temperature regulating system does not function as efficiently and chronic diseases may exist as well (Li et al. 2017). Researchers have also mentioned that excess mortality among elders may be due to physiologic changes in cellular and humoral immunity, as well as behavioral factors. Understanding these differences may help identify susceptible populations and mechanisms whereby temperature affects populations (Dadbakhsh et al. 2017). Similar to the results of these studies, in our study, the elderly were more at risk than younger people. In Iran, retired men are more likely to spend their free time in the outdoors or start to work in a job not related to their previous profession. The reason for less vulnerability of women in Kerman may be behavioral patterns such as staying indoors, using appropriate clothing, and avoiding working during the hot hours. Clothing is different from the western countries in Iran. Women wear long pants and long sleeves and cover most of their skin in public, which prevents skin exposure to the sun. Traditionally, there are still old houses made of mud and straw and wind towers in Kerman which cool the house interior (Khanjani and Bahrampour 2013).

Plotting daily mortality relative risk by the lags (Fig. 1) showed an interesting pattern. The heat wave appeared to increase deaths on the early days, but later the death rate decreased. This might suggest a possible mortality displacement or harvesting effect for the heat waves. "Harvesting" vulnerable individuals can introduce autocorrelation; a high number of deaths on 1 day may leave a smaller number of vulnerable individuals at risk of dying on succeeding days (Spix et al. 1993). In order to assess the harvesting effect with this perspective, sensitivity analysis was performed; two models were compared in which the second model had additional terms to adjust for autocorrelated errors. Three autocorrelation terms were created to capture three lag-autocorrelations with mortality. Only the coefficient of autocorrelation term with lag 1 was significant ($p = 0.0395$). The goal of this model was to check whether adjustment for autocorrelation changes parameter estimates of interest and their variance estimates. The changes were not substantial for all definitions of heat wave, suggesting the harvesting effect is less likely to have substantial effect on our estimates. The YLL had a similar pattern and suggested that harvesting did not have a significant effect on the result. This is probably because in estimating YLL, more weight is given to deaths that happen among younger people which are less vulnerable.

People's socioeconomic status and their adaptability to climate vary in different regions, and this might have affected the results in different studies (Huang et al. 2012). On the other hand, various studies have used different definitions of heat waves. Evidence suggests that the higher the percentile and the longer the period, the stronger the heat wave becomes (Anderson and Bell 2009; Gasparrini and Armstrong 2011; Hajat et al. 2006). A systematic review published in 2016, showed that the intensity of the heat wave (percentiles) plays a more important role in impact of heat waves on mortality, and the relative risk of mortality is higher at higher percentiles (Xu et al. 2016). In our study, the higher percentile (98th) had a more important impact on both death and YLL, and the most significant cumulative relative risk was seen in the 98th percentile which lasted for at least 3 consecutive days. Therefore, the higher percentile heat waves are likely to affect YLL more than others.

In this study, the 95th percentile was not a strong predictor for YLL as compared to mortality because there was no significant effect on YLL in the 95th heat waves, in any subgroup, except among men over 65 years. Therefore, our results show that, the 98th percentile is a stronger predictor for both YLL and death, and men over 65 are the most vulnerable to heat wave impact.

There has been an increase in the aging population and reduced fertility in Iran recently. The aging population has increased from 7.22% in 2006 to 8.20% in 2011 and is estimated to increase to 10.5% and 21.7% by 2025 and 2050 respectively (Tourani et al. 2018). On the other hand, various studies have shown that the average temperature has increased in Iran in the recent decades (Alizadeh-Choobari and Najafi 2018; Soltani et al. 2016). Therefore, it is not unexpected to see more heat waves in the future, and these heat waves might have negative effects on YLL (as a component of burden) and mortality. Results of multi-country studies have shown that some countries could face a significant increase in temperature and heatwave-related mortality in the near future (Guo et al. 2018; Vicedo-Cabrera et al. 2018), and it is necessary to pay more attention to this issue in health policies. Considering the fact that the greatest influence of heat wave on both YLL and mortality happened at lag time 0, interventions should be carried out immediately on the first days of heat waves.

### Strengths and limitations

The use of the DLNM statistical model was a strength of this study, because it evaluates the impact of heat waves using a two-dimensional function. One of the limitations of this study is its low generalizability. Iran is a country with different climates, and it is suggested that other studies be conducted in other regions of Iran. Missing data was one of the limitations in our study. The missing percentage was high for some confounder variables like $NO_2$, $PM_{10}$, and $O_3$. However, we did not impute the missing data. Eventually, we only entered two variables ($PM_{10}$ and $O_3$) in the model because sensitivity analysis showed that the precision of some estimates were influenced by the confounders. Goodness of fit results also showed a better fitness in the model without imputation. Fortunately, there were low missing (below 2%) in outcome data, main exposures, and other confounders.

Another limitation is that Kerman city had only one weather station and temperature might have been slightly different across Kerman city. However, this small variation is unlikely to have had a significant effect on our results.

## Conclusion

Considering that the greatest influence of heat wave on both YLL and mortality was seen at lag time 0, interventions should be implemented from the first days of heat waves. Men, especially those over 65 years old, are more vulnerable to heat waves.

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### Compliance with ethical standards

**Conflict of interest** The authors declare that they have no conflict of interest.

**Statement of informed consent** All information was inquired as aggregated and without identity. The research proposal was approved by The Ethics Committee of Kerman University of Medical Sciences. Ethics Code IR.KMU.REC.1396.2374.

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