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Climate change and health in Kuwait: temperature and mortality projections under different climatic scenarios

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Abstract

It is uncertain what climate change could bring to populations and countries in the hot desert environment of the Arabian Peninsula. Not only because they are already hot, countries in this region also have unique demographic profiles, with migrant populations potentially more vulnerable and constituting a large share of the population. In Kuwait, two-thirds of the population are migrant workers and record-high temperatures are already common. We quantified the temperature-related mortality burdens in Kuwait in the mid- (2050–2059) and end-century (2090–2099) decades under moderate (SSP2-4.5) and extreme (SSP5-8.5) climate change scenarios. We fitted time series distributed lag non-linear models to estimate the baseline temperature–mortality relationship which was then applied to future daily mean temperatures from the latest available climate models to estimate decadal temperature-mortality burdens under the two scenarios. By mid-century, the average temperature in Kuwait is predicted to increase by 1.80 °C (SSP2-4.5) to 2.57 °C (SSP5-8.5), compared to a 2000–2009 baseline. By the end of the century, we could see an increase of up to 5.54 °C. In a moderate scenario, climate change would increase heat-related mortality by 5.1% (95% empirical confidence intervals: 0.8, 9.3) by end-century, whereas an extreme scenario increases heat-related mortality by 11.7% (2.7, 19.0). Heat-related mortality for non-Kuwaiti migrant workers could increase by 15.1% (4.6, 22.8). For every 100 deaths in Kuwait, 13.6 (−3.6, 25.8) could be attributed to heat driven by climate change by the end of the century. Climate change induced warming, even under more optimistic mitigation scenarios, may markedly increase heat-related mortality in Kuwait. Those who are already vulnerable, like migrant workers, could borne a larger impact from climate change.

1. Background

Kuwait is a small country in the Middle East with a population of 4.1 million people; two-thirds of whom are non-Kuwaiti migrant workers predominantly from Arab, South and south-east Asian countries. The country is known for its harsh, desert, hyper-arid and hot environment; with climate change likely reducing biodiversity of its marine life, increasing scarcity of water resources, elevating sea level in Kuwaiti coastal areas and increasing magnitude of heat (Kuwait EPA 2019). In recent years, Kuwait recorded temperatures in excess of 50 °C on many occasions. In summer of 2016, for instance, a temperature of 54 °C was measured in Mitribah, Kuwait, which was one of the highest temperatures ever recorded in recent history (Merlone *et al* 2019).

Studies have found that extreme temperatures in Kuwait are associated with a doubling to tripling of mortality risk, with unacclimatized migrant workers and those with cardiovascular diseases at highest risk (Alahmad *et al* 2019, 2020a, 2020c). We know of no similar studies in other countries in the Arabian Peninsula. While projection studies have asserted that this region may potentially be 'uninhabitable' by the end of the century (Pal and Eltahir 2016), such estimations were based on qualitative assessments (Lelieveld *et al* 2016), wet bulb temperatures alone (Pal and Eltahir 2016), or on estimates of mortality rates (Ahmadalipour *et al* 2019). To date, no analysis has utilized country-specific local temperature and mortality data in countries in the Arabian Peninsula to project future climate change impacts.

Countries in this region share a lot of similarities in their demographic and climatological profiles. In this study, we used Kuwait as an example. We applied state-of-the-art methods using local stratified mortality data and the latest temperature projections to quantify temperature-related mortality burdens in the near future (2050–2059) and the end of the century (2090–2099) under moderate and extreme climate change scenarios.

2. Methods

2.1. Historical data

Daily cause-specific mortality was obtained from the National Centre for Health Information, Department of Vital Statistics, Ministry of Health, Kuwait, for the period from 1 January 2000 to 31 December 2016. A total of 73 748 deaths were collected administratively and includes all deaths that occurred inside the country. Overall sum and average deaths per day for each population stratum are provided in table 1. We examined all-cause non-accidental and cardiovascular mortality according to the International Classification of Diseases 10th version codes of A00-R99 and I00-I99, respectively. Daily ambient temperatures (24 h average in °C) and relative humidity (24 h average in %) data were obtained from the meteorological services in Kuwait Airport for the same study period.

Table 1. Descriptive statistics of the observed mortality and weather data in Kuwait from 2000 to 2016.

	N	Daily Mean (SD)
Deaths		
All non-accidental	73 748	11.9 (4.5)
Cardiovascular	35 285	5.7 (2.8)
0–65years	41 704	6.7 (3.0)
65+ years	32 044	5.2 (2.7)
Men	43 898	7.1 (3.2)
Women	29 850	4.8 (2.5)
Kuwaitis	39 389	6.3 (2.9)
Non-Kuwaitis	34 359	5.5 (2.8)
Temperature (°C)	6208[a]	27.1 (9.8)
Relative humidity (%)	6190[a]	34.4 (21.5)

[a] Represent total number of days in the time series.

2.2. Climate projections

Simulations of daily average temperature in Kuwait for the future decades until 2099 were obtained from a number of general circulation models (GCMs) in the Copernicus climate change service climate data store based on output of the Coupled Model Inter-comparison Project 6 (CMIP6) an initiative of the Intergovernmental Panel on Climate Change (IPCC) 6th assessment report (Eyring *et al* 2016, O'Neill *et al* 2016). We chose two (moderate and extreme) climate change scenarios that incorporate the shared socioeconomic pathway (SSP) as well as the approximate level of radiative forcing by the end of century, which is the difference in energy flux in the atmosphere in watts per square meter (W m^{-2}). The moderate scenario involves a 4.5 W m^{-2} forcing by 2100 (SSP2-4.5). The extreme scenario reflects 8.5 W m^{-2} forcing by 2100 (SSP5-8.5). From the entire CMIP6 ensemble, we chose the following 18 GCMs that provided historical and future temperature simulations for the two selected climate change scenarios (SSP2-4.5 and SSP5-8.5): ACCESS_CM2, AWI_CM_1_1_MR, BCC_CSM2_MR, CESM2, CNRM_CM6_1, CNRM_CM6_1_HR, CNRM_ESM2_1, GFDL_ESM4, IITM_ESM, INM_CM4_8, INM_CM5_0, IPSL_CM6A_LR, MIROC_ES2L, MIROC6, MPI_ESM1_2_LR, MRI_ESM2_0, NORESM2_MM and UKESM1_0_LL. The temperature projections were downscaled to Kuwait's coordinates and then bias-corrected using monthly averages of the historical (observed) temperature data to preserve the trend and the variability. This calibration method has been described elsewhere (Lange 2019). We chose two future decades: the near future (2050–2059) and the end of the century (2090–2099), to be compared to a baseline decade (2000–2009).

2.3. Temperature–mortality relationship

In this procedure we determine the shape of the baseline exposure–response (temperature-mortality) in the observed range from 2000 to 2016. The relationship between temperature and mortality in Kuwait was previously described using distributed lag non-linear models (DLNMs) in time series analyses (Alahmad *et al* 2019, 2020a, 2020c). The DLNM function is a flexible modelling framework that estimates potentially non-linear associations with delayed effects (Gasparrini *et al* 2010). We fitted a quasi-Poisson regression with mortality counts as the outcome. Based on our previous efforts to model observed temperature in Kuwait, we used a natural spline with four degrees of freedom for the exposure–response dimension, with an extended lag of 30 days modelled using a natural spline with three degrees of freedom spaced equally in the log scale. We adjusted for relative humidity (natural spline with two specified knots at 30% and 40%), seasonality and time trend (natural spline with eight degrees of freedom per year), and day of the week (categorical variable). The minimum mortality temperature (MMT) is defined as the temperature that is associated with the least mortality between the 1st and 99th percentiles of the temperature distribution. Cold temperatures are those that are below the MMT, whereas hot temperatures are those that are above the MMT.

2.4. Temperature-mortality projections

The analysis applies a methodologic framework developed by one of us (A.M.V-C.) to estimate future health impacts under climate change scenarios based on state-of-the-art advanced statistical techniques developed, specifically, in time-series analyses for environmental epidemiology (an example code is provided in a hands-on tutorial (Vicedo-Cabrera *et al* 2019)).

First, to project the outcome, we compute an annual series of total mortality count for each day of the year using the observed mortality data. The average count per day is then replicated for the whole future period. The readers must be cautioned that this assumption does not hold into the future as mortality patterns will likely change. However, the simple procedure of assuming that outcome rates will remain constant in the future helps us isolate the climate effect from other trends in future mortality. (Baccini *et al* 2011, Vicedo-Cabrera *et al* 2019). Second, we use the projected exposure and extrapolate the baseline exposure–response relationship into future decades. The use of restricted natural splines in modelling baseline temperature-related mortality allows a log-linear extrapolation of the exposure–response curve beyond the observed range. We computed attributable number of deaths and fractions (%) from time series analyses applicable to the DLNM framework (Gasparrini and Leone 2014). We reported changes in mortality fractions comparing the temperature distribution of future decades (e.g. 2050–2059 and 2090–2099) to the temperature distribution of a baseline decade (2000–2009) in the additive scale. The uncertainty around the estimates was computed by generating 1000 samples of the coefficients through Monte Carlo simulations, assuming a multivariate normal distribution for the estimated spline model coefficients, and then generating results for each of the 18 GCMs. The median across the ensemble was used as the central estimate. The empirical confidence intervals (eCI) were then defined as the 2.5th and 97.5th percentiles of the empirical distribution of the attributable mortality across coefficients samples and climate models. This way, we account for the uncertainty of the exposure–response association as well as the variability across climate models.

The analysis assumes no adaptation and no changes in the demographic structure of the population. However, we conduct specific projections for all-cause non-accidental and cardiovascular deaths as well as across different strata of the Kuwaiti population: men, women, under 65 years, over 65 years, Kuwaitis and non-Kuwaitis. We additionally examined different baseline relationships at different time intervals from 2000 to 2016 to check for evidence of adaptation where the exposure–response relationship flattens with time. All analyses were conducted using R (version 3.6.0) and the *dlnm* package (Gasparrini 2011).

3. Results

3.1. Temperature projections

Across more than 2600 days of observed temperature from 1 January 2000 to 31 December 2016, the annual mean was 27.1 °C with a standard deviation of 9.8 °C and the annual mean relative humidity was 34.4% with a standard deviation of 21.5% (table 1). The temperature density distribution in Kuwait shows two peaks for winter and summer. However, in future decades, the temperature distribution will likely shift to the right with a higher frequency of extreme hot temperatures compared to the 2000–2009 baseline (figure 1). Future decades, especially under SSP5-8.5, will see longer right distribution tails too. By mid-century, even a moderate scenario will result in 3.5-fold increase in the proportion of days where average 24 h temperature exceeds 40 °C (18.9% vs. 5.4%) (figure 1).

In the moderate SSP2-4.5 scenario, temperatures are projected to increase 1.80 ± 0.58 °C in the by mid-century (2050–2059) and 2.70 ± 0.73 °C by the end of the century (2090–2099) as compared to the 2000–2009 baseline. In an extreme scenario, the corresponding increases in temperatures are projected to be 2.57 ± 0.67 °C and 5.54 ± 1.27 °C for mid and late century, respectively (table 2). Figure 2 shows that

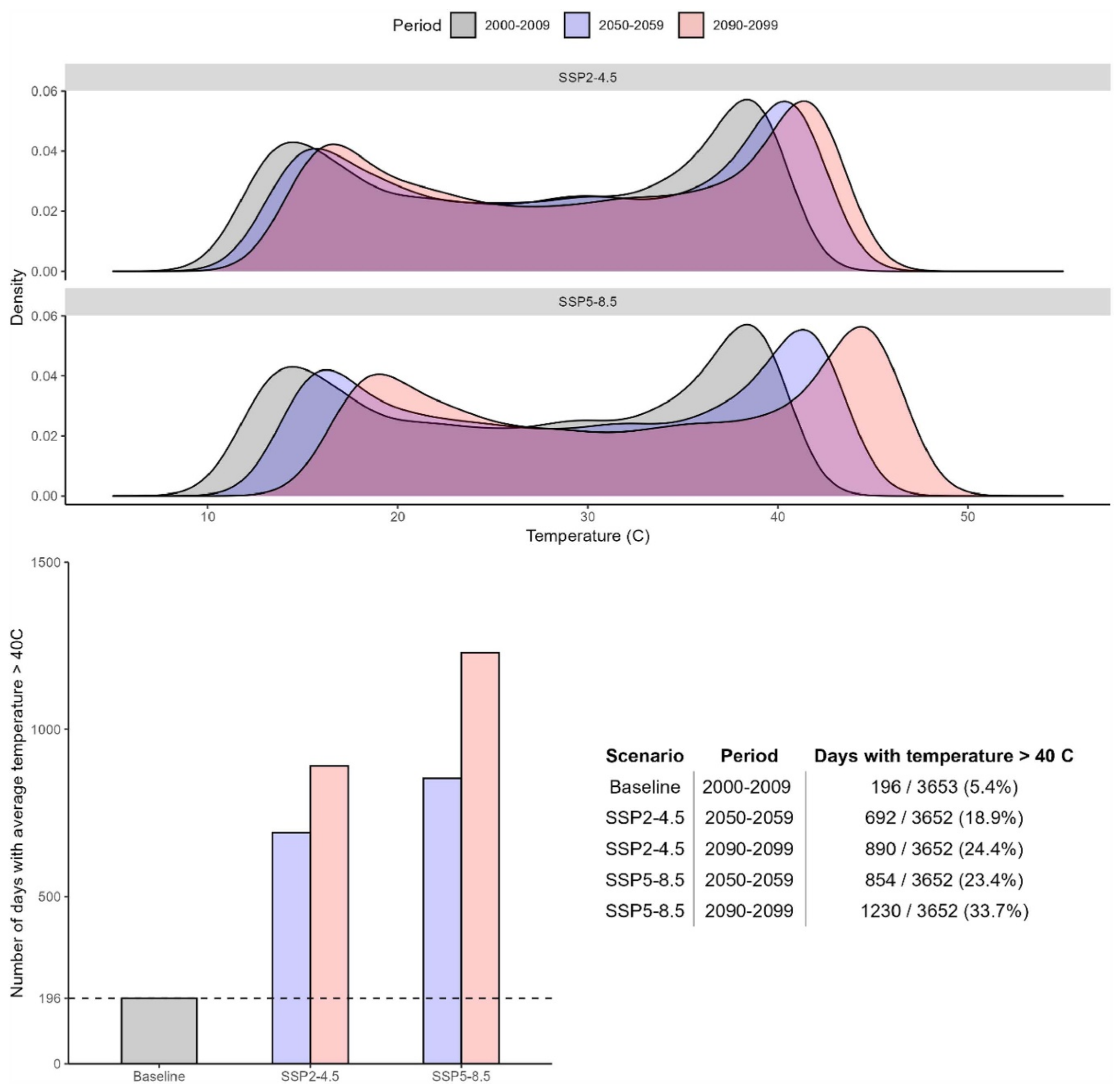

Figure 1. Distribution of future temperatures. Top panel shows the temperature density in baseline (2000–2009), mid (2050–2059) and end-century (2090–2099) decades under two climate change scenarios in Kuwait. Bottom panel and table show the corresponding number of days where average 24 h temperature in Kuwait exceeds 40 °C.

Table 2. Average increase in future temperatures compared to a baseline decade from 2000 to 2009 under two climate change scenarios: moderate (SSP2-4.5) and extreme (SSP5-8.5).

	SSP2-4.5		SSP5-8.5	
	Mean	SD	Mean	SD
Mid-century (2050–2059 vs 2000–2009)	1.80 °C	0.58 °C	2.57 °C	0.67 °C
End-century (2090–2099 vs 2000–2009)	2.70 °C	0.73 °C	5.54 °C	1.27 °C

the temperatures in Kuwait are anticipated to increase quickly in both scenarios until mid-century before warming slows in the moderate scenario.

3.2. Temperature-related mortality projections

The baseline relationship was U-shaped with an increase in the relative risk of death for temperatures above and below the MMT (figures S2–S4).

Compared to the baseline period of 2000–2009, heat-related mortality is projected to increase up to 3.4% (95% eCI: 0.4, 5.9) and 5.0% (0.8, 8.4) by mid-century under SSP2-4.5 and SSP5-8.5, respectively. By the end of the century, heat-related mortality is projected to increase by 5.1% (0.8, 9.3) and 11.7% (2.7, 19.0) under SSP2-4.5 and SSP5-8.5, respectively. Cold-related mortality will substantially decrease but may not offset greater heat-related mortality (figure 3); potentially decreasing by 2.3% (−4.3, −0.5) and 4.6% (−8.1, −0.9) by end of the century under SSP2-4.5 and SSP5-8.5, respectively. The net mortality will therefore increase by 3.4% (−1.6, 7.7) and 8.4% (−1.8,15.8). In absolute terms, by 2090–2099, for every 100 deaths in Kuwait, 7.1 (−6.8, 17.1) and 13.6 (−3.6, 25.8) are expected to

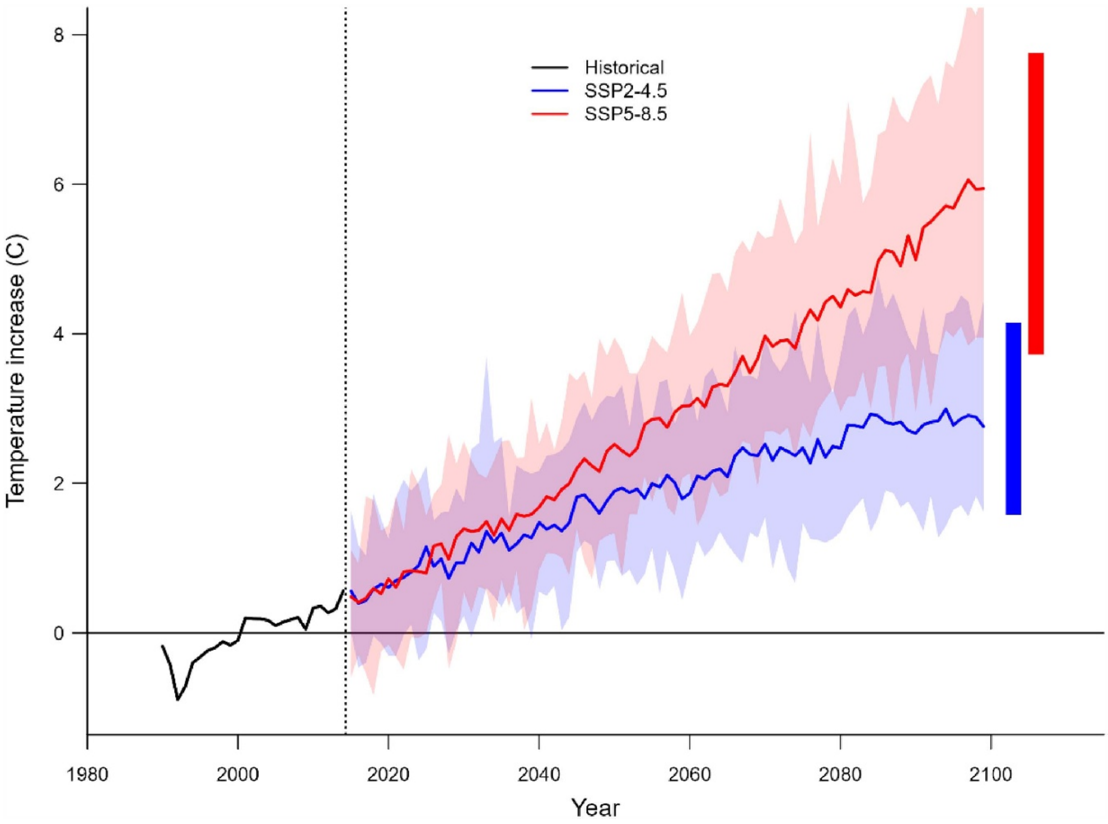

Figure 2. Average annual temperature increases in the future compared to historical temperatures in Kuwait.

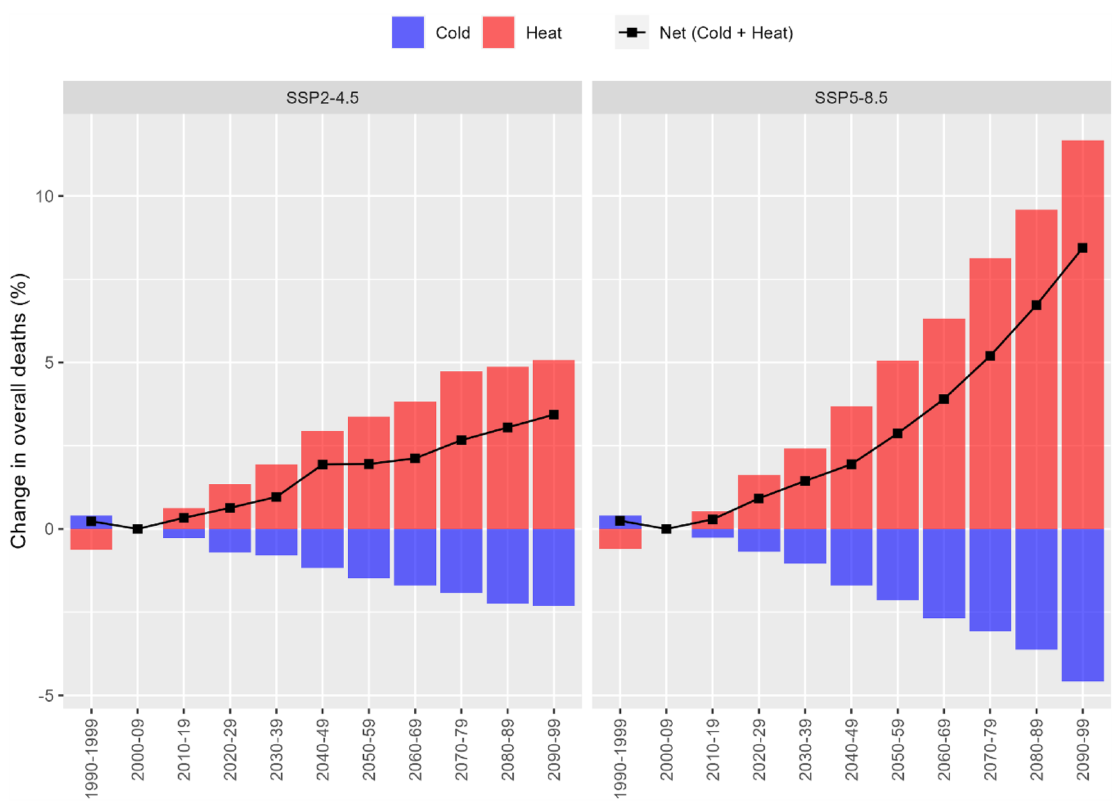

Figure 3. Change in mortality (all-cause non-accidental) for cold and hot temperatures in future decades under two climate change scenarios compared to the 2000–2009 baseline period in Kuwait.

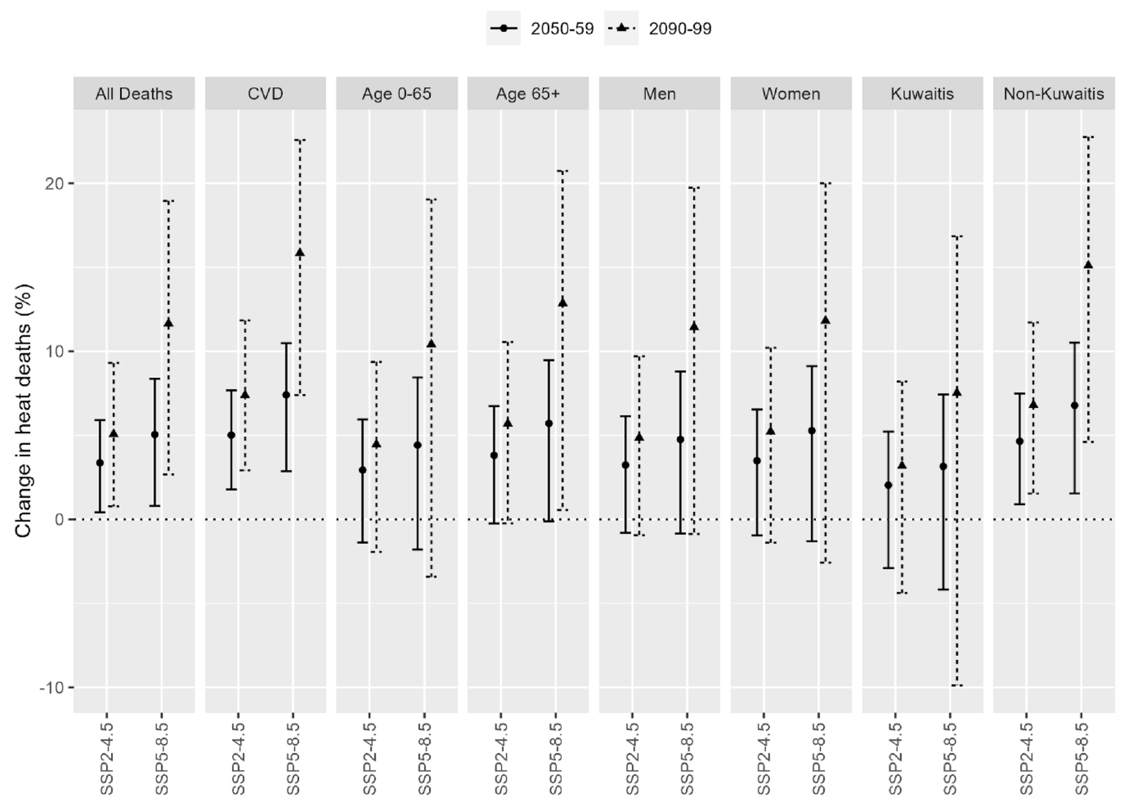

Figure 4. Change in heat-related mortality in the mid (2050–2059) and end-century (2090–2099) decades compared to a baseline decade (2000–2009) across different strata in Kuwait.

be attributable to heat driven by climate change under SSP2-4.5 and SSP5-8.5, respectively.

Heat-related mortality is expected to vary across population strata (figure 4). Statistically significant increases in heat-related mortality are seen for cardiovascular deaths, those aged above 65 years and non-Kuwaitis. By the end of the century and under SSP5-8.5, non-Kuwaitis could see an increase of heat-related mortality by 15.1% (95% eCI: 4.6, 22.8) compared to the 2000–2009 baseline. All effect estimates by mid and late century are provided in the supplemental material (tables S2 and S3).

4. Discussion

Here we present what we believe to be the first quantitative assessment of climate change and country-specific temperature-mortality projections in an inherently hot and hyper-arid area in the Arabian Peninsula. We find substantial increases in heat-mortality associated with moderate warming projections by mid-century. At the end of the century, we find projected warming to be associated with an increase of heat-related mortality risk of 5.1% in a moderate climate change scenario and by 11.7% in an extreme one, compared to the baseline decade. Climate-induced mortality seems inevitable even in moderate scenarios. However, put another way, heat-related mortality by the end of century in Kuwait can be reduced two-fold if warming follows the SSP2-4.5 trajectory rather than the SSP5-8.5.

Other temperature-mortality projection studies reported an increase in heat-related mortality in regions having a hot climate. Central and South America, southern Europe, and southeast Asia are projected to encounter an increase ranging from 10% to 17% in heat-related mortality under RCP8.5 and by the end of the century (Gasparrini *et al* 2017). Similarly, hotter regions in China showed stronger future mortality burdens, especially under extreme emission scenarios (Yang *et al* 2021). In Houston, Texas, there was a notable increase in projected heat-related mortality and a much larger magnitude if the size and age of the population were accounted for, albeit with higher uncertainty (Marsha *et al* 2016).

The IPCC sixth assessment report was '*virtually* certain' that the magnitude and frequency of heat events have increased on the global scale since the last century (Intergovernmental Panel Climate Change 2021). Compared to pre-industrial times (from 1850 to 1900), the IPCC estimated that there will be a 2.4 °C (SSP2-4.5) and 4.4 °C (SSP5-8.5) average increase in global temperatures by the end of the century. In Kuwait, compared to 2000–2009 rather than pre-industrial times, we estimated a 2.6 °C (SSP2-4.5) and 5.5 °C (SSP5-8.5) increase by the end of the century. The global average increase is worrying in Kuwait for two reasons. First, Kuwait is already on the extreme end of the temperature distribution. An upwards mean shift of a global 2.4 °C or 4.4 °C increase will result in frequent, and possibly unprecedent heat in Kuwait. Second, the Kuwaiti population, with a high percentage of migrants and growing prevalence of non-communicable diseases, may be particularly vulnerable.

Migrant workers work in hazardous occupations. They tend to work for extended periods outdoors in extreme heat. We previously found that non-Kuwaiti migrant workers were especially vulnerable to extreme temperatures and air pollution (Achilleos *et al* 2019, Alahmad *et al* 2020c). We now estimate that heat-related mortality could increase by more than 15% in the distant future for non-Kuwaitis. This is not surprising given the numerous stressors that may impair the health of migrant workers (Alahmad *et al* 2020b). Greater occupational protections for heat exposure are needed to protect migrant workers and ensure health equity.

This study has several limitations. First, we provide effect estimates assuming no adaptation. This simplification enables isolating the potential influence of climate change from other factors. Adaptation to extreme temperatures has been studied before. In an analysis for a number of U.S. cities over a 42 year period, the exposure–response curves flattened with time and there was a nation-wide decrease in non-accidental heat-related mortality (Nordio *et al* 2015). An analysis of temperature-mortality projections in hot U.S. cities in portions of Texas, Louisiana, Alabama, Florida, southern California, Nevada and Arizona states, showed an overall decline in the temperature attributable mortality over time, essentially pointing out that these locations may have adapted to warmer temperatures (Schwartz *et al* 2015). In Kuwait, we found the opposite.

The exposure–response relationship in 2012–2016 was steeper than prior periods (2000–2005 and 2006–2011) (figure S3). We hypothesize that harms from heat and cold have gotten more rather than less pronounced over time. The steepness of the dose response curve did not differ based on migrant worker status. Therefore, our no-adaptation assumption as applied to the overall 2000–2016 exposure–response relationship in Kuwait may underestimate the true future mortality burden should maladaptation persist. It would of interest to examine whether a similar maladaptive pattern is present in other countries in the region in future work.

A second limitation of our study is its assumption of a static population age structure and migration levels. Population ageing, for example, can amplify future population vulnerability to extreme temperatures (Chen *et al* 2020). Projecting the country's migration size into the future would be a very difficult task given the unpredictability of the legal, social and economic interdependencies that dictate the mobility of migrant workers. Projecting future age and migration structures in Kuwait would introduce additional uncertainty that could mask some of the potential impacts of extreme temperatures. Alternatively, we reported separate projection analyses for certain vulnerable subgroups including the elderly population in Kuwait (above 65 years) and non-Kuwaiti migrants. Finally, when making projections we are essentially assuming that the baseline exposure–response relationship is correctly specified and that the scenarios will correctly predict the future temperatures.

5. Conclusion

Warming of our planet is not evenly distributed. Kuwait, an already hot country, is expected to endure more frequent and extreme temperatures even under moderate climate change scenarios. Extreme heat in the future may result in additional deaths barring effective adaptation. Vulnerable populations, including migrant workers, could bear disproportionate harm from climate change induced warming.

Data availability statement

The data generated and/or analysed during the current study are not publicly available for legal/ethical reasons but are available from the corresponding author on reasonable request.

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Author contribution

B A drafted the original manuscript. B A and A M V C did the statistical analysis. B A and K C did the data collection and curation. E G, A S B, J S and P K conceptualized and supervised the analysis. All authors reviewed and edited the manuscript.

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