Government of **Western Australia**
Department of **Health**

Projecting heat-related health impacts under climate change in Perth

health.wa.gov.au

Projecting heat-related health impacts under climate change in Perth

Epidemiology Directorate

Public Health and Aboriginal Health Division

Department of Health, Western Australia

January 2024

Suggested citation:

Sharma S, Sun W, Jian L, Landrigan T, Kirkland L, Joyce S and Scalley B (2024). Projecting heat-related health impacts under climate change in Perth. Perth: Department of Health WA.

Acknowledgements:

The authors would like to thank Dr Ivan Hanigan from the WHO Collaborating Centre for Environmental Health Impact Assessment, Sharna Nolan from the Department of Water and Environmental Regulation, and several members of the WA Department of Health, Health Sector Adaptation Plan Steering Committee meeting, for their expertise, advice and/or provision of climate data.

Contents

Executive summary

Heat-related deaths projected to increase by 61.4% in 2050s from 2010s.

Heat-related healthcare costs projected to increase by $30.6 million.

Up to 5x increase in summers with extreme heat-related mortality.

This report investigates the escalating heat-related health impacts in Perth, Western Australia, within the context of climate change. Extreme heat exposure has been closely associated with an increase in mortality and morbidity, particularly from ischemic heart disease, stroke, respiratory diseases, renal diseases, and mental health conditions in previous studies. Building upon this work, this report analyses a broader period of historical data and a wider range of health outcomes, including cause-specific mortality, hospital admissions, emergency department presentations and health care costs. Utilising a distributed non-linear lag model with data spanning from 1990 to 2019, the report explores current associations between heat exposure and adverse health outcomes. These associations are then projected under RCP 4.5, or an average of 1.64°C of warming by the 2050s as compared to the reference period from 1986 to 2005.

The analysis reveals a significant increase in heat-related deaths, increasing by 61.4% from 5.29 deaths per 100,000 (95% CI: 2.34-8.25) in the 2010s to 8.54 deaths per 100,000 (95% CI: 4.36-12.7) in the 2050s, with individuals over 75 and those susceptible to cardiovascular diseases impacted most. Heat-sensitive hospital admissions and ED presentations are expected to rise by 33.8% and 29.8%, respectively, leading to an estimated $30.6 million increase in healthcare costs. Additionally, extreme heat-related mortality during summer (more than 11.5 deaths per 100,000) is expected to shift from a 1 in 50-year event under the climate of 2020 to nearly a 1 in 10-year event by 2050.

These results align with similar studies, reinforcing the urgency for adaptive measures as recommended in the Australian National Health and Climate Strategy. However, the challenges in establishing direct causality and the uncertainties in extrapolating current health impacts to future unobserved temperature extremes necessitate a cautious interpretation of these results. Ongoing monitoring is essential to accurately understand and mitigate the evolving health impacts of rising temperatures in the region.

Background

Heat stands as a primary cause of extreme weather-related fatalities in Australia, significantly contributing to both death and disease (1–3). Its adverse effects manifest in increased mortality, emergency department (ED) visits and hospital admissions, especially due to ischemic heart disease (IHD), stroke, respiratory problems, renal diseases, and mental health issues. The physiological impacts of heat are multifaceted, exacerbating heart and renal strain through peripheral vasodilation and dehydration (4). In cases of extreme heat stress, the failure of the body's adaptive mechanisms can precipitate life-threatening conditions such as heat stroke and acute respiratory distress syndrome. Notably, older adults and those with pre-existing cardiopulmonary conditions are at heightened risk from heat's harmful effects.

The threat of heat and heatwaves is poised to increase with climate change. Since 1910, Australia has experienced an average surface temperature rise of 1.47 °C, a trend expected to continue, bringing more frequent, intense, and prolonged heatwaves (5). The 2009 south-eastern Australian heatwave, one of the most extreme in the region's history, exemplifies these trends, leading to an estimated 374 and 35 excess deaths in Victoria and Adelaide, respectively (6,7). Such events not only impact human health but also exert broad economic, social and environmental effects.

Perth, located in Western Australia's southwest and characterised by a Mediterranean climate, faces hot, dry summers and mild, wet winters (6). The city has witnessed a rise in average temperatures, resulting in drier conditions and an increase in extreme heat events, a pattern likely to intensify in the coming years. Without targeted strategic planning and adaptation, the changing climate could severely impact mortality, morbidity, and the burden on health services.

Current research on the health impacts of heat in Perth is sparse, with few studies projecting future effects. Williams et al. reported a 9.8% increase in daily mortality for every 10 °C rise in maximum temperatures above the 34-36 °C threshold (8). Tong et al. projected a significant increase in heat-related hospital costs, potentially rising from $79.5 million (2006-2012) to $181 million under a medium emissions scenario (9). This report aims to build on these insights by analysing a broader period of historical data and examining a wider range of health outcomes including cause-specific mortality, hospital admissions, and ED presentations. It seeks to project these impacts to the 2050s using climate models tailored to the Australian context and assesses the likelihood and implications of particularly severe summers. These projections could inform public health strategies and policy-making in Western Australia, emphasising the urgent need to understand and mitigate the health impacts of climate.

Methodology

Data sources

Health data

Daily all-cause mortality data was obtained from the Western Australia Births, Deaths, and Marriages Registry from January 1, 1990, to December 31, 2019 for the Perth metropolitan area. Causes of death were classified according to the Tenth Revision of the International Classification of Diseases (ICD-10), including ischemic heart diseases (I20–I25), strokes (I60–I69), and respiratory diseases (J00–J99). Additionally, the data was aggregated into daily counts of mortality, and segmented by age groups (0–74 and 75+ years) and Australian seasons (10). Data beyond 2019 was not considered due to the potential confounding health and societal effects of COVID-19.

Data from January 1, 2012, to December 31, 2019 on heat-sensitive hospital admissions and ED presentations, as well as their associated costs, were collected for the 13 largest hospitals in the Perth metropolitan area from the WA Hospital Morbidity Data System and the WA Emergency Data Collection (a shorter period was selected due to data availability). Following the methodology outlined by Wondmagegn et al. (11) only hospitalisations and ED presentations for renal diseases (N00-N39.9), mental health disorders (F00-F99.9), IHD (I20-I25), diabetes (E10-E14), and heat-related illnesses (E86, T67, X30) were considered, and referred collectively as “heat-sensitive” hospital admissions and ED presentations. This focus was based on evidence from prior research (12–14), which suggests these disease categories are most sensitive to heat exposure and analysing all-cause health service utilisation would mask this relationship.

Observed meteorological data

Population-weighted daily mean temperature data, spanning from January 1, 1990, to December 31, 2019, was provided by the WHO Collaborating Centre for Environmental Health Impact Assessment (15). Following the approach outlined in Hanigan et al. (16), this dataset merges the Australian Bureau of Meteorology (BOM) weather grids with SA1 polygons and population counts to yield precise exposure data. This approach facilitates the calculation of average daily minimum and maximum temperatures, weighted by population, across the Perth metropolitan area. The population-weighted daily minimum and maximum temperature were then averaged to derive the population-weighted daily mean temperature.

Projected meteorological data

For future projections, the BOM recommended using four general circulation models (GCMs) to estimate daily mean temperatures from 1990 to 2059 (17). The BOM selected these models — ACCESS 1.0, CNRM-CM5, GFDL-ESM2M, and MIROC5 — for their accuracy in representing Australian climate conditions and their representativeness among the broader set of GCMs in the World Climate Research Programme’s Coupled Model Intercomparison Project Phase 5 (CMIP5). The BOM downscaled and bias corrected these models to align with Western Australia’s specific climatology (17). To maintain consistency with observed data, the model outputs were recalibrated using the population-weighted daily mean temperature data described above. Representative Concentration Pathway (RCP) 4.5, a greenhouse gas concentration trajectory as defined in the 2014 IPCC report (18), was selected above other available scenarios (RCP2.6 and RCP 8.5), as it was considered the most realistic scenario till 2059 (19).

Projected population data

Population data between 2001 and 2019 for Perth, and projections spanning from 2020 to 2059 were sourced from the Australian Bureau of Statistics (ABS) (20). Due to unavailability of data, Perth population estimates for 1990 to 2000 were calculated based on WA ABS data for the same period and interpolated using the increasing Perth and WA population ratio. The ABS's projection methodology incorporates various national and international trends, such as fertility rates, mortality rates, net overseas migration, and net interstate migration. To encompass the entire spectrum of potential population changes, three distinct growth scenarios were employed: high growth, medium growth, and zero growth (i.e. the population does not grow after 2019).

Projected baseline health data

Daily baseline rates of mortality, hospital admissions, and ED visits from 2000 to 2059 were estimated by calculating the average rates for each day of the year, using the observed health dataset. These average daily rates were then consistently applied across the entire projection period (2000-2059).

Statistical analysis

All statistical analyses were performed using R software (version 4.0.1). The statistical analysis method outlined by Vicedo-Cabrera et al. (21) (see here for tutorial) and replicated by others (9,11,22) was used. It consists of two primary steps:

1. Estimation of the baseline exposure-response relationships.
2. Projecting future heat-related mortality, hospitalisations and ED presentations.

Estimation of the baseline exposure-response relationships

The relationship between daily mean temperature and health outcomes (listed in Table 1) were modelled using a time series quasi-Poisson regression. The model can be summarised as follows:

$$\log \mathrm{E}\left[Y_{(t)}\right] = \mathrm{f}(T_t;\theta) + s(t;\beta) + \gamma \mathrm{DOW}_t + \delta H_t + \alpha$$

Where:

- $Y_{(t)}$ represents the observed rate of health outcomes per 100,000 population at time t.
- $f(T_t;\theta)$ specifies the association with the environmental exposure of interest T at time t. The exposure response function is represented by a distributed lag nonlinear model to articulate both non-linear and delayed temperature effects on health outcomes, extending up to 21 days. Natural cubic splines are utilised to model the relationship across temperature and lag dimensions. The temperature dimension includes internal knots at the 10th, 75th, and 90th percentiles, while the lag dimension has equally spaced internal knots across a log scale.

- $s(t;\beta)$ accounts for baseline trends, including seasonality and long-term trends, to adjust for slow-moving confounders.
- γDOW_t and δH_t represent adjustments for daily-varying confounders, including the day of the week DOW_t and public holidays δH_t.
- α denotes the intercept of the model.

Table 1: Baseline outcomes assessed and projected against daily temperature

Mortality	All-cause, IHD, stroke and respiratory.
Morbidity	Heat-sensitive ED presentations, heat-sensitive ED costs, heat-sensitive hospital admissions, heat-sensitive hospital costs.

Projecting future heat-related health outcomes

Daily historical and future heat-related health outcomes O_{heat} were then projected using the modelled exposure-response relationship from Step 1:

$$O_{\mathrm{heat}} = O \cdot \left(1 - e^{-\left(f^*\left(T^*_{\mathrm{proj}};\theta^*_b\right) - f^*\left(T^*_{\mathrm{mm}};\theta^*_b\right)\right)}\right)$$

Here:

- O represents the projected baseline daily outcome of interest (mortality, hospitalisations and ED presentations).
- $f^*$and θ^*_bdenotes the cumulative temperature-mortality association.
- T^*_{proj} is the projected temperature series.
- T^*_{mm} is the temperature where the outcome is lowest.

The number of outcomes related to high temperatures was calculated by summing subsets of days with temperatures above T^*_{mm} and aggregated across decadal time frames between 2000 and 2050. Notably, this approach assumes no changes in adaptation strategies or population demographics that might alter baseline mortality or the exposure-response function. Further, following the methodology of Tong et al (9), future projected health care costs were not discounted, as no present day health intervention was evaluated for which present day value needed to be determined.

Quantifying uncertainty

Monte Carlo simulation was used to quantify the uncertainty in the relationship between heat and the outcomes analysed. The coefficients of the spline model were sampled a thousand times assuming multivariate normal distributions and applied to each GCM projection. The results were presented as point estimates, including the mean and the 95% confidence intervals (CI), across both the simulations and the GCM projections.

Projecting mortality with population growth

To assess the impact of population growth on heat-related mortality, projected heat-related death rates were initially converted into decadal totals and subsequently annualised for each respective period. Following this, the annual heat-related mortality figures were adjusted for each population trajectory. This adjustment entailed applying a factor that represents the ratio of the projected population for each year, under both medium and high growth scenarios, to the average population of the 2010s.

Estimating return periods

Return periods represent the expected time interval between events of a minimum intensity or magnitude, such as natural disasters. Here, they denote the frequency of years experiencing a minimum number of heat-related deaths. The methodology for estimating return periods of heat-related mortality was based on the approach outlined by Luthi et al. (23) consisting of several key steps:

1. Calculation of Annual Mortality Numbers: Daily heat-related mortality for each simulation were aggregated to yield annual mortality numbers.
2. Simulation Data Set: This approach produced a total of N=8,040 simulations for each 20-year period, which translates to 100 simulations per year for each GCM.
3. Empirical Probability of Occurrence: Each year within a 20-year period was considered to have an equal and independent probability of occurrence, with the probability (p) for any given year defined as p = 1/N.
4. Sort and rank simulation dataset: The simulated data was sorted in descending order from the simulated year with the highest heat-related mortality to the lowest.
5. Quantification of Return Periods: The return period $T(x)$ for a specific impact level were determined by the formula

$$T(x) = \frac{N+1}{m(x)}$$

   Where N is the total number of years in the simulated dataset and $m(x)$ is the rank of the specific event.

Results

Descriptive statistics

Descriptive statistics on mortality, and heat-sensitive ED presentation and hospital admission datasets are provided in Table 2. Spanning from January 1990 to December 2019, the period saw a total of 290,987 deaths. Of these, IHDs accounted for 28,380 fatalities, strokes for 19,244, and respiratory diseases for 22,764. A significant portion of deaths, 216,509, occurred in individuals aged 75 and above. Seasonal patterns in mortality rates were evident, with winter months registering a higher daily mean of 26.8 deaths, in contrast to 22.3 deaths in summer months. During a narrower time frame from January 2012 to December 2019, there were 709,817 ED presentations and 468,770 hospital admissions for heat-sensitive diseases, from a total of 4,929,012 ED presentations and 7,603,627 hospital admissions.

In the broader analysed period between January 1990 to December 2019, the mean temperature was 18.7°C and 99th percentile was 30.4°C. The year 2011 was the warmest within this timeframe, exhibiting a mean temperature of 19.8°C (Figure 1). In contrast, the years 2010 and 2012 witnessed a peak in days above the 99th mean temperature percentile, tallying 10 instances each.

Table 2: Summary of descriptive statistics for Mortality (1990-2019), and heat-sensitive ED presentation and WA hospital admission (2012-2019) datasets.

	Total	Daily - mean	Daily - sd
Causes of death			
All-cause	290,987	26.6	6.8
Stroke	19,244	1.8	1.3
IHD	28,380	2.6	1.8
Respiratory	22,764	2.1	1.6
Age group			
0 to 74	112,008	10.2	3.3
75+	173,734	15.9	5.4
Season			
Winter	80,157	29.0	6.8
Summer	66,826	24.7	6.4
Heat-sensitive health service utilisation			
ED presentations	709,817	242.9	32.6
Hospital admissions	468,770	160.4	34.3

Note: Summary statistics for all observational data used in the analysis, not only heat-related effects.

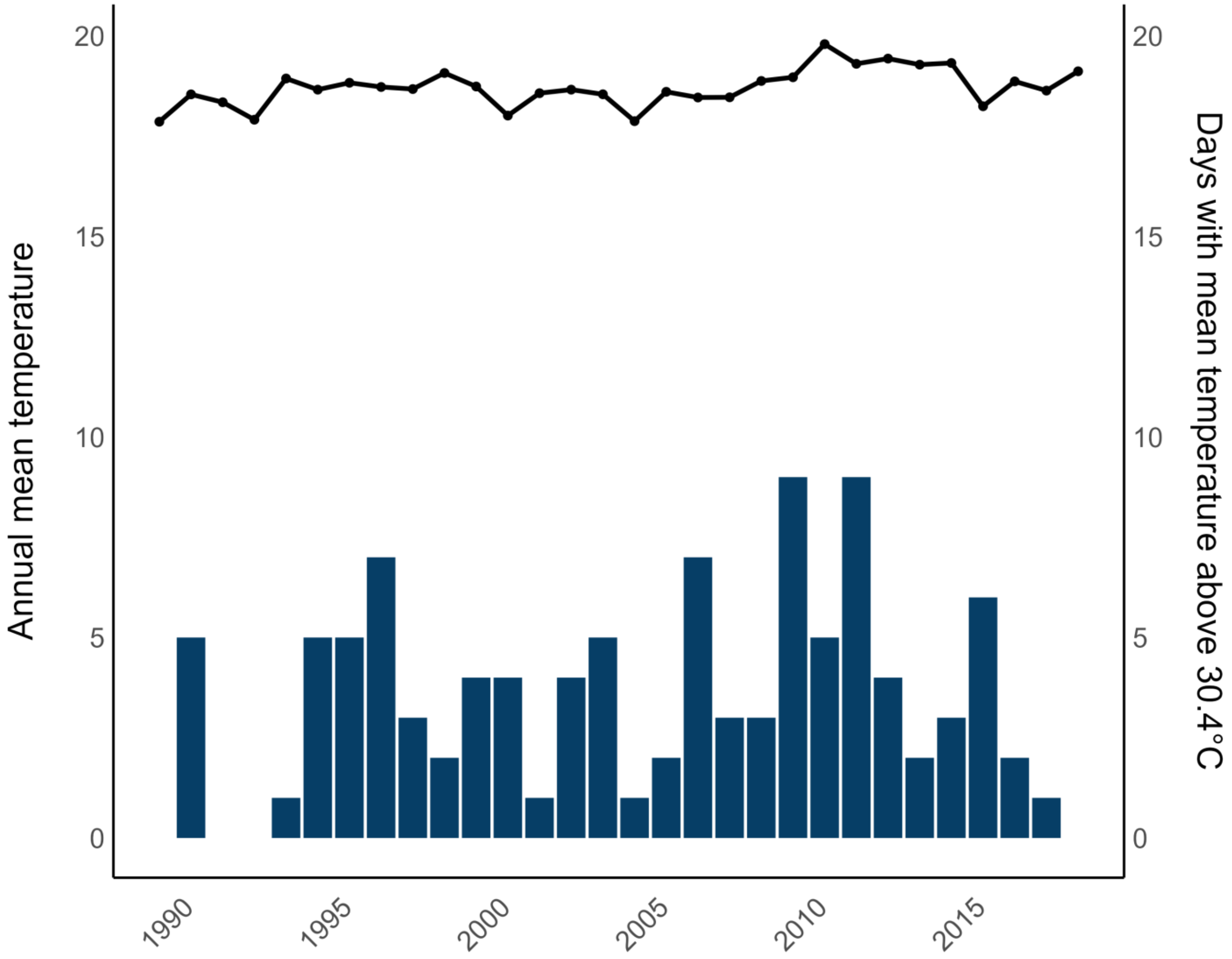

Figure 1: Temporal Trends in annual mean temperature (line graph) and days above the 99th percentile mean temperature (30.4°C) per year (column graph), 1990-2019.

Present day association between temperature and mortality

The relationship between daily mean temperature and all-cause mortality, cause-specific and age-specific mortality are presented in Figure 2. The curves illustrate a non-linear dose-response relationships between temperature and mortality, with associations either reverse J shaped or U shaped. For all-cause mortality, the minimum mortality temperature (T^{*}_{mm}) is identified at 23.7°C. Beyond this threshold, there's a sharp increase in mortality risk as temperatures rise. For example, at mean temperature of 30.4°C, which is the 99th percentile for daily mean temperatures, correlates with a 28% increase in all-cause mortality risk (95% CI: 11–48%). From the specific causes examined, the highest increase in mortality risk was observed in IHD. On a day with a mean temperature of 30.4°C, IHD mortality risk increases by 80% (95% CI: 18–277%) from the minimum mortality temperature, though this estimate comes with considerable uncertainty. The analysis also highlights age as an important factor: individuals aged 75 and older face a 25% higher mortality risk compared to those younger than 75 on a day with a mean temperature of 30.4°C and above. Figure 3 breaks down the effects of heat exposure over time. Heat impacts are most apparent within the first days from exposure but peak again at day 21.

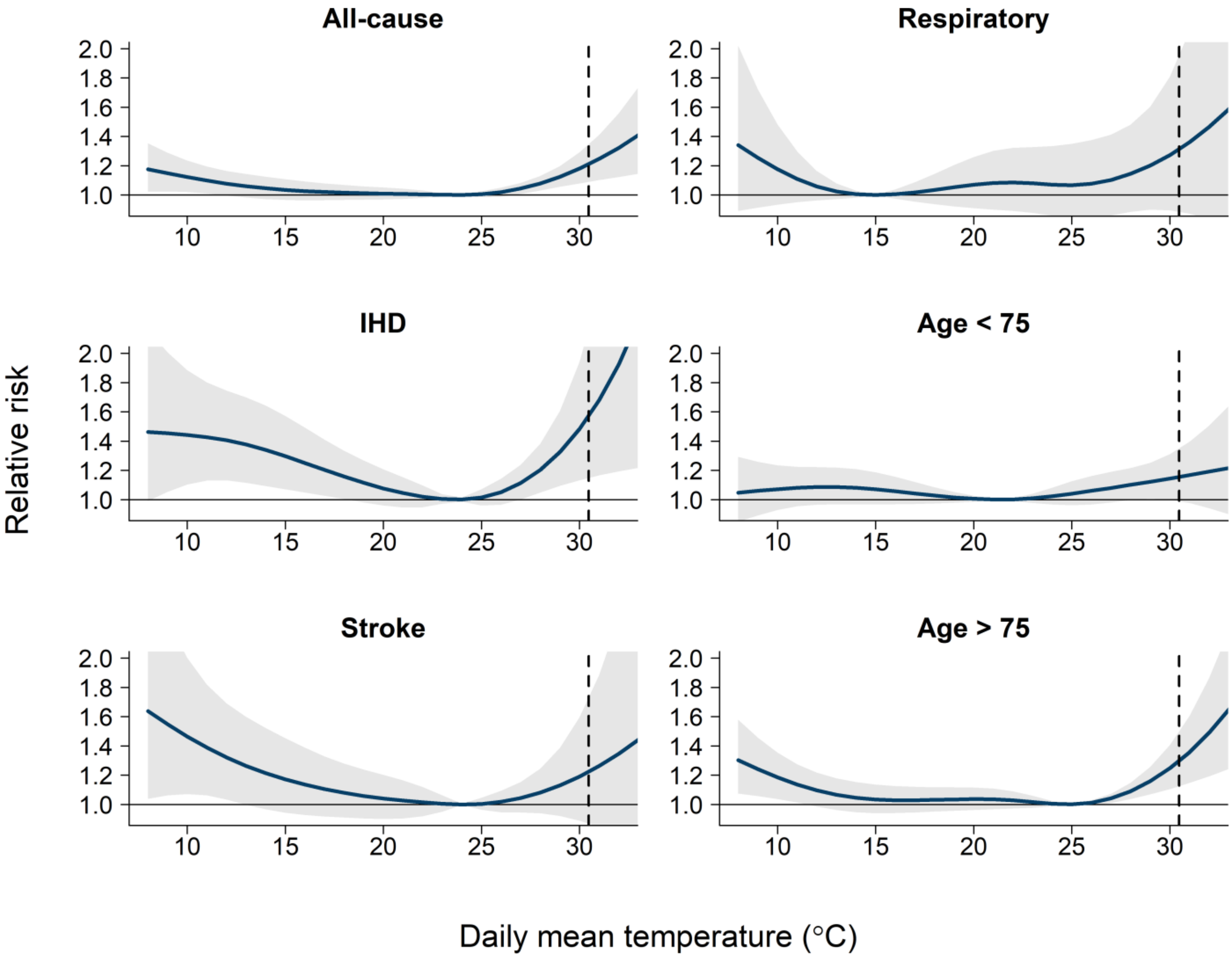

Figure 2: Present day association between daily mean temperature and relative risk of all-cause, cause-specific and age-specific mortality. For context, the vertical dashed line indicates the 99th percentile of daily mean temperature (30.4°C) during the observation period. Shaded areas represent 95% confidence intervals for the estimated relative risk.

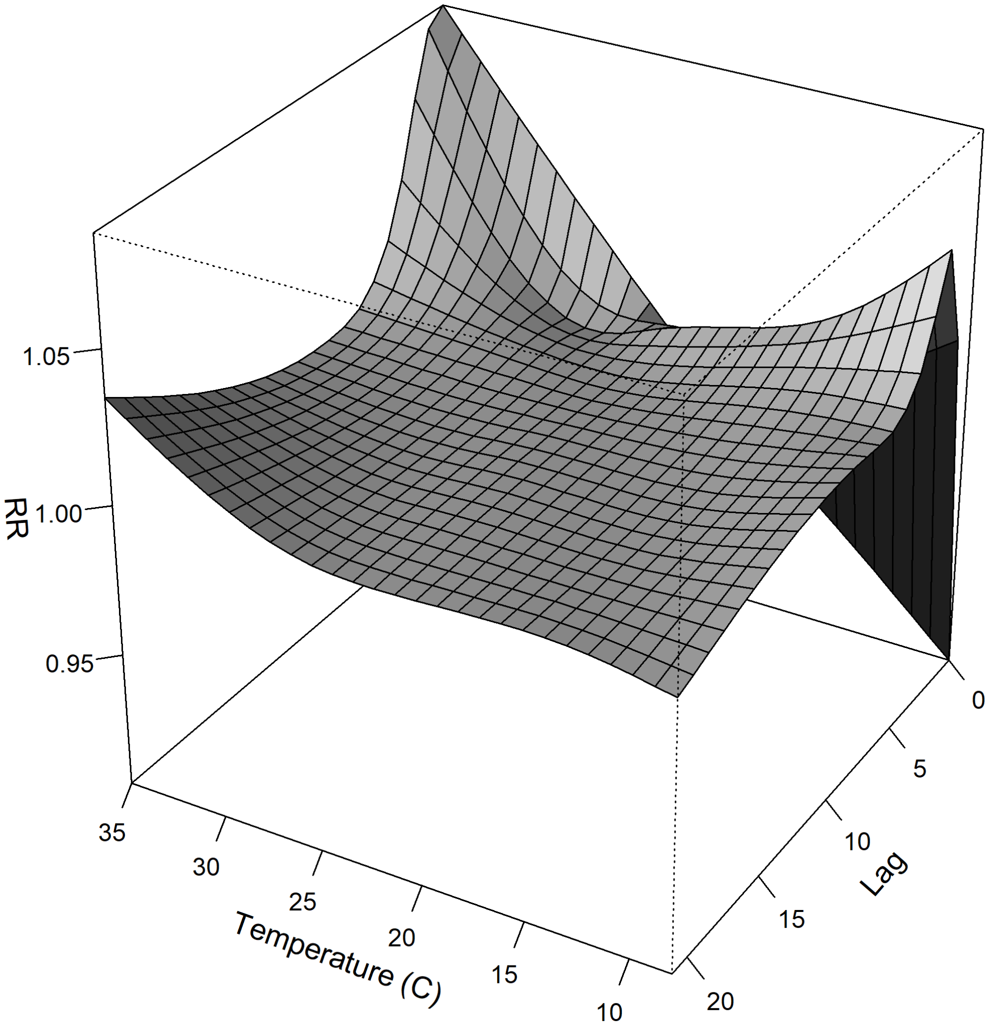

Figure 3: Three-dimensional representation of the lagged association between temperature and all-cause mortality. The z-axis (vertical) represents the relative risk, the y-axis represents the lag time in days since exposure, and the x-axis shows the daily mean temperature.

Present day association between temperature and health service utilisation

The plots in Figure 4 portray the association between daily mean temperature and a range of health-service utilisation outcomes. Compared to mortality outcomes, daily mean temperature appears to have a lower effect on ED presentations and hospital admissions. For ED visits, the relative risk rises from the T^*_{mm} and reaches its peak at approximately 27°C, followed by a subsequent decline and wider confidence intervals. In the case of ED costs, the relative risk similarly peaks around 27°C; however, it then stabilises at higher temperatures instead of decreasing. In contrast, hospital admissions and associated costs display a dose-response relationship, marked by escalating risk and uncertainty at elevated daily mean temperatures after the T^*_{mm}.

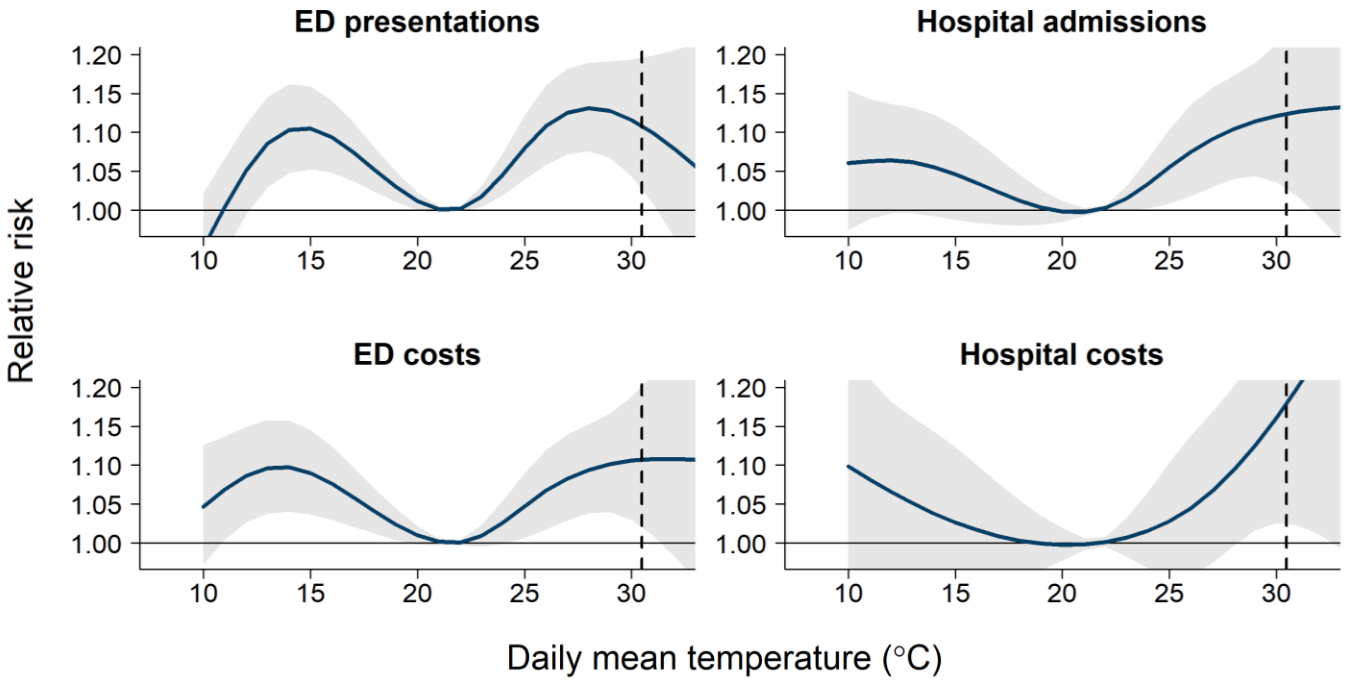

Figure 4: The association between daily mean temperature and relative risk of health service utilisation, including ED presentations and hospital admissions and their associated costs. For context, the vertical dashed line indicates the 99th percentile of daily mean temperature (30.4°C) during the observation period. Shaded areas represent 95% confidence intervals for the estimated relative risk.

Projected increase in temperature

Figure 5 presents the trends in historical and future projected temperatures in Perth from the GCMs for the period 1971-2059, under RCP 4.5. The GCMs forecast a consistent upward trajectory in temperatures up to the 2050s, with an anticipated average increase of 1.64°C in the annual mean temperature compared to the baseline period of 1986-2005. Additionally, the projections indicate a substantial rise in extreme temperature events: the frequency of days with temperatures exceeding 30.4°C is expected to increase by 185%, escalating from 30 days in the 2000s to 84 days by the 2050s.

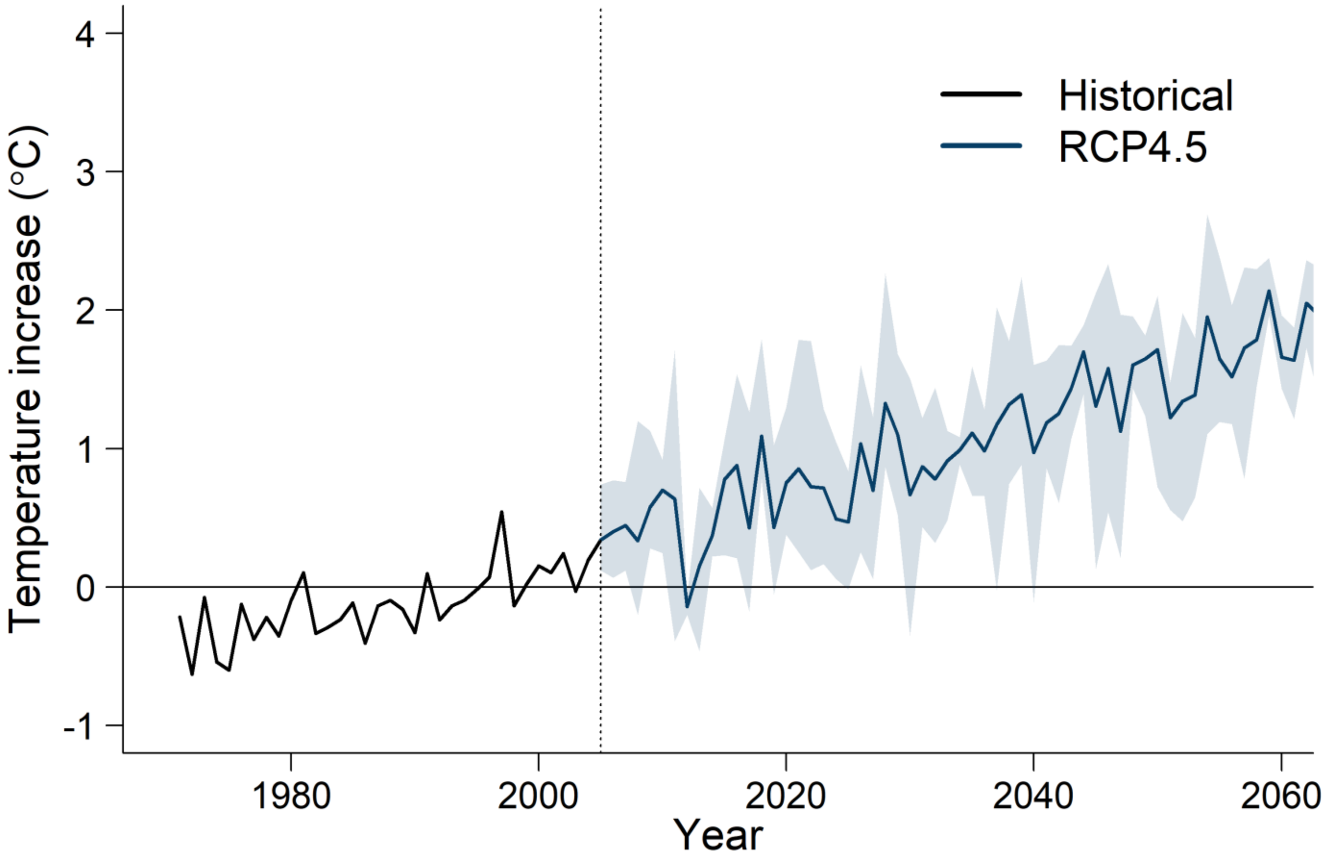

Figure 5: Historical and projected temperatures under RCP 4.5 for Perth based on an ensemble of four climate models from CMIP-5 - ACCESS 1.0, CNRM-CM5, GFDL-ESM2M, MIROC5. The solid line denotes the mean annual temperature increase from the historical average. The shaded area illustrates the range of projected temperature variability among these models.

Projected heat-related deaths, ED presentations and hospitalisations

Table 3 shows heat-related mortality and healthcare utilisation projections for 2010-19 and 2050-59, based on days above the T^{*}_{mm} (on average, ~24°C). A marked increase in heat-related all-cause mortality is projected, with a rise of 61.4% from 5.29 deaths per 100,000 (95% CI: 2.34-8.25) in the 2010s to an anticipated 8.54 deaths per 100,000 (95% CI: 4.36-12.7) in the 2050s. A differential impact on specific health conditions is observed, with the highest projected increase in heat-related fatalities expected in cases of IHD and stroke, showing a projected increase of 55.1% and 56.1% respectively in the same period. Projections also suggest a disproportionate effect on older populations; individuals aged over 75 are expected to experience a 66.7% increase in heat-related deaths from the 2010s to the 2050s, compared to a 43.8% increase for those aged under 75. Projections accounting for scenarios of medium and high population growth indicate that, under these conditions, heat-related deaths in the 2050s could rise by an additional 53.6% and 90.6% respectively (see Table 4). This implies an overall increase in heat-related deaths of 115.0% and 152.0% considering the respective population growth scenarios. Moreover, the projections indicate growth in heat-related healthcare services usage. Specifically, a 29.8% rise in ED presentations and a 33.8% increase in hospital admissions during the same timeframe.

Table 3: Projections of heat effects on mortality and heat-sensitive healthcare utilisation for 2010-19 and 2050-59 based on days above the T^*_{mm}. Estimated impacts are provided in population rates (per 100,000) with 95% confidence intervals in brackets.

	2010-19	2050-59	Increase (%)
Causes of death			
All-cause mortality	5.29 (2.34-8.25)	8.54 (4.36-12.7)	61.4
IHD mortality	1.38 (0.394-2.24)	2.14 (0.792-3.27)	55.1
Stroke mortality	0.483 (-0.5-1.33)	0.754 (-0.667-1.87)	56.1
Respiratory mortality	2.78 (-1.97-6.76)	3.46 (-2.16-8.11)	24.5
Age group			
Age <75 mortality	3.15 (-0.576-6.47)	4.53 (-0.152-8.7)	43.8
Age >75 mortality	3.33 (1.45-5.26)	5.55 (2.65-8.38)	66.7
Heat-sensitive healthcare utilisation			
Hospital admissions	41.1 (14.7-66.4)	55 (20.9-87)	33.8
ED presentations	75.4 (42.7-107)	97.9 (55.7-138)	29.8

Table 4: Projections of heat effects on mortality for 2010-19 and 2050-59 under different population trajectories. Estimated impacts are provided in decadal counts with 95% confidence intervals in brackets.

	2010-19	2050-59	Increase (%)
Population trajectory			
No change	1040 (461-1620)	1680 (858-2500)	61.4
Medium growth	1040 (461-1620)	2240 (1140-3340)	115.0
High growth	1040 (461-1620)	2620 (1340-3900)	152.0

Projected heat-related deaths and years with extreme heat-related deaths

Figure 6 illustrates projected heat-related mortality in Perth over multiple time periods. It shows a clear upward trend in the number of projected heat-related deaths, starting from 4.61 per 100, 000 (95% CI: 2.02-7.28) in 2000-09 and increasing in each subsequent period. The error bars suggest a substantial range of uncertainty in these projections, with the upper bounds of the estimates showing a possible increase to nearly 13 heat-related deaths per 100,000 in 2050-59.

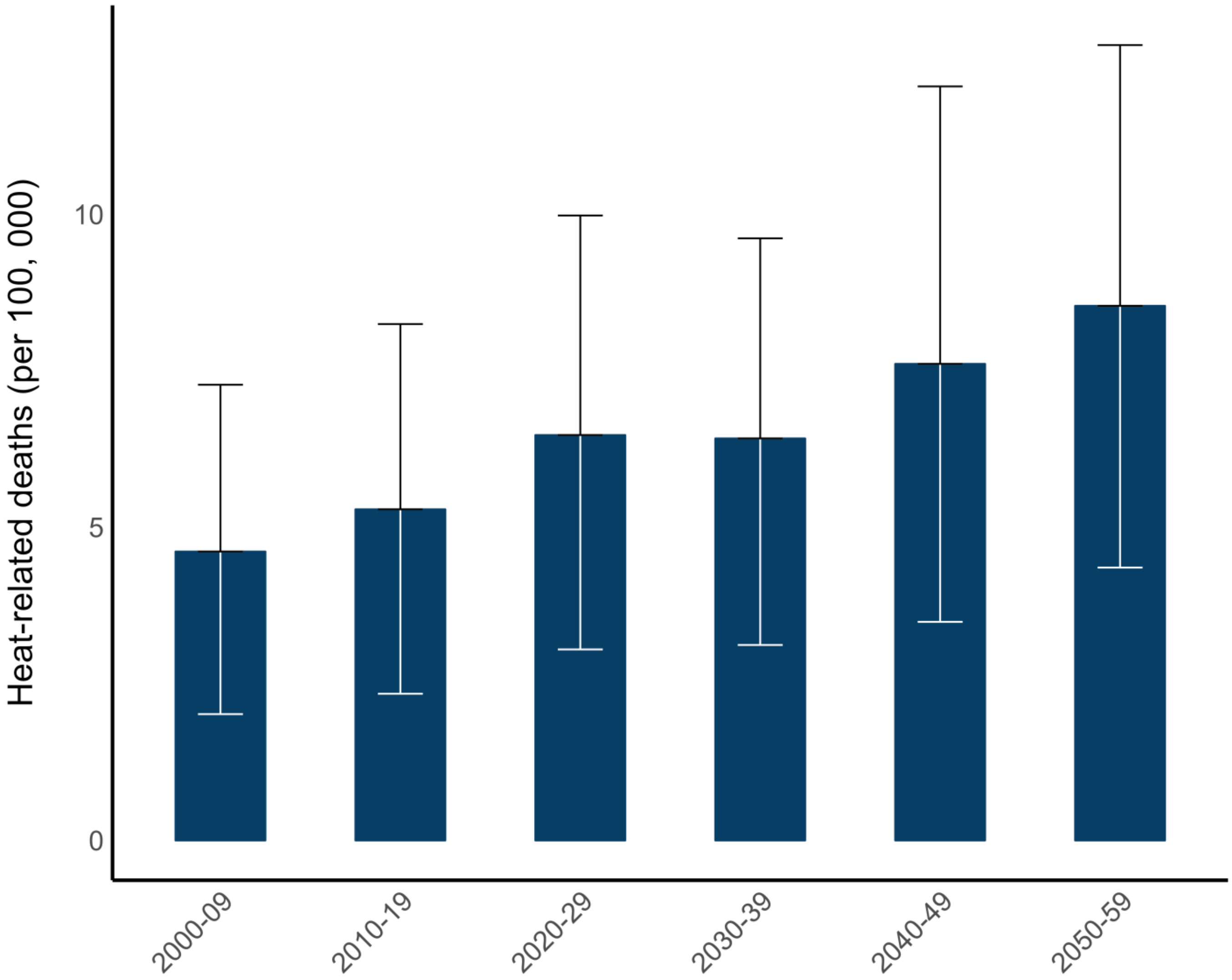

Figure 6: Projected heat-related mortality by decade with error bars representing the 95% confidence interval.

Figure 7 illustrates the relationship between annual heat-related deaths and their return periods. It demonstrates a significant shift in the likelihood of extreme heat-related mortality years. For instance, a year with over 11.5 heat-related deaths per 100,000 , a higher heat-related death rate than the severe 2009 Victoria heatwave, was considered a 1-in-50-year event in the climate conditions of 2020s in Perth. This is projected to occur much more frequently, nearly as often as once every ten years by 2050. The dotted trend line in Figure 7 illustrates the observed return period during the 2010s, demonstrating that the estimated impact in the 2010s is approaching the projected impact under the climate conditions of 2020.

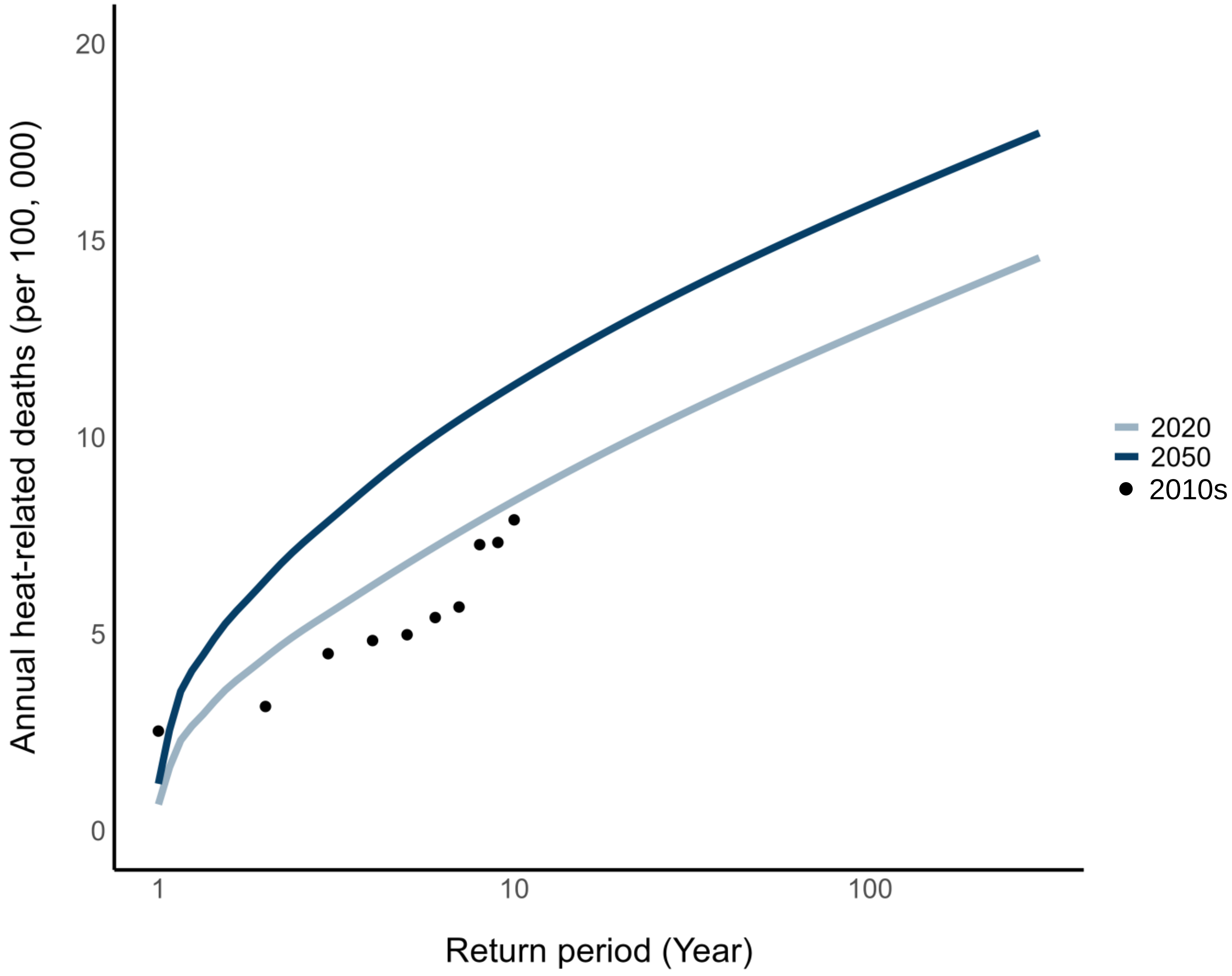

Figure 7: Annual heat-related deaths against return periods for the years 2020 (light blue) and 2050 (dark blue), with the dotted trend representing the observed data in the 2010s (black). Return periods in this context represent the expected frequency of years exceeding a certain number of heat-related deaths.

Projected costs associated with heat-sensitive health service utilisation

The projected costs linked to heat-sensitive health service utilisation show a notable increase, mirroring the projected rise in demand for these services (see Table 5). Specifically, hospital admission costs are estimated to grow by 44.9%, rising from $53.2 million in the 2010s to $77.1 million in the 2050s, assuming health service utilisation stays constant. In contrast, the increase in ED costs are anticipated to be more moderate, owing to a lower baseline cost. Overall, the total healthcare costs for heat-sensitive conditions are projected to increase from $63.7 million in the 2010s to $94.3 million in the 2050s.

Table 5: Projected changes in heat-related hospital admissions and ED presentations for the 2010s and 2050s. Projections include service utilisations and associated costs (in millions), with the 'Increase (%)' column highlighting the cost percentage growth over the period.

	2010-19	**2050-59**	**Increase (%)**
Hospital admissions	8100 (2890-13100)	10800 (4120 -17100)	33.8
Hospital costs (millions)	$53.2 (-13.6-118)	$77.1 (-6.97-160)	44.9
ED presentations	14800 (8410-21100)	19300 (11000-27200)	29.8
ED costs (millions)	$10.5 (2.83-12.9)	$17.2 (4.02-17.2)	63.8
Total costs	$63.7 (-10.7-130.9)	$94.3 (-2.95-177.2)	48.0

Note: Assumes baseline health service utilisation stay constant from 2010-19 to 2050-59. Negative values imply heat related effects may be cost-saving.

Discussion

This report finds that Perth is poised to see a substantial rise in heat-related deaths, with an expected increase of 61.4%, from 5.29 deaths per 100,000 in the 2010s to 8.54 deaths per 100,000 deaths in the 2050s, under RCP 4.5 or 1.64°C of warming from the 1986-2005 average. This trend is likely to disproportionately impact individuals over 75 and those prone to cardiovascular and cerebrovascular diseases. In tandem, there is a projected escalation in heat-related health service utilisation, though at a lesser rate. Specifically, hospital admissions are set to grow by 33.8%, and emergency department visits are anticipated to rise by 29.8%. This upsurge is expected to lead to an additional healthcare expenditure of $30.6 million, assuming current health service utilisation rates are maintained. While the projected increase is lower than deaths, it still poses a concerning finding, considering bed occupancy are at limits already at Perth hospitals. Additionally, the report projects a significant change in the frequency of extreme heat-related mortality events, or seasons with more than 11.5 heat-related deaths per 100,000. These events, which occurred once in fifty years under the climate of 2020, are projected to occur nearly every ten years by 2050, marking a fivefold increase in frequency.

The mortality projections are similar to analysis conducted by other groups using the same methods. For example, in their multi-country analysis, Gasparrani projected heat-related excess mortality in Australia would increase to 0.9% in the 2050s from 0.5% (representing a 80% increase), with data collated and aggregated from Sydney, Melbourne and Brisbane (24). Notably, they observe a much larger heat-related impact in Southeast Asia and Southern Europe that are likely explained by a range of factors including the urban heat island effect, higher rates of poverty, poorer health care infrastructure and an ageing population. In contrast, the hospital health care costs projections differ considerably from Tong et al – they estimate heat-sensitive hospital health care costs would increase by 127.7% in the 2050s under RCP 4.5 compared to this report’s 33.8% increase (9). Their analysis differs in important ways including the incorporation of population growth, the use of daily minimum temperature as the exposure variable, a 28-day lag period, and 5 degrees of freedom per year for long term trend splines. The substantial discrepancy observed may largely be attributed to the inclusion of population growth. In the current report, when medium population growth was factored in, the projected mortality estimates increased by over 50%. However, population growth was deliberately excluded from the central cost projection of this report in order to isolate the impact of rising temperatures.

The projected increase in heat-related health impacts in Perth underscores the need for adaptation to mitigate these effects. The recently published Australian National Health and Climate Strategy outlines a range of measures that could help manage the health impacts of heat including heatwave warning systems, effective risk communication and targeted outreach for at-risk populations (25). An evaluation of the South Australian heatwave warning system estimated that public message and daily welfare checks on at-risk residents reduced heat-related morbidity, with a 55% reduction in cardiac-related ambulance callouts and 30% reduction in renal-related emergency department presentations (7). The health care savings generated from the intervention was estimated to outweigh the cost of the intervention by at least two-fold (26). Opportunities to act on the wider determinants of health should also be sought to reduce population exposure to heat, including through increasing vegetated and aquatic space and improving building insulation, shading and ventilation (25). Recent modelling suggests that widespread tree planting could offset the increases in heat-attributable deaths in Australian cities, with tree canopies mitigating additional heat that comes from increasing density and urbanisation (27).

This report possesses several strengths. To the best of our knowledge, it stands out as the first to concurrently examine projected heat-related mortality and morbidity effects of climate change in Australia, offering a comprehensive view of future heat impacts. This dual focus equips decision-makers with a more complete understanding of potential climate change repercussions on health. Additionally, the report leverages an extensive health dataset that spans between 1990 and 2019, coupled with precise daily mean temperature exposure data. This helps with establishing robust relationships between heat and health outcomes, allowing for more reliable projections of future heat effects. Another strength is its inclusion of a catastrophic event analysis. This approach is important for defining worst-case scenarios and their likelihoods, which can assist with health system preparedness and resilience planning. The report's modular model design is another significant advantage. It allows for straightforward updates with better data and modifications to meet new objectives. For example, upon the availability of the more advanced CMIP-6 models specifically tailored for Perth, the report's projections can be refined. Similarly, the model's flexibility enables application to other Australian regions, accommodating varying climates and contextual differences, which may lead to distinct projections.

However, it is also important to acknowledge several limitations that could affect the interpretation and generalisability of these projections. One of the primary limitations is the difficulty in establishing a direct causal relationship between daily mean temperature and health outcomes. While the report employs established statistical techniques to quantify the relationship between daily mean temperature and observed health outcomes, it assumes that impacts on health outcomes are attributable to the effects of heat exposure on days above a certain temperature threshold. This approach does not explicitly determine a direct causal link, which means that other confounding factors that were not adequately controlled might also contribute to the observed mortality patterns. Secondly, this report focuses on the impact of heat instead of heatwaves, which may be more relevant for policy discussions. Although heatwaves may be more significant in this context, the methodologies for examining and projecting their effects are not as well-established. An initial exploration was conducted into using the excess heat factor as an exposure variable, as was previously done by Tong et al (28). However, this approach encountered challenges due to the limited availability of data points and uncertainties in calculating the excess heat factor for future temperatures. Thirdly, the report does not account for potential adaptation strategies and demographic changes over the projected period. Adaptation measures, both at the individual and systemic levels, could mitigate the impacts of heat exposure on health (29). Similarly, demographic shifts, such as changes in age distribution, health status, and urbanisation patterns, might alter the vulnerability of the population to heat stress (22). Finally, there is difficulty in applying the current understanding of the relationship between temperature and mortality to future scenarios, especially when these involve extreme temperatures that have not been observed previously. The extrapolation of existing relationships to such conditions carries inherent uncertainties, as the physiological and societal responses to unprecedented temperature extremes might differ significantly from current patterns. This uncertainty underscores the need for cautious interpretation of the projected impacts. It also highlights the need for ongoing surveillance and regular updates to modelling approaches, employing advances in methods to monitor the temperature-mortality relationship in near real-time.

Conclusion

In summary, this report projects a significant increase in heat-related health impacts in Perth by the 2050s, including a rise in heat-related deaths, healthcare service utilisation and related costs. While interpreting these results, caution is advised due to the challenges in establishing direct causality and the uncertainties involved in extrapolating current health impacts to future scenarios with unprecedented temperatures. Despite these limitations, the findings align with similar studies and underscore the urgency of implementing adaptation strategies, as recommended in the Australian National Health and Climate Strategy. Moreover, the evolving health impacts of rising temperatures necessitate continuous monitoring to ensure effective risk appraisal and mitigation.

References

1. Bhatta M, Field E, Cass M, Zander K, Guthridge S, Brearley M, et al. Examining the Heat Health Burden in Australia: A Rapid Review. Climate. 2023 Dec;11(12):246.

2. Cheng J, Xu Z, Bambrick H, Su H, Tong S, Hu W. Impacts of heat, cold, and temperature variability on mortality in Australia, 2000–2009. Sci Total Environ. 2019 Feb 15;651:2558–65.

3. Coates L, van Leeuwen J, Browning S, Gissing A, Bratchell J, Avci A. Heatwave fatalities in Australia, 2001–2018: An analysis of coronial records. Int J Disaster Risk Reduct. 2022 Jan 1;67:102671.

4. Ebi KL, Capon A, Berry P, Broderick C, de Dear R, Havenith G, et al. Hot weather and heat extremes: health risks. Lancet Lond Engl. 2021 Aug 21;398(10301):698–708.

5. State of the Climate 2022: Bureau of Meteorology [Internet]. corporateName=Bureau of Meteorology; [cited 2024 Jan 3]. Available from: http://www.bom.gov.au/state-of-the-climate/australias-changing-climate.shtml

6. State Government Victoria, Department of Human Services. January 2009 Heatwave in Victoria: An Assessment of Health Impacts. 2009.

7. Nitschke M, Tucker G, Hansen A, Williams S, Zhang Y, Bi P. Evaluation of a heat warning system in Adelaide, South Australia, using case-series analysis. BMJ Open. 2016 Jul 1;6(7):e012125.

8. Williams S, Nitschke M, Weinstein P, Pisaniello DL, Parton KA, Bi P. The impact of summer temperatures and heatwaves on mortality and morbidity in Perth, Australia 1994–2008. Environ Int. 2012 Apr 1;40:33–8.

9. Tong MX, Wondmagegn BY, Williams S, Hansen A, Dear K, Pisaniello D, et al. Hospital healthcare costs attributable to heat and future estimations in the context of climate change in Perth, Western Australia. Adv Clim Change Res. 2021 Oct 1;12(5):638–48.

10. World Health Organization. ICD-10 : international statistical classification of diseases and related health problems. 2004.

11. Wondmagegn BY, Xiang J, Dear K, Williams S, Hansen A, Pisaniello D, et al. Increasing impacts of temperature on hospital admissions, length of stay, and related healthcare costs in the context of climate change in Adelaide, South Australia. Sci Total Environ. 2021 Jun 15;773:145656.

12. Hansen A, Bi P, Nitschke M, Ryan P, Pisaniello D, Tucker G. The Effect of Heat Waves on Mental Health in a Temperate Australian City. Environ Health Perspect. 2008 Oct;116(10):1369–75.

13. Zhang Y, Nitschke M, Bi P. Risk factors for direct heat-related hospitalization during the 2009 Adelaide heatwave: A case crossover study. Sci Total Environ. 2013 Jan 1;442:1–5.

14. Nitschke M, Tucker GR, Bi P. Morbidity and mortality during heatwaves in metropolitan Adelaide. Med J Aust. 2007 Dec 3;187(11–12):662–5.

15. Hanigan IC. Weather_sa1_2016_1910_2022. https://github.com/cardat/DatSci_weather_sa1_2016_1910_2022; 2023.

16. Hanigan I, Hall G, Dear KB. A comparison of methods for calculating population exposure estimates of daily weather for health research. Int J Health Geogr. 2006 Sep 13;5(1):38.

17. DWER. Guide to future climate projections for water management in Western Australia. 2023 Nov.

18. Jubb I, Canadell P, Dix M. Representative Concentration Pathways (RCPs). 2016.

19. Capellán-Pérez I, Arto I, M. Polanco-Martínez J, González-Eguino M, B. Neumann M. Likelihood of climate change pathways under uncertainty on fossil fuel resource availability. Energy Environ Sci. 2016;9(8):2482–96.

20. ABS. Population Projections, Australia [Internet]. 2023 [cited 2024 Jan 3]. Available from: https://www.abs.gov.au/statistics/people/population/population-projections-australia/latest-release

21. Vicedo-Cabrera AM, Scovronick N, Sera F, Royé D, Schneider R, Tobias A, et al. The burden of heat-related mortality attributable to recent human-induced climate change. Nat Clim Change. 2021 Jun;11(6):492–500.

22. Yang J, Zhou M, Ren Z, Li M, Wang B, Liu DL, et al. Projecting heat-related excess mortality under climate change scenarios in China. Nat Commun. 2021 Feb 15;12(1):1039.

23. Lüthi S, Fairless C, Fischer EM, Scovronick N, Ben Armstrong, Coelho MDSZS, et al. Rapid increase in the risk of heat-related mortality. Nat Commun. 2023 Aug 24;14(1):4894.

24. Gasparrini A, Guo Y, Sera F, Vicedo-Cabrera AM, Huber V, Tong S, et al. Projections of temperature-related excess mortality under climate change scenarios. Lancet Planet Health. 2017 Dec 1;1(9):e360–7.

25. Department of Health and Aged Care. National health and climate strategy [Internet]. 2023. Available from: https://www.health.gov.au/sites/default/files/2023-12/national-health-and-climate-strategy.pdf

26. Williams S, Nitschke M, Wondmagegn BY, Tong M, Xiang J, Hansen A, et al. Evaluating cost benefits from a heat health warning system in Adelaide, South Australia. Aust N Z J Public Health. 2022 Apr 1;46(2):149–54.

27. Chaston TB, Broome RA, Cooper N, Duck G, Geromboux C, Guo Y, et al. Mortality Burden of Heatwaves in Sydney, Australia Is Exacerbated by the Urban Heat Island and Climate Change: Can Tree Cover Help Mitigate the Health Impacts? Atmosphere. 2022 May;13(5):714.

28. Tong MX, Wondmagegn BY, Xiang J, Williams S, Hansen A, Dear K, et al. Emergency department visits and associated healthcare costs attributable to increasing temperature in the context of climate change in Perth, Western Australia, 2012–2019. Environ Res Lett. 2021 Jun;16(6):065011.

29. Carleton T, Jina A, Delgado M, Greenstone M, Houser T, Hsiang S, et al. Valuing the Global Mortality Consequences of Climate Change Accounting for Adaptation Costs and Benefits*. Q J Econ. 2022 Nov 1;137(4):2037–105.

This document can be made available in alternative formats on request for a person with disability.