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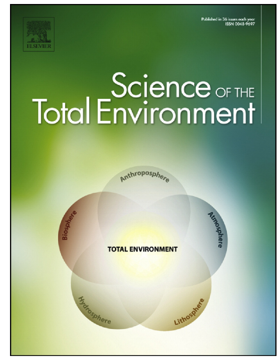

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Projection of mortality attributed to heat and cold; the Impact of Climate change in a dry region of Iran, Kerman

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Abstract

Background: Estimating the effects of climate change on human health can help health policy makers plan for the future. In Iran, there are few studies, about investigating the effects of climate change on mortality. This study aimed to project the effect of low (cold) and high (heat) temperature on mortality in a dry region of Iran, Kerman.

Methods: Mortality attributed to temperature was projected by estimating the temperature-mortality relation for the observed data, projection of future temperatures by the statistical downscaling model (SDSM), and quantifying the attributable fraction by applying the observed temperature-mortality relation on the projected temperature. Climate change projection was done by three climate scenarios base on Representative Concentration Pathways (RCP2.6, RCP4.5 and RCP8.5). Adaptation was considered by using different minimum mortality temperatures (MMT) and risk reduction approaches. The current decade (2010-19) was considered as the reference period.

Results: All three climate change scenarios, showed that the mean of temperature will rise about 1°C, by 2050 in Kerman. The number of deaths attributed to heat were obviously higher than cold in all periods. Assuming no adaptation, over 3700 deaths attributed to temperature will happen in each decade (2020s, 2030s and 2040s) in the future, in which over 3000 deaths will be due to heat and over 450 due to cold. In the predictions, as Minimum Mortality Temperature (MMT) went up, the contribution of heat to mortality slightly decreased, and cold temperature played a more important role. By considering the risk reduction due to adaptation, the contribution of heat in mortality slightly and insignificantly decreased.

Conclusion: The results showed that although low temperatures will contribute to temperature-related mortality in the future, but heat will be a stronger risk factor for mortality, especially if adaptation is low.

Key words: Climate change, Projection, Temperature, Mortality, Attributable Risk

1. Introduction

Many studies during the past decades, have shown increased mortality when extreme temperatures occur (1-3). This effect has been particularly shown during the last three decades; and for example the heat waves that occurred in 1995 in Chicago (4) and in 2003 in Europe (5), increased mortality significantly. Exposure to extreme temperature raises the risk of physiological and psychological disorders which threaten the health of people with cardiorespiratory problems, children, and the elderly (6, 7). More recently, some studies have explored new evidence about the effect of temperature on mortality. For example the study conducted by Shi et al (8) showed that increase in temperature variability has adverse effects on mortality. Also. Hu et al (9) have shown that rural counties had higher relative risks (RRs) and attributable fractions of mortality due to ambient temperature than urban counties in China.

As greenhouse gas emissions increase and temperature rises, human health may be more threatened, and the situation can get worse in the future (10, 11). Based on the high-end emissions scenarios reported by the fifth Intergovernmental Panel on Climate Change (IPCC) (12), world temperature will raise, between 2.6 and 4.8°C by the end of the century. This suggests that heat or cold related mortality will probably increase even more in the future. For example, the projected temperature-related mortalities in the UK for the 2020s, 2050s and 2080s were 3281, 7040 and 12538, per year, respectively; and a %2 decline was predicted for cold-related mortality (13). Also a study conducted in Germany based on simulations showed that future heat waves will be significantly more frequent, longer lasting and more severe. This study projected that by the end of the 21st century the annual number of ischemic heart disease deaths attributed to heat waves in Germany will increase 2.4 and 5.1 times in the acclimatization and non-acclimatization approach, respectively (14). Similar projections have been reported from Canada, Australia and the USA (15).

Estimating the effects of climate change on human health by using accurate models can help health policy makers to plan better for future health crises. However, some evidence shows that adaptation and acclimatization may decrease heat-related mortality (16, 17). This makes studying the effect of climate change on mortality more complicated. Minimum Mortality Temperature (MMT) is one indicator of acclimatization which is different in different countries. It ranges from −2°C, in a Northern city (Teruel) up to 26°C in the Southern Mediterranean region (18). Therefore the impact of climate change is different in different countries.

In Iran, there are few studies, about the effect of climate change on mortality, especially in a dry region, Kerman. Kerman has a population of about 740,000 people with mean daily mortality about 10 per day (2) and is located in Kerman province in southeastern Iran. This city 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 1753.8 meters. Its climate is semi-arid to dry with hot summers and cold winters. Its air temperature varies from about -8 to 37 °C throughout the year (19-21).

This study aimed to project the average temperature for 2030, 2040 and 2050s; and find its impact (both heat and cold) on future mortality, in a dry region of Iran, Kerman.

2. Methods

This was an ecological study, conducted in Kerman, Iran; in which in addition to modeled data from General Circulation Models (GCMs), the observed mortality and meteorological data were used to project the Attributable Fraction (AF) of mortality related to ambient temperature.

Mortality data were obtained from the Health Deputy of Kerman University of Medical Science from 2005 to 2017 and meteorological data were obtained from the National Meteorology Organization of Iran from 1960 to 2017. The weather station is located in Kerman airport at 56°E and 30°N, with code 40841 and altitude 1753.8 meters from sea level. In this study daily mean temperature was used to predict mortality, because evidence shows that mean temperature is a more important predictor of mortality than minimum or maximum temperature (22-24). Mean temperature also had the best goodness of fit based on AIC, in our study.

There was no missing data for the mortality or temperature variables. In fact, at least one death, had occurred in almost every day in Kerman and the temperature had been correctly recorded for every day. It should be mention that the date of death is accurately recorded in Iran, because otherwise burial permission will not be granted.

Future mortality attributed to temperature was estimated by the temperature-mortality relation calculated according to the observed data, projection of future temperatures by the statistical downscaling model (SDSM), and quantifying the attributable fraction by applying the calculated temperature-mortality relation on the projected temperature; and assuming total future mortality does not change due to other factors. The first and last steps have been explained elsewhere by Vicedo-Cabrera et al. (25). The process is briefly explained in the following sections:

2.1 Determining the temperature-mortality relation

Quasi Poisson time-series regression analysis was used to account for over dispersion, in order to estimate the relative risk of mortality due to daily temperature. Studies conducted in China (26), Germany (27), Canada (28) and even multi-country studies (29) have shown that the effect of temperature on mortality is non-linear. Therefore, Distributed Lag Non-linear Models (DLNM), introduced in previous studies (30, 31) were applied on our data. Natural cubic splines with three knots located on the 10th, 75th and 90th percentiles of temperature and equal-spaced log-scaled lag dimensions were fitted for both exposure and lag dimensions. In order to account for seasonality and trend, natural cubic splines with 8 degree of freedom per year were used. In addition, an indicator of days of the week was used in the model to control for this variable. The maximum lag of 21 days was considered because previous studies have shown that cold temperatures usually show their acute effects in three weeks (32-34).

In order to calculate the cumulative relative risk, minimum mortality temperature (MMT) was selected as the reference value. This is the temperature with the minimum risk of mortality. Temperatures below and over this value are defined as cold and heat, respectively. In order to find the MMT, a natural spline was fitted to mortality and temperature daily series. The temperature with the lowest relative risk was considered as MMT. As seen in supplementary figure 1 (Fig. S1), there is a wide uncertainty about MMT in Kerman; and it can be from -8.5°C to 21.3°C. It should be mentioned that the method used by Miron et al (35, 36) was also applied to find the MMT. The results of this method showed a big uncertainty in MMT in Kerman as well.

Eventually, the MMT (in case of no adaptation) was supposed to be 11°C based on the above mentioned simple model and the Monte Carlo simulation method (18).

2.2 Projection of temperature

GCMs are climate models which use projected concentrations of greenhouse gases and air pollutants and land-use change from different Representative Concentration Pathways scenarios (RCPs) to simulate new climate scenarios. They simulate future temperatures in coarse spatial resolution (typically 50,000 km^2) (37, 38). We downscaled the simulated temperature to local scale.

SDSM was used to downscale the spatially high-resolution output from GCMs to local-scale measures by using statistical relations between the output (predictors) and observed variables (predictant) in regression analysis, and a stochastic weather generator.

The process of projection by SDSM has been explained elsewhere by Wilby et al. (37, 39, 40). In brief, the process includes: (1) screening predictor variables; (2) model calibration; (3) analysis of observed data; (4) generation of climate change scenarios; (5) testing the validity of the model and statistical analyses. In this model, the NCEP (National Centers for Environmental Prediction) and CanESM2 (second generation Canadian Earth System Model) data were used. There are 26 predictors in both the NCEP

(1961–2005) and CanESM2 (1961–2100) at a spatial resolution of about 2.81°, with approximately uniform longitude and latitude (41). In the first step, significant predictors are selected based on the correlation matrix. In this step, temperature was selected as a significant predictor for our study. Model calibration comprises optimizing multiple linear regression equations for daily temperature as a function of the selected large-scale NCEP reanalysis predictors. In step 3, historical daily temperature is simulated by the weather generator in the model, driven by the predictors in NCEP. In fact, the synthesis operation generates many ensembles of daily weather series based on daily observed data or re-analysis of atmospheric predictor variables. Likewise, in step 3, the ”generate scenario operation” command produces ensembles of synthetic past, current and future daily weather series, according to observed daily atmospheric predictor variables supplied by CanESM2. The same predictors exist in all three scenarios, RCP2.6, RCP4.5 and RCP8.5, in the CanESM2 model. Temperature was projected in the three scenarios differently, because they represent the relatively “better case”, “medium case” and “worse case” for future greenhouse gas emissions, respectively (38). A range of factors including socio-economic change, technological change, energy and land use, emission of greenhouse gases and air pollutants are used as input variables for the climate modelers. As there is uncertainty in the factors, we provided the results for all three different scenarios (RCP2.6, RCP4.5, RCP8.5). These three scenarios refer to a very low forcing level (RCP2.6), medium stabilization scenarios (RCP4.5) and very high baseline emission scenarios (RCP8.5). More information about these models can be found in Van

Vuuren et al 2011 (38). These scenarios make better comparisons between our study and studies done in other countries, possible.

In the last step we evaluated the SDSM's validity. The model was evaluated based on comparison between the simulated and observed daily temperature series for the period 2005-2017. The results of this step are provided in figure S2 of the supplementary file. In all three scenarios, the simulated data have almost the similar distribution compared to observed data.

It should be mentioned that the average daily mortality, obtained from 12 years data, was used for estimations in the future. The annual series of daily mortality is provided in supplementary Fig S3. It was assumed that the same annual series, with the same seasonal pattern for mortality, will be seen in the future. Although this is a limitation, but some previous studies have used this approach as well (25). This approach visualizes that today's population is taken to the future, which has higher temperatures than today (16).

2.3 Estimate Attributable Fraction

In this study, both AF (Attributable Fraction) and AN (Attributable Number) were calculated by the coefficients estimated from DLNM and the assumed daily mortality, through the following equations:

Equation 1

$$\mathrm{AF} = \frac{\mathrm{RR} - 1}{\mathrm{RR}} = 1 - \mathrm{e}^{-\beta}$$

Equation 2

$$\mathrm{AN} = \mathrm{AF}.\mathrm{N}$$

In these equations β, RR and N are the coefficient, Relative Risk and number of deaths, respectively. As previously mentioned, the coefficients are obtained from DLNM. This has been explained elsewhere by Gasparrini et al (42).

In order to estimate the AN in the future, the coefficients obtained from the reduced DLNM (model without including lags) were applied to projected temperature ($\mathrm{T_{mod}}$) by the following equation explained by Vicedo-Cabrera et al (25):

Equation 3

$$\mathrm{AN} = \mathrm{N}.(1 - e^{-(f(\mathrm{T_{mod}};\theta_b) - s(\mathrm{T_{mm}};\theta_b))})$$

In equation 3, f and θ represent the uni-dimensional overall cumulative exposure–response curves without lag dimensions. AN and AF were primarily calculated for every day and then, they were calculated for ranges of temperature (i.e. heat and cold). So, heat and cold-related mortality can be separated by summing the subsets corresponding to days with temperatures higher or lower than MMT ($\mathrm{T_{mm}}$) in the above equation.

There might be some uncertainty in both projected temperature and estimated coefficients. Taking into account these sources of uncertainty, simulation methods were used in both processes. 1000 samples of coefficients were produced by Monte Carlo simulations and 20 stochastic temperature series were generated by weather generator in SDSM.

Another issue in estimating the results is human adaptation. People may adapt to warm climate (43), or they may stay more indoors during the heat peak hours and use air conditioners, in the future. This adaptation can be taken into account by minimum mortality temperatures (approach A) and risk reduction (approach B) approaches. It is likely to see an increase in MMT in the future. If we assume that in case of no adaptation the MMT is 11°C (Scenario A1), then one likely scenario is that people might be able to physiologically acclimatize to increased temperature levels in the future by about 50%, and this causes a shift in the temperature threshold (14, 44). Therefore in Scenario A2, MMT was set equal to 16°C (instead of 11°C).

There is uncertainty about MMT in Kerman and a big range of temperature can be chosen as MMT (Fig S1), especially if confounders are not considered in these calculations.

In our previous study (45), the MMT was 22.7°C based on a more complicated model; in which we considered all potential confounders (air pollutants) using a simulation method. Therefore, in this study in Scenario A3 MMT was set at 22.7 °C.

However, there is no clear evidence about how adaptation will affect mortality rates in the future. Therefore, another approach was based on risk reduction in heat-related mortality due to reasons, such as behavioral change, improvement of physical activity, better housing, and environmental changes which can indirectly affect physiological changes (46). In this study, similar to a previous study (25) we assumed that these factors may decrease the risk by 20% (Scenario B1) or 30% (Scenario B2) in the future.

Assuming the observed temperature-mortality relation for specific age groups remains constant in the future for those age groups, the AF was eventually estimated for elderly people (>=65 year old). Studies have shown that the mean age of the Iranian population will increase in the future, and the number of elderly will probably reach over 10 million people, which is more than 11%, in 2036 (47-50). Therefore, calculating a separate AF for this group will help better address the effect of climate change on health, according to demographic change.

In order to see if there will be an increase or decrease in cold and heat related mortality in future, the current decade (2010-2019) was selected as baseline and the future decades (2030, 2040 and 2050s) were compared to the AF in baseline. The current decade was also used as the baseline for past decades (1980-89, 1990-99 and 2000-09) to see whether current the period has a higher AN or not.

3. Results

All three climate change scenarios (RCP2.6, RCP4.5, RCP8.5) showed that mean temperature will rise up to 1°C by 2050 in Kerman (Fig S4)

Figure 1, a shows the association between observed daily mean temperature and mortality across different lags. The temperature effect is nonlinear, and high temperatures, tend to have a higher relative risk of mortality than low (cold) temperatures. The relative risk is the biggest at lag 0 for high temperatures (around 30°C) and after a short decrease, it tends to slightly increase again at middle lags (lags 5 to 10), showing a probable harvesting effect. Figure 1, b shows the cumulative effect of different temperatures until 21 days. Extreme temperatures such as 29°C had the highest cumulative effect on mortality.

In figure 2, the AN has been shown for heat, cold and all non-optimum temperatures from 1980 to 2050 in the three scenarios. In figure 2 adaptation has not been taken into account (MMT=11°, Scenario A1). Here, the number of deaths attributed to heat in all three decades were obviously higher than cold in all three climate change scenarios (RCP2.6, RCP4.5, RCP8.5). Over 3700 deaths will probably be attributed to temperature during each decade (2020s, 2030s and 2040s) in the future, in which over 3000 deaths are due to heat and about 450 due to cold. Totally, the AN due to heat is expected to increase in future, and it will be at its highest in 2050 based on the worst climate scenario (RCP8.5). However, the AN in 2040-2049 is slightly lower than 2030-2039 based on RCP4.5 and RCP2.6, but they are still higher than current years (2010-2019). In all three climate change scenarios (not including adaptation), there is a slight insignificant decrease in cold-related mortality, in the future.

Table 1 compares the AN of future and past periods to the current time period (2010-19) along with 95% confidence intervals. Firstly, the number of deaths attributed to both heat and cold during the past decades has been non-significantly lower than current deaths. However, the results of sensitivity analysis, based on 10 and 15 days lag (Table S2 and

Table S3), showed that significantly less heat related mortality has happened in the past decades. Secondly, the number of deaths related to heat will probably increase significantly in the future compared to the current period; but cold related deaths will tend to decrease insignificantly or not change.

Table 2 shows the difference in attributable fraction between future and current periods in four scenarios (Scenario A2: MMT=16°C; Scenario A3: MMT=22.7°C; Scenario B1: 20% reduction in risk ; Scenario B2: 30% reduction in risk) . As the MMT goes up (moving from scenario A2 to A3), the contribution of heat to AF slightly decreases, and cold temperature plays a more important role.

Figure 3 shows the AN for elderly mortality during 1980-2050 based on the RRs for that group which are shown in Fig S6. A substantial proportion of the attributed number of deaths in this age group in the future will be related to heat rather than cold. However, cold-related mortality will be higher in the elderly than the general population (the blue lines in figure 3 vs blue line in figure 2).

4. Discussion

In this study, we estimated the change in cold, heat and total temperature-related mortality and its attributable fraction over three decades by changing assumptions about future greenhouse gas emissions in three different climate change scenarios. In the absence of adaptation, acclimatization, and population change; and holding all other factors stable, the results of this study showed that heat-related mortality will rise in the future, while cold related mortality will not change significantly. It is plausible that fewer cold-related deaths will happen, because temperature will probably increase in the future (51). After taking into account adaption, the projected cold-related mortality tended to be higher, but with big uncertainty; although heat-related deaths were definitely increasing.

Increase in heat-related mortality and decrease in cold-related mortality by 2050 has been shown in studies from other countries as well. For example Knowlton et al (52) conducted a study in New York and projected that heat-related mortality will increase by 2050 ranging from 38% to a 208% , with a mean 70% increase, compared to 1990s. Also Guo et al (46) compared heat–related mortality in 2031-2080, to 1970-2020 in several cities; and predicted that these deaths will increase from 2000% in Colombia to 150% in Moldova, under the highest emission and high-variant population scenario . Our study did not show changes as big as Guo et al's study, which is partly due to the smaller effect of heat on mortality and the smaller projected changes in temperature in Kerman. Our projections were based on different assumptions, but we still observed a similar pattern of increasing mortality related to increasing temperatures in the future.

There are many ways that can help future people adapt to increasing temperatures. For example, the use of air conditioners are likely to increase in the future. Therefore, researchers suggest that adaption should be taken into account when heat or cold-related mortality is projected, in order to prevent overestimations (46). Wang et al (53) reported a considerable increase in heat-related mortality by 2050, when they did not take into account adaption. But after considering adaption, they found that the changes were not substantial compared to 2006. The impact of acclimatization on mortality change has also been shown by Knowlton et al (52). In this current study, we took adaption into account by two approaches, but still an increase in heat-related mortality by 2050 was observed. The projected number of heat-related mortality slightly decreased when adaptation is taken into account, because the MMT was higher.

As literature shows, if we use lower versus a higher greenhouse gas emissions scenario (i.e., RCP 2.6 rather than RCP 8.5), it will result in smaller elevations in mean temperatures. Consequently, smaller raising in heat-related deaths would be seen. As mentioned before, according to our projections, mean temperature will raise about 1°C by 2050 ; in all three climate change scenarios. But, heat related mortality was slightly higher in RCP2.6 in which lower greenhouse gas emission was assumed. The reason might be the little difference in extreme temperature between scenarios. As seen in figure S5, RCP2.6, the temperature of 29°C which has almost the highest relative risk based on figure 1,b will be seen more frequently in future. Also, the frequency of extreme temperatures (more than 29°C), was slightly more in the RCP2.6 scenario than others (table S1). Table S1 shows that RCP2.6 will have about 80 days with extreme temperatures more than RCP8.5, and this can explain the higher heat related mortality in RCP2.6. SDSMs, in which daily temperature is simulated, have been widely used to project temperature in many studies from different countries (54-57), but it has been used less in projecting temperature-related mortality. There are many GCMs to project the impact of climate change on human health; and the most accurate model for doing these projections is still under question. It is hardly possible to do a perfect and exact projection. Different climate models, and potentially different specifications of scenarios can project different distributions of days with extreme temperature in the future, and might generate different results (58). As seen in table S1, different frequencies of days with extreme temperatures were predicted in our scenarios, because we downscaled the temperature from GCMs, in which local-scale temperature is simulated based on linear regression model. However the predictors for the model were from CanESM2 (second generation Canadian Earth System Model) high-resolution data at 58.8°E and 29.6°N, which corresponds to Kerman province.

In addition to the source of heterogeneity (models), the different analytical approaches used in our study might make the results difficult to compare with previous studies .

Although, there was a small difference in heat-related mortality changes in different scenarios, but heat-related mortality significantly increased in all scenarios. This highlights the fact that higher heat related mortality is very likely to increase in the future, and it is necessity to implement preventive programs to slow down temperature rises and prevent mortality. There is evidence that shows the use of heat warning systems, heat response plans, and perhaps other adaptation measures can mitigate some of the effects of extreme heat (51).

Some studies have found a considerable reduction in cold-related mortality in the future. For example Donaldson et al (59) showed a 25% reduction in cold-related mortality by 2050 in UK; but, these authors did not consider demographic population changes. Onozuka et al (12) used a method similar to our study and showed that cold-related morbidity will probably decrease from 19.9% (95% CI: -0.1, 33.4) in 2010–2019 to 13.8% (95% CI: -2.5, 25.5) in 2090–2099 under scenarios of intense warming (RCP8.5). In contrast, our study showed a slight reduction in cold-related mortality which was not significant. However, the number of cold related mortality will be higher in our projections, if we take into account the demographic changes of the population (the increasing number of elderlies) and adaptation. Similar to our findings, Hajat et al (13) showed that reductions in cold-related mortality in the future are unlikely to be large, and in part due to changes in the demographics of the population (population ageing). Similarly, a study conducted in 209 US cities showed a small decrease in cold-related mortality by 2050s. This US study considered long-term adaptation by including mean winter temperature (MWT) as an effect modifier for cold wave's effect on mortality. But, in Wang et al's study, the projected mortality when taking into account MWT, was close to the mortality when not accounting for it. This suggests that the future decrease in cold-related mortality is mainly related to decrease in the number of cold waves and not increased MWT (60). As seen in figure S5, in Kerman, the frequency of heat days is always higher than cold days, but there will be a small change in the frequency of heat and cold days in the future; which can cause significant changes in temperature related mortality.

Limitations

This study had some limitations. The data from one weather station (Kerman Airport Weather Station) was used, and we assumed that the weather variables were similar for the whole city. The results of this study cannot be generalized to other cities, because of differences in population demographics, climate variables and adaptation patterns; and therefore, more studies are recommended to be done in different regions of Iran.

In this study, SDSM was used in order to project temperature. However, previous studies have used other downscaled GCMs like the Inter-Sectoral Impact Model Inter comparison Project (ISI-MIP) database; and this makes it difficult to compare our results with other studies. Although the models' validity was acceptable in this study (according to figure S2), the validity of different models should be compared with each other, in future studies.

Another limitation of this study is that air pollutants were not taken into account, because the main objective of the study was to project deaths related to change in temperature. However, greenhouse gases were taken into account in the climate scenarios and of course, temperature changes are related to air pollutions (61).

5. Conclusion

This study showed that increased temperature will be an important public health risk factor in the future, even after considering adaptation. But, cold temperature will slightly contribute to temperature-related mortality, and will be of less concern in the future.

In Iran, health policy makers have to pay more attention to the adverse effect of climate change on health. Establishing cooling centers, standard air conditioning, and heat health warning systems should be considered to decrease heat related mortality in Iran.

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Fig 1 The exposure-lag-outcome relation across 21 lags (a) and the overall cumulative relative risk until 21 lags (b) along with 95% confidence intervals (gray line)

Fig 2 Mortality number attributed to temperature (total), heat and cold from 1980 to 2050 by different climate change scenarios (RCP2.5, RCP4.5 and RCP 8.5) in Kerman, Iran

Fig 3: Elderly mortality number attributed to temperature (total), heat and cold from 1980 to 2050 by different scenario in Kerman, Iran

Table 1: Change in mortality numbers attributed to heat and cold from 1980 to 2050, relative to the current period (reference) by different climate change scenarios in Kerman, Iran. The bold values are significant based on the 95% confidence interval.

Scenario	Year	Total	Cold	Heat
RCP2.6	1980-89	-244(-653, 260)	-15(-151, 122)	-229(-619, 215)
	1990-99	-327(-732, 143)	-47(-193, 120)	-280(-660, 162)
	2000-09	-136(-372, 117)	39(-71, 110)	-175(-384, 71)
	2010-19	Reference	-	-
	2020-29	**157(22, 266)**	14(-55, 72)	**143(13, 251)**
	2030-39	**233(78, 352)**	8(-13, 25)	**225(70, 343)**
	2040-49	135(-34, 271)	-23(-79, 35)	**158(19, 271)**
RCP4.5	1980-89	-310(-780, 229)	-23(-160, 119)	-287(-720, 212)
	1990-99	-394(-832, 138)	-55(-204, 119)	-338(-766, 157)
	2000-09	-203(-475, 94)	28(-60, 90)	-232(-476, 62)
	2010-19	Reference	-	-
	2020-29	**103(11, 179)**	1(-38, 41)	**102(27, 161)**
	2030-39	119(-26, 247)	-29(-92, 36)	**149(31, 241)**
	2040-49	99(-9, 200)	-12(-52, 28)	**111(19, 188)**
RCP8.5	1980-89	-295(-746, 229)	-24(-157, 114)	-271(-693, 211)
	1990-99	-378(-809, 127)	-57(-203, 117)	-322(-733, 155)
	2000-09	-163(-432, 112)	48(-115, 162)	-211(-427, 45)
	2010-19	Reference	-	-
	2020-29	**75(6, 129)**	-11(-50, 27)	**85(21, 140)**
	2030-39	21(-106, 135)	-30(-114, 53)	51(-6, 98)
	2040-49	147(-12, 277)	-19(-75, 35)	**167(30, 277)**

Table 2: Changes of mortality attributable fraction (AF), related to temperature (total), heat, cold from 2020 to 2050 compared to the current period (reference), taking into account adaptation

Climate change scenario	Approach for taking account in adaptation		Period	Total	Cold	Heat
RCP2.6	Change in MMT	MMT=16	2020-29	**0.38(0.02,0.68)**	0.06(-0.13,0.25)	0.31(-0.02,0.6)
			2030-39	**0.60(0.20,0.93)**	0.03(-0.03,0.07)	**0.58(0.2,0.89)**
			2040-49	0.34(-0.13,0.75)	-0.01(-0.24,0.24)	0.35(-0.02,0.65)
		MMT=22.7	2020-29	**0.43(0.02,0.81)**	0.14(-0.09,0.4)	0.29(-0.09,0.6)
			2030-39	**0.68(0.21,1.15)**	**0.29(0.03,0.59)**	**0.39(0.07,0.67)**
			2040-49	0.39(-0.15,0.92)	0.14(-0.18,0.53)	0.25(-0.16,0.58)
	Change in risk	20% reduction in risk	2020-29	**0.30(0.02,0.65)**	0.05(-0.14,0.21)	0.26(-0.02,0.6)
			2030-39	**0.49(0.2,0.9)**	0.02(-0.04,0.06)	**0.47(0.19,0.89)**
			2040-49	0.27(-0.13,0.69)	-0.03(-0.17,0.09)	0.31(-0.02,0.67)
		30% reduction in risk	2020-29	**0.27(0.02,0.65)**	0.04(-0.14,0.21)	0.23(-0.02,0.6)
			2030-39	**0.43(0.2,0.9)**	0.01(-0.04,0.06)	**0.42(0.19,0.89)**
			2040-49	0.25(-0.13,0.69)	-0.03(-0.17,0.09)	0.27(-0.02,0.67)
RCP4.5	Change in MMT	MMT=16	2020-29	**0.29(0.04,0.52)**	0.04(-0.12,0.22)	**0.25(0.08,0.39)**
			2030-39	0.36(-0.03,0.74)	-0.03(-0.26,0.23)	**0.38(0.12,0.6)**
			2040-49	**0.31(0.01,0.61)**	0.02(-0.19,0.23)	**0.29(0.1,0.45)**
		MMT=22.7	2020-29	**0.33(0.04,0.67)**	0.14(-0.11,0.46)	**0.18(0.02,0.33)**
			2030-39	0.41(-0.03,0.94)	0.18(-0.18,0.64)	**0.22(0.04,0.38)**
			2040-49	**0.35(0.01,0.77)**	0.18(-0.14,0.56)	**0.17(0.05,0.29)**
	Change in risk	20% reduction	2020-29	**0.23(0.04,0.47)**	0.01(-0.08,0.11)	**0.22(0.07,0.41)**
			2030-39	0.29(-0.04,0.68)	-0.05(-0.2,0.1)	**0.33(0.09,0.65)**

		in risk	2040-49	**0.25(0.01,0.55)**	-0.01(-0.09,0.05)	**0.26(0.06,0.53)**
		30% reduction in risk	2020-29	**0.21(0.04,0.47)**	0.01(-0.08,0.11)	**0.19(0.07,0.41)**
			2030-39	0.26(-0.04,0.68)	-0.04(-0.2,0.1)	**0.30(0.09,0.65)**
			2040-49	**0.22(0.01,0.55)**	-0.01(-0.09,0.05)	**0.23(0.06,0.53)**
RCP8.5	Change in MMT	MMT=16	2020-29	**0.19(0,0.35)**	-0.01(-0.12,0.1)	**0.2(0.02,0.34)**
			2030-39	0.10(-0.24,0.45)	-0.02(-0.31,0.29)	**0.12(0.01,0.21)**
			2040-49	**0.45(0.03,0.84)**	0(-0.23,0.23)	**0.46(0.13,0.72)**
		MMT=22.7	2020-29	**0.21(0,0.43)**	0.05(-0.07,0.2)	0.16(-0.02,0.31)
			2030-39	0.11(-0.26,0.57)	0.07(-0.29,0.5)	0.04(-0.05,0.11)
			2040-49	**0.52(0.03,1.08)**	0.26(-0.15,0.73)	**0.26(0.07,0.45)**
	Change in risk	20% reduction in risk	2020-29	**0.15(0,0.32)**	-0.01(-0.1,0.06)	**0.16(0.03,0.33)**
			2030-39	0.08(-0.26,0.41)	-0.04(-0.22,0.13)	0.12(-0.06,0.31)
			2040-49	**0.37(0.03,0.78)**	-0.02(-0.14,0.08)	**0.39(0.12,0.76)**
		30% reduction in risk	2020-29	**0.14(0,0.32)**	-0.01(-0.1,0.06)	**0.15(0.03,0.33)**
			2030-39	0.07(-0.26,0.41)	-0.03(-0.22,0.13)	0.11(-0.06,0.31)
			2040-49	**0.33(0.03,0.78)**	-0.02(-0.14,0.08)	**0.35(0.12,0.76)**

CRediT author statement

Omid Aboubakri: Conceptualization, Methodology, Software, Validation, Formal analysis, Writing - Original Draft

Narges Khanjani: Supervision, Conceptualization, Writing - Review & Editing, Visualization, Project administration

Younes Jahani: Visualization

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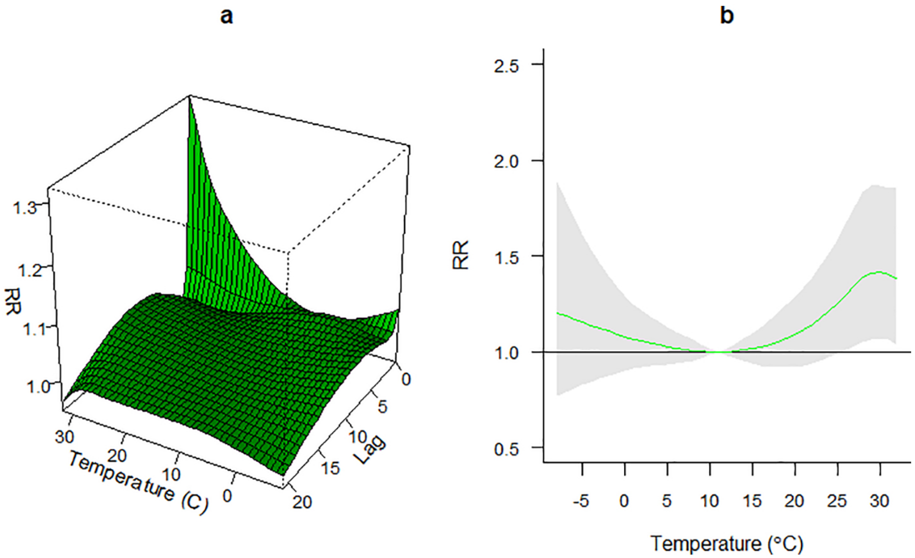
Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Graphical abstract

Highlights

- This study provides some evidences, showing the effect of climate change on mortality while taking account of adaptation in a dry region of Iran.
- The model, based on all three scenario, showed that mean temperature will similarly rise up to 1°C by 2050 in each scenario in Kerman.
- Heat-related mortality will rise in the future, while cold related mortality might slightly decrease.
- After taking adaption into account, the projected cold-related mortality tended to be higher, though, there was a big uncertainty in cold-related deaths.


a
b
RR
1.3
1.2
1.1
1.0
30
20
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Temperature (C)
0
5
10
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Lag
2.5
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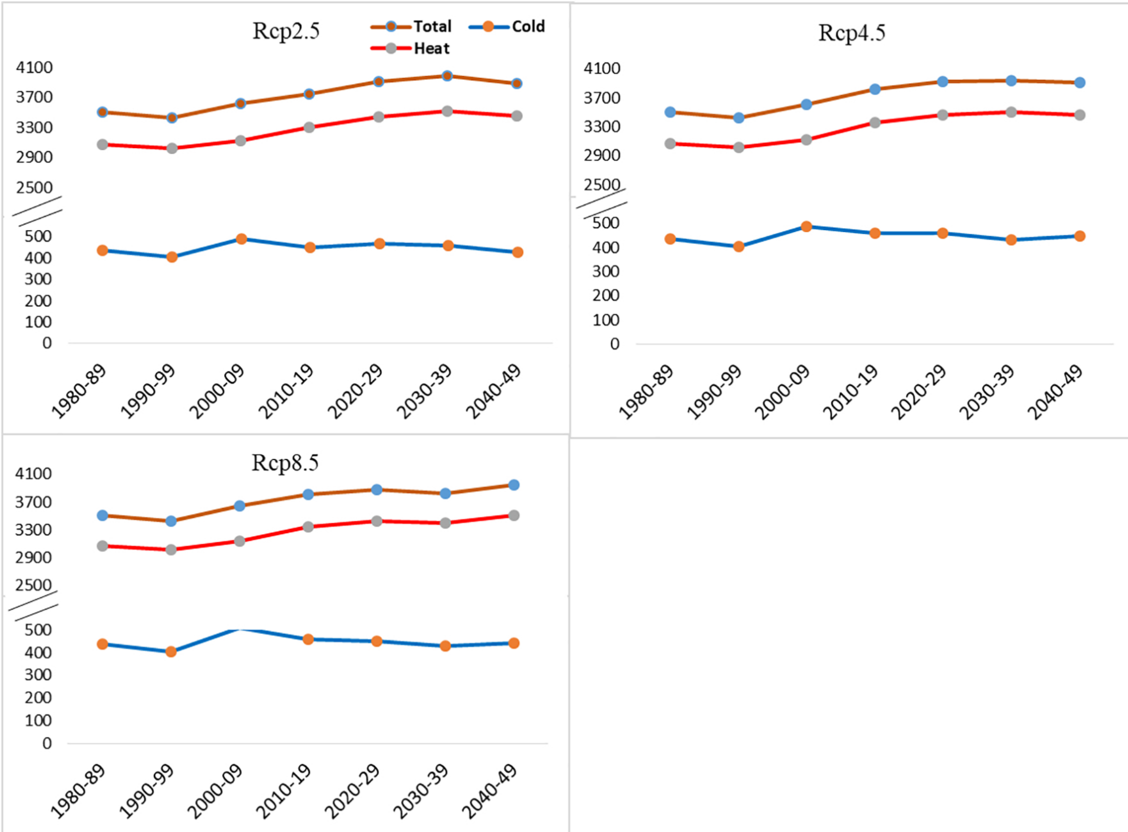
20
25
30
Temperature (°C)

Figure 1



Rcp2.5
Total
Cold
Heat
4100
3700
3300
2900
2500
500
400
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200
100
0
1980-89
1990-99
2000-09
2010-19
2020-29
2030-39
2040-49
Rcp4.5
4100
3700
3300
2900
2500
500
400
300
200
100
0
1980-89
1990-99
2000-09
2010-19
2020-29
2030-39
2040-49
Rcp8.5
4100
3700
3300
2900
2500
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200
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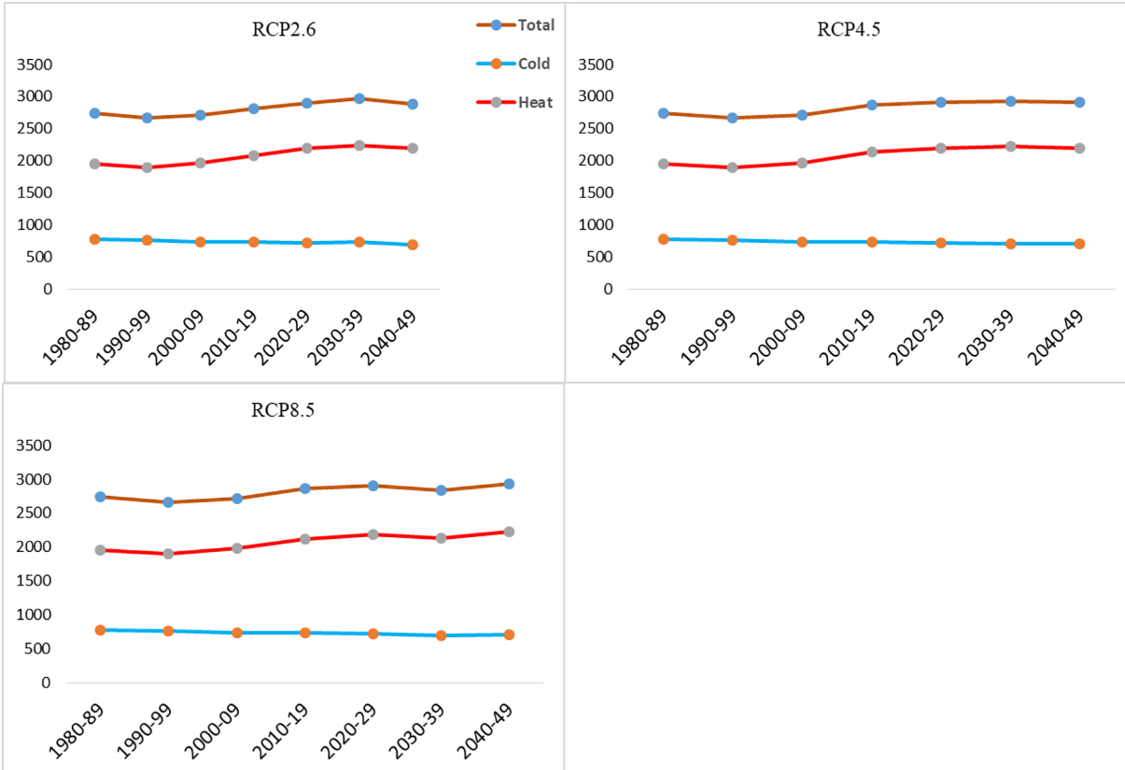
1980-89
1990-99
2000-09
2010-19
2020-29
2030-39
2040-49

Figure 2


RCP2.6
Total
Cold
Heat
3500
3000
2500
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1980-89
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2020-29
2030-39
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RCP4.5
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1980-89
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RCP8.5
3500
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2040-49

Figure 3