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

Evaluation of the Heatwave Measurement used in the State Hazard Plan – Heatwave, and Related Health Effects

Epidemiology Directorate
Public and Aboriginal Health Division
Department of Health WA

September 2022

Acknowledgements

Dr Le Jian, Dimpalben Patel, Dr Jing Guo, Dr Jianguo Xiao, Dr Grace Yajuan Yun and Dr Ting Lin and Dr Andrew Robertson authored this report. Dr Laura Kirkland and Mr Tim Landrigan reviewed this report and provided valuable input and advice and Dr Robert Fawcett from the Bureau of Meteorology provided the EHF data for the project.

Suggested citation

Epidemiology Directorate, 2022. Evaluation of the Heatwave Measurement used in the State Hazard Plan – Heatwave, and Related Health Effects. Department of Health, Western Australia.

Abbreviations

ABS	Australian Bureau of Statistics
CI	Confidence Interval
ADT	Average Daily Temperature
DER	Department of Environmental Regulation
DOH	Department of Health
DPMU	Disaster Preparedness and Management Unit
ED	Emergency Department
EDA	Emergency Department Attendance
EHF	Excess Heat Factor
EHI	Excess Heat Index
GRF	Geographical Random Forest
HW	Heatwave
IDW	Inverse Distance Weighted
MAE	Mean Absolute Error
MHW	Mild Heat Wave
NHW	No Heat Wave
RMSE	Root Mean Square Error
RR	Rate Ratio
R^2	R-squared
%IncMSE	Percentage Increase in Mean Square Error
SA2	Statistical Area Level 2
SA3	Statistical Area Level 3
SHW	Severe Heat Wave
WA	Western Australia
3DAT	3-day average daily temperature

Contents

List of tables

List of figures

Appendices

Executive summary

Heatwave (HW) measurement is important as a heat exposure indicator in evaluation of a HW management system and to determine whether the system is effective in preventing or reducing adverse HW related health effects and to identify opportunities for improvement. An often used definition of HWs is a period of abnormally hot weather for a location, however, there is no standard measurement for HW around the world. The State Hazard Plan for Heatwave (SHP-HW), originally called WESTPLAN-Heatwave is a State level plan on the HW management, introduced in Western Australia (WA) by the Department of Health (DOH) since 2012. This report aimed to use the current HW measurement (3 day average daily temperature (3DAT)) in the SHP-HW to compare HW related morbidity and mortality in WA before and after the introduction of the SHP-HW, compare the sensitivity between 3DAT and Excess Heat Factor (EHF) on identifying additional health service utilisation related to HW exposure, and to provide evidence for the areas that could be improved or added to the Plan from the health point of view.

Objectives

1. Evaluate HW related health service utilisation in WA before and after the implementation of the SHP-HW by the HW measurement defined in the plan.
2. Identify the most suitable HW indicator between the HW measurement created by the Australian Bureau of Meteorology (the Bureau) and the WA DOH.
3. Identify the most suitable triggers for HW activation.
4. Identify the lag effect of HW on health service utilisation.
5. Identify populations and geographical locations vulnerable to HW in WA.

Methods

Daily records of hospitalisations, emergency department (ED) presentations, deaths, temperature, and EHF were collected for Perth, WA from 2009 to 2015. HW definition in the SHP-HW (3DAT) was used to assess the HW exposure. The Bureau's HW definition EHF was compared with 3DAT on sensitivities. The SHP-HW was implemented in 2012. The period 2009–2011 was defined as "before implementation period (pre-period)" and the period 2013–2015 as "after implementation period (post-period)".

Descriptive analyses were conducted to examine the patterns of HW and health service utilisation before and after the implementation of the SHP-HW Plan using HW definitions created by the Bureau and the WA DOH. Rate ratios (RRs) and 95% confidence intervals (CIs) were calculated to evaluate the effect of HW on health service utilisation.

Different percentiles of the Bureau's EHF (i.e. 70^{th}, 75^{th}, 80^{th}, 85^{th}, and 95^{th}) were used to measure the sensitivity of each HW cut-off to the change in health service utilisation rates before and after the implementation of the SHP-HW Plan and among different severities of HWs to identify the most suitable triggers for HW activation, response, and recovery.

Finally, Poisson regressions and machine learning approaches were used to obtain the most suitable model to rank the important risk factors and identify vulnerable populations and locations for health service utilisation related to HW.

Key findings

1. The current HW trigger defined in the SHP-HW for the Perth metropolitan area (i.e., a 3-day average daily temperature (3DAT) at 32 degrees Celsius and above) could only identify very rare extreme HW events.
2. The Bureau's EHF was more sensitive compared with the WA DOH's. During the pre-period, it could identify more HW events and additional heat-related health service utilisation than the one by WA DOH. During the post-period, HW events were reduced but still could be identified by the Bureau's HW definition.
3. The majority of HW events were mild. These mild HW events were identified as being associated with significant increases in ED presentations and hospitalisations. Severe HW events were even more strongly linked to increased health service utilisation.
4. When the Bureau's 85th EHF trigger was applied, not only did ED presentations and hospitalisations increase significantly, but also mortalities increased significantly.
5. The most significant lag effect of HW on health service utilisation was on day 3 of a HW event, but it can be longer than 3 days.
6. The study identified vulnerable populations and locations, including children aged 0–4 years, adults aged 60 years and over, Aboriginal people, those living in socio-economically disadvantaged areas, and southern areas (i.e., Mandurah, Kwinana, and Serpentine – Jarrahdale).
7. The Bureau's HW forecasting warning service is a good resource that can be used for WA to timely identify HW hotspots and severity.

Recommendations:

To improve HW management and prevent HW related adverse health effects, we recommend the following:

1. Agencies responsible for HW management can consider the use of the Bureau's HW definition, the Bureau's HW severity classifications, and the Bureau's 85th percentile EHF cut-off as the trigger for activation for effectively managing and preventing HW related adverse health effects in WA.
2. The health effects of HW exposure may appear and exist for longer periods than the HW days and may occur a few days after an HW event. This information is important for allocating sufficient resources (i.e., education, training, and infrastructure) for vulnerable populations and locations.
3. Agencies responsible for HW management can consider the inclusion of children aged 0–4 years old and those living in socio-economically disadvantaged areas in the "At Risk Population List".
4. The Bureau's HW forecasting operational resource—HW service for Australia can be used during warm months to timely and cost-effectively monitor HW hot spots, identify HW severity levels, activate responses and recovery plans in WA. It also has the potential to be used for predicting additional health service utilisation related to HW.

1. Introduction

1.1 Background

Climate change is anticipated to increase the frequency, duration, and severity of heatwaves in Australia and across the world [1, 2]. Epidemiological studies have reported that HWs have caused a greater increase in premature deaths in Australia than any other natural hazard, making it a relatively more serious public health issue [3, 4]. HWs have also increased the risk of morbidity in terms of increasing utilisation of health services, such as emergency department (ED) presentations, emergency hospitalisations, and ambulance transports [5-10].

A heatwave is considered as a period of unusual or exceptionally hot weather. However, there is no standard measurement for HW across countries and regions. In Australia, different jurisdictions also use various measurements of HW and have their own HW management systems [11-14]. Evaluation of such systems is very important to provide information on the effectiveness of the system to reduce HW related adverse health effects and the burden on the healthcare systems. Current studies on the evaluation of HW management systems are limited and only a few attempts have been made in countries such as India [12], England [11], the Netherlands [15], and Australia [13].

The HW management plan was initially released in October 2012 as WESTPLAN-HW by the Western Australia Department of Health (WA DOH) [16]. In May 2018, the plan was updated to the new State Hazard Plan format and has since been known as the State Hazard Plan – Heatwave (SHP-HW) [17]. The update also included the substitution of the calculation acronym EHF with 3DAT. This report will refer to the updated name and acronym. However, the method to measure HW has remained the same (3DAT).

The SHP-HW details strategic arrangements for the prevention, preparedness, response and recovery from HW emergencies in WA. It defines the trigger for activating the response efforts for HW, including the roles and responsibilities of the WA DOH and other emergency management agencies.

This report aimed to use current HW measurement (3DAT) in the SHP-HW and comparing HW related morbidity and mortality in WA before and after the introduction of the SHP-HW, compare the sensitivity between 3DAT and Excess Heat Factor (EHF) on health service utilisations, and to provide evidence for the areas that could be improved or added to the Plan from the health point of view.

1.2 Objectives

The objectives of this project were to:

1. Evaluate HW related health service utilisation in WA before and after the implementation of the SHP-HW by the HW measurement defined in the Plan (3DAT).

2. Identify the most suitable HW indicator between the HW measurements created by the Australian Bureau of Meteorology (the Bureau) and the WA DOH.
3. Identify the most suitable triggers for HW activation.
4. Identify the lag effect of HW on health service utilisation.
5. Identify populations and geographical locations vulnerable to HW in WA.

1.3 Benefits of the study

This study has provided evidence-based information on the method used to measure a HW in the current SHP-HW Plan and HW related health service utilisation in WA before and after the implementation of the Plan. Populations and geographical locations vulnerable to HW have been identified using an innovative approach.

Recommendations are provided for relevant agencies to consider on implementing a better HW measurement and an appropriate trigger for the SHP-HW Plan. This would enable early responses for HW related health services to prevent and reduce severe adverse health effects and improve HW management in WA. In addition, by using innovative technologies, the most important risk factors, the most vulnerable age groups, and vulnerable locations have been identified as the focus for the effective allocation of health resources to manage HW in the future.

2. Methods

2.1 Study setting

Perth, the capital city of WA, has a warm temperate climate where summers are hot and dry because of the domination of subtropical high-pressure systems, while winters have moderate temperatures with rain because of the polar front [18]. The majority of WA residents (2.04 million or 79 per cent) lived in the Perth metropolitan area in 2015 (the end of the study period) [19]. The whole population of the Perth metropolitan area was included in this study, with a total of 21 statistical area level 3 (SA3s) and 174 statistical area level 2 (SA2s). One SA3 generally has a population of between 30,000 and 130,000 people, and one SA2 has about 3,000 to 25,000 people, as defined by the Australian Bureau of Statistics (ABS) [20]. Figure 1 shows the map of Perth with the blue borders of the 21 SA3s and the grey borders of the 174 SA2s. The six weather stations and the eight air quality monitoring stations are also displayed on the map.

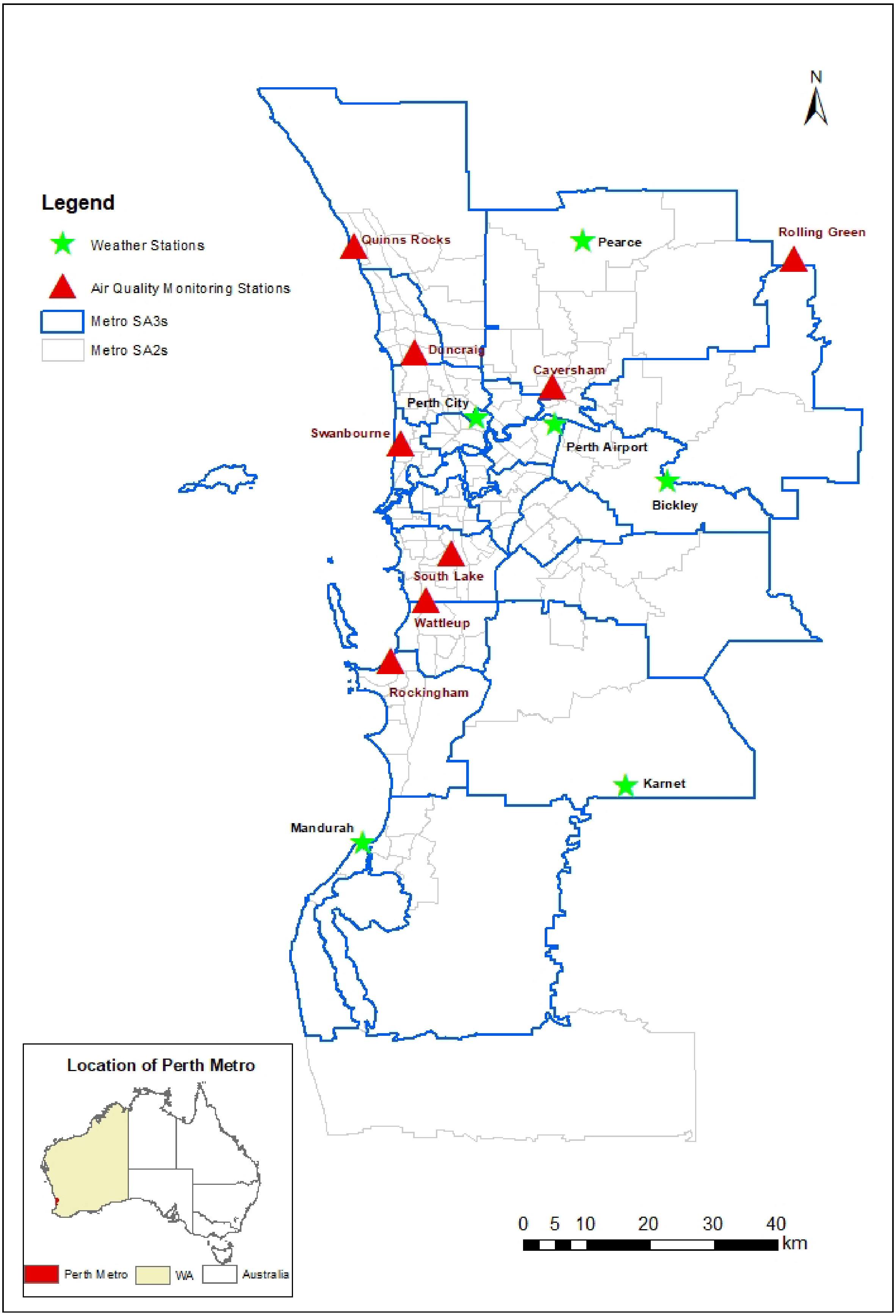

Figure 1. Map of the Perth metropolitan (SA2 and SA3) with weather and air quality monitoring stations

2.2 Data sources and data management

A population-based time-series dataset was collected for this study. Daily data on health, weather, and air quality from 2009 to 2015 for warm months (i.e. January, February, March, April, November, and December) in the Perth metropolitan area were included for analysis. The two HW measurements used in the evaluation were the WA DOH's 3DAT defined in the SHP-HW and the Bureau's EHF. The five health service utilisation indicators used in the evaluation were all-cause ED presentations, heat-related ED presentations, all-cause hospitalisations, heat-related hospitalisations, and all-cause mortality. The detailed data sources, defined variables, and their classifications used in the study are described below.

2.2.1 Population data

The estimated resident populations for Perth were sourced from the ABS for the study period. Populations per month were calculated by using a linear interpolation method, which was based on a mid-year estimated resident population, and these calculated populations were then applied to all days of the month.

2.2.2 ED presentation data

Daily ED presentation data was sourced from the WA Emergency Department Data Collection including overall (all-cause) ED and heat-related ED presentations (i.e. presentations with a principal diagnosis ICD-10-AM codes of L55, L74.0, T67, X30 or X32) [21]. In total, 5,511,111 all-cause ED presentations and 3,658 heat-related ED presentations were examined.

2.2.3 Hospitalisation data

Daily hospitalisation data was sourced from the Hospital Morbidity Data Collection, including overall (all-cause hospitalisations) and heat-related hospitalisations. Heat-related hospitalisations were defined as hospital admissions with a principal or any additional diagnosis codes of L55, L74.0, T67, X30 or X32 based on the International Statistical Classification of Diseases and Related Health Problem, Tenth Version, Australian Modification (ICD-10-AM). In total, 3,247,487 all-cause hospitalisations and 1,396 heat-related hospitalisations were examined.

2.2.5 Mortality data

Daily all-cause mortality data was sourced from the Australian Coordinating Registry, the Registries of Births, Deaths, and Marriages, the Coroners, the National Coronial Information System, and the Victorian Department of Justice and Community Safety. In total, 101,666 all-cause mortality cases were examined. Heat-related mortality was not examined due to small counts.

2.2.4 HW data

a) HW measurement by WA DOH

The temperature data was sourced from the Bureau for six weather stations in Perth (Figure 1). An inverse distance weighted method [22] was used to estimate temperature for the areas without station data. In WA SHP-HW, the HW trigger in the Perth metropolitan area was defined and calculated using a forward-looking 3-day average daily temperature (3DAT) [16] as below:

$$3DAT = (ADT1 + ADT2 + ADT3) / 3$$

Where the average daily temperature (ADT) was calculated by averaging the daily maximum temperature and the subsequent minimum temperature:

$$ADT = (Temperature_{max} + Temperature_{min})/2.$$

Currently, the trigger of HW activation for Perth is a 3DAT of 32°C. This means if a forward-looking three-day prediction reaches 32°C, it will trigger the activation of the SHP-HW. In this evaluation study, when WA DOH's 3DAT reaches 32°C or above in a day, the day is considered as a HW day.

b) HW measurement by the Bureau

The Bureau created an intensity measure for HW exposure in 2013 [3]. This measure combines the effects of excess heat (an index of long-term temperature anomaly categorised by every locality's distinctive climatology of heat) and heat stress (a short-term temperature anomaly based on recent thermal acclimatisation). The Bureau's EHF provides a relative measure of load, intensity, spatial distribution, and duration of a HW event.

$$\text{The Bureau's EHF} = EHI_{sig} \times \max(1, EHI_{accl})$$

where $EHI_{sig} = 3DAT – ADT\ 95^{th}$ and $EHI_{accl} = 3DAT – (ADT_{-1}+...+ADT_{-30})/30$.

The Significant Excess Heat Index (EHI_{sig}) compares the continuous 3-day ADT with the historical temperature (95th percentile of ADT for the climate reference period 1971-2000) for that area. The Acclimatisation Excess Heat Index (EHI_{accl}) compares the continuous 3-day ADT to the average temperature over the preceding 30 days as a short-term (acclimatisation) temperature anomaly. If the Bureau's EHF value was > 0 in a day, the day was defined as a HW day, and a non-heatwave (NHW) day if the value was ≤ 0. To simplify the analysis, all negative EHF values were converted to zero, indicating no HWs.

In this evaluation study, the Bureau's EHF values were originally available in gridded data with 5×5 kilometre pixels in a NetCDF format (Network Common Data Form—a format for storing multidimensional scientific data such as temperature). The EHF data extraction process was completed using ESRI ArcMap software (version 10.5). The data was converted into a raster layer with EHF values varying over space and time, and then each raster layer was created separately for each day of the study period. The population weighted centroid (i.e., the population central point) was used to represent each SA2 area. Those central points were then used to extract the EHF values for SA2s from the raster layer. For the analysis based on SA3, a median of EHF values for all SA2s within an SA3 was calculated to represent the EHF value for that SA3.

For both HW measurements, a 50 per cent cut-off value was used to define the total number of HW days for the whole Perth metropolitan area (SA3s). If more than 50 per cent of SA3s in Perth had a HW on a specific day, that day was deemed as a HW day for the whole of Perth.

2.2.6 Air quality data

Air quality data, such as carbon monoxide (CO), nitrogen dioxide (NO_2), sulphur dioxide (SO_2), ozone (O_3), particulate matters with an aerodynamic diameter $\leqslant$10 micrometres (PM_{10}), and aerodynamic diameter $\leqslant$2.5 micrometres ($PM_{2.5}$), were sourced from the Department of Environmental Regulation, WA from eight air quality monitoring stations (Figure 1). The average of the top eight hourly values of each air pollutant for the day of each station was calculated to derive a daily measure. Due to the limited number of monitoring stations available in the study area, the air pollutant values for each SA3 were estimated using the Inverse Distance Weighted method, a type of deterministic method for multivariate interpolation with a known scattered set of points in the geospatial analysis [22, 23]. Finally, all air pollutants' values were classified into three levels based on their distribution percentiles: low (25th percentile), middle (25th-75th percentile), and high (> 75th percentile).

Daily data on the size and location of landscape fire burns (including wildfires and government-managed prescribed burns) over the study period was sourced from the Department of Biodiversity, Conservation, and Attractions, WA.

2.3 Evaluation approach

The SHP-HW was implemented in 2012 in WA. Therefore, the period of 2009–2011 was defined as the pre-period, the period after 2012 (2013–2015) as the post-period, and the year 2012 was deemed as the cut-off year.

Because a HW event could affect not only health service utilisation on the same day of the event but also several days after the event, lag effects of HWs on health service utilisation were assessed first. Regression analyses between the Bureau's EHF (HW day vs NHW day) and cumulative health service utilisation rates were conducted for the same day (Day-1), and the cumulative 2, 3, 4, ... up to 10 days following a HW event. For instance, cumulative Day-3 ED counts were the sum of the ED presentation counts for the current day and the subsequent two days. The same principle applies to the calculation of cumulative populations, hospitalisations, and mortality data. The day with the greatest association between the Bureau's EHF and the rate of each cumulative health service utilisation indicator in the regression models was finally selected and used for the evaluation purpose.

The rate ratios (RRs) were calculated by dividing the crude rates for HW days by those for NHW days. If an RR value is 2, it means the health service utilisation rate during HW days is 2 times higher than that in NHW days. The 95% confidence intervals (CIs) were also calculated for RRs to evaluate whether there were significant elevations in health service utilisation during HW days compared with NHW days for the pre- and post- periods. If the 95% CIs of a RR include a value of 1, there is no significant difference in the rate of this health service utilisation indicator between HW and NHW days. Otherwise, if the 95% CIs do not include a value of 1 and the RR >1, there is a significant difference in that rate between HW and NHW days, and the rate in HW days is significantly higher than that in NHW days.

Sensitivity analysis was used to evaluate the patterns of HWs and health service utilisation by the Bureau's EHF measurement at different percentiles (cut-offs, i.e., 70^{th}, 75^{th}, 80^{th}, 85^{th}, and 95^{th}) and to identify the most suitable triggers for activation of the SHP-HW Plan. Firstly, comparisons of HW related health service utilisation between the pre- and post-periods were conducted for different EHF percentiles. Crude rates were calculated by dividing the number of health service utilisation by the total population. Then the dose-response relationships between the intensity of HW events and health service utilisation in the pre- and post-periods were assessed for different EHF percentiles. If more intense HW (i.e., dose) was associated with a higher health utilisation rate (i.e., response), this would be considered as a strong dose-response relationship, providing strong epidemiological evidence that there exists a strong association between HW and health utilisation. All positive EHF values for the whole study period were used to calculate the percentiles of EHF values. For example, the 75^{th} percentile EHF value was 9.91. Therefore, a HW day based on the 75^{th} percentile was a day with EHF values of ≥ 9.91, and a day with values of < 9.91 was defined as an NHW day. The intensity (severity) of HW was categorised into 3 levels, named as severe HW (SHW), mild HW (MHW), and NHW. For example, the HW intensity level based on the 75^{th} percentile EHF would be SHW (high level) - if the EHF values were ≥ 75^{th} percentile; MHW - if the EHF values were between >0 and <75^{th} percentile; and NHW - if the EHF values were ≤ 0. The same principle was applied to derive all percentile cut-offs to define the HW intensities. The details of the values used for each HW measurement can be found in Appendix 1.

To compare the trigger for HW activation currently used in WA DOH with the Bureau's 85^{th} percentile EHF (a potential new trigger) between HW days and NHW days in the pre- and post-periods, additional analysis on RRs of the five health utilisation indicators was conducted. Further analysis on the severity of HW was also conducted, and RRs were calculated for the five health service utilisation indicators using the Bureau's 85^{th} percentile EHF for the two periods.

ED data was selected and used to identify populations and geographical locations vulnerable to HW related acute health service utilisation and the potential joint effect of HW and air quality on acute health service utilisation. To increase the statistical power of the analysis, ED data from 2006 to 2015 was included for the analysis. Poisson regression models and machine learning approaches (including decision tree and random forest) were used to select the most important risk factors and the most suitable models for predicting ED presentations. Spatial analyses (including geographical random forest (GRF)) were conducted to examine the geographic variations of the risk factors (i.e., HW, age groups, Aboriginal status, social economic status (SEIFA) and air quality). Detailed descriptions of these methods are outside the scope of this report but will be included in a separate final project report for the Telethon-Perth Children's Hospital Research Fund 2016 (Round 5). The root mean square error (RMSE), mean absolute error (MAE), and R-squared (R2) were used to determine the goodness of fit of the models. Validation was performed by comparing actual and predicted ED presentations.

3. Results

3.1 The lag effect of HW

The regression analysis examining how the Bureau's EHF was associated with cumulative health utilisation rates on Day-3 showed (Table 1) the greatest effect of HW on health service utilisation for the four health utilisation indicators except for all-cause hospitalisations, where the cumulative rate for Day-5 reached the highest. All these lag effects were statistically significant as all RRs are greater than 1 and all lower confidence limits for the 95% CIs are greater than 1. Therefore, the lag Day-3 was used in all subsequent analyses for assessing the associations between HW and health utilisation measures, except for all-cause hospitalisation data, where the lag Day-5 was used.

Table 1. Greatest significant lag effect days and RRs for each health service utilisation indicator

Health effect	Greatest significant lag effect days	RR (95% CI) (based on the Bureau's EHF)
All-cause ED presentations	3	1.021 (1.018, 1.024)
Heat-related ED presentations	3	3.047 (2.851, 3.307)
All-cause hospitalisations	5	1.018 (1.015, 1.022)
Heat-related hospitalisations	3	3.188 (2.822, 3.581)
All-cause mortality	3	1.028 (1.007, 1.048)

RR: rate ratio; CI: confidence interval. EHF: excess heat factor. ED: emergency department. In the regression models, cumulative health utilisation rates were used as dependent variables and HW (Yes/No) as an independent variable.

3.2 Number of HW days by different HW measurements

Table 2 presents the number of HW days by year and period based on the two EHF measurements. When WA DOH's 3DAT was used, only one HW day was identified in the pre-period and no HW days in the post-period. Compared with WA DOH's EHF definition, more HW days were identified using the Bureau's EHF measurement. Based on the Bureau's EHF measurement, there were a total of 58 HW events (days) during the pre-period and 45 in the post-period. Table 2 also shows that using the various Bureau's EHF percentile cut-offs results in different numbers of HW events. The higher the percentile, the fewer the number of HW events. When the 95th EHF percentile was used, only 2 HW events were identified during the pre-period and no HW events were identified during the post-period.

Table 2. Number of HW days by year, period and HW definitions in Perth, 2009–2015

Year	DOH	The Bureau					
	3DAT*	EHF	70thEHF	75thEHF	80thEHF	85thEHF	95thEHF
2009	0	9	1	1	1	0	0
2010	1	21	10	7	5	5	2
2011	0	28	4	3	3	1	0
2009–2011	**1**	**58**	**15**	**11**	**9**	**6**	**2**
2013	0	16	6	5	4	3	0
2014	0	15	4	4	2	1	0
2015	0	14	3	2	1	0	0
2013–2015	**0**	**45**	**13**	**11**	**7**	**4**	**0**

* EHF: excess heat factor.
For the Bureau's EHF, when ≥ 50 per cent of SA3s had a HW on a day, the whole Perth metropolitan area was counted as a HW day. For calculating the severity of HW events, all EHF values >0 were included.
2012 data was not included as this year was used as a boundary year to separate pre- and post-periods.

3.3 Sensitivity of the Bureau's EHF cut-offs and health service utilisation

3.3.1 Comparison of health service utilisation between the pre- and post-periods by the Bureau's EHF cut-offs

Table 3 presents the rates of the five health service utilisation indicators during HW days in the pre- and post-periods using the Bureau's EHF percentile cut-offs. The rates with significant differences between the pre- and post-periods during HW days were highlighted in light green. While the heat-related ED presentation rates were significantly higher in the pre-period at the 80th and 85th percentiles of EHF, all other four indicators were significantly higher during the post-period at most cut-offs. Using the 80th percentile EHF, all five health indicators showed significant differences between the pre- and post-periods. While using the 85th percentile EHF, four health indicators had significant differences.

Table 3. Comparison of health service utilisation indicators (rate/100,000 population) between the pre- and post-periods during HW days defined by the Bureau's EHF cut-offs

HW measure	ED presentations all-cause		ED presentations heat-related		Hospitalisations all-cause		Hospitalisations heat-related		Mortality all-cause	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
EHF	76.21	79.67	0.12	0.13	27.03	27.74	0.03	0.06	1.49	1.47
70th EHF	76.34	80.23	0.18	0.16	26.26	28.07	0.03	0.09	1.44	1.45
75th EHF	74.33	79.68	0.19	0.15	26.00	28.34	0.04	0.08	1.39	1.46
80th EHF	71.83	79.14	0.19	0.13	25.78	28.44	0.04	0.08	1.38	1.55
85th EHF	72.80	79.20	0.21	0.14	26.10	29.41	0.05	0.08	1.37	1.59
95th EHF	67.79	73.58	0.36	0.76	24.46	26.40	0.08	-	1.44	0.76

EHF: excess heat factor; Pre: pre-period 2009–2011; Post: post-period 2013–2015.

The light green colour cells denote the rates with significant differences between the pre- and post- periods during HW days.

3.3.2 Comparison of health service utilisation between the pre- and post-periods by different HW severities of the Bureau's EHF cut-offs

Table 4 presents the results of the dose-response relationships between the severities (SHW, MHW and NHW) of the Bureau's EHF cut-offs and the health service utilisation indicators. Cells shaded in light green represent significantly higher rates on severe or mild HW days compared to NHW days.

For rates of heat-related ED presentations and heat-related hospitalisations, there were significant dose-response relationships among different severity levels of HW during the pre- and post-periods at all EHF cut-offs. The rates for all-cause ED presentations and all-cause hospitalisations showed similar patterns but were less significant, and these results weren't included in Table 4.

During the pre-period, there were no statistically significant differences in all-cause mortality rates among different HW severities. While in the post-period, there were significant increases in all-cause mortality rates for SHW or MHW compared with NHW. At the 85th EHF percentile, there was a significant dose-response relationship between the HW intensity (NHW, MHW and SHW) and the mortality rates. In other words, with the increase in HW intensity, the all-cause mortality rates increased significantly at the 85th percentile of EHF.

Table 4. Comparison of 3 health service utilisation rates (/100,000) between severe, mild HW days and NHW days in the pre- and post-periods by the Bureau's EHF cut-offs

	Heat-related ED presentations						Heat-related hospitalisations						All-cause mortality					
	Pre-period			Post-period			Pre-period			Post-period			pre-period			post-period		
	SHW	MHW	NHW	SHW	MHW	NHW	SHW	MHW	NHW	SHW	MHW	NHW	SHW	MHW	NHW	SHW	MHW	NHW
70th EHF	0.178	0.099	0.043	0.155	0.115	0.042	0.034	0.029	0.011	0.086	0.049	0.020	1.44	1.50	1.48	1.45	1.47	1.4
75th EHF	0.190	0.102	0.043	0.151	0.120	0.042	0.039	0.029	0.011	0.082	0.053	0.020	1.39	1.51	1.48	1.46	1.47	1.4
80th EHF	0.193	0.105	0.043	0.125	0.128	0.042	0.043	0.028	0.011	0.081	0.056	0.020	1.38	1.51	1.48	1.55	1.45	1.4
85th EHF	0.214	0.106	0.043	0.141	0.126	0.042	0.048	0.028	0.011	0.077	0.058	0.020	1.37	1.50	1.48	1.59	1.46	1.4
95th EHF	0.359	0.110	0.043	0	0.127	0.042	0.079	0.029	0.011	0	0.060	0.020	1.44	1.49	1.48	0	1.47	1.4

ED: emergency department; EHF: excess heat factor; HW: heatwave; SHW: severe heatwave; MHW: mild heatwave; NHW: non-heatwave; Pre-period: 2009–2011; Post-period: 2013–2015.

Cells in green shade denote that the rate was significantly higher during severe or mild heatwave days compared to NHW days.

Note: there was no SHW during the post period.

3.4 Comparison between the Bureau's 85th percentile EHF and DOH's 3DAT for triggering the SHP-HW activation plan

3.4.1 Selection of the Bureau's 85th percentile EHF

The results from the sensitivity analysis showed that the 80th and 85th percentile EHFs were the most appropriate triggers among all percentile cut-offs for the activation of the SHP-HW Plan. These two percentiles were sensitive enough to detect the differences between the five health utilisation indicators, including the all-cause mortality rate between the pre- and post-periods during HW days as well as the difference between HW and NHW days. This outcome was supported by the Centre for Australian Weather and Climate Research technical report [3], in which the 85th percentile of the EHF value was used to represent the severe HW threshold. Nationally, in a research project led by the Bureau in 2014 HW, forecasting methods for the whole of Australia were explored (http://www.bom.gov.au/australia/heatwave/). In the project, the Bureau's EHF measurement and severity classifications (mild, severe, and extreme) were used where the 85th percentile EHF was adopted to represent the severe HW threshold. This resource can be potentially used in WA to identify hotspot areas for HW forecasting. To facilitate the smooth transition to the national HW service system, we selected the Bureau's 85th percentile EHF (severe HW) as the trigger point for the activation of the HW response in WA and conducted further analysis on rate ratios of HW related health service utilisation for the same five health indicators.

3.4.2 Comparison of HW related health service utilisation (RRs) during the pre- and post-periods by the Bureau's 85th percentile EHF and DOH's 3DAT

Using the Bureau's 85th percentile EHF and DOH's 3DAT, Figure 2 shows the associations between HW and RRs (RR = rate in HW days/rate in NHW days) of the five health service utilisation indicators in the pre- period (left) and post-period (right), respectively. The vertical solid line equals to a RR value of 1, indicating the rate during HW days is the same as that in NHW days. If an indicator's RR value is greater than 1, it means that the rate during HW days is higher than that in NHW days. The left- and right-hand side ends of the horizontal bars denote the lower and upper 95% confidence intervals (CIs). If the lower CI value of an indicator is greater than 1, it means the rate of that indicator is significantly higher during HW days compared to that during NHW days. The square in the middle of the bar is the RR value of the indicator.

During the pre-period, there were significantly higher rates of heat-related hospitalisations and heat-related ED presentations in HW days compared to NHW days using both the Bureau and DOH WA measurements. No HWs were identified during the post-period using DOH WA's measurement. However, using the Bureau's 85th percentile EHF, we were able to identify HW events and assess the RRs for heat-related health outcomes in the post-period. The rates of heat-related hospitalisations and heat-related ED presentations remained significantly high, and the rates of all-cause hospitalisations and mortality increased significantly during HW days as compared with NHW days in the post-period.

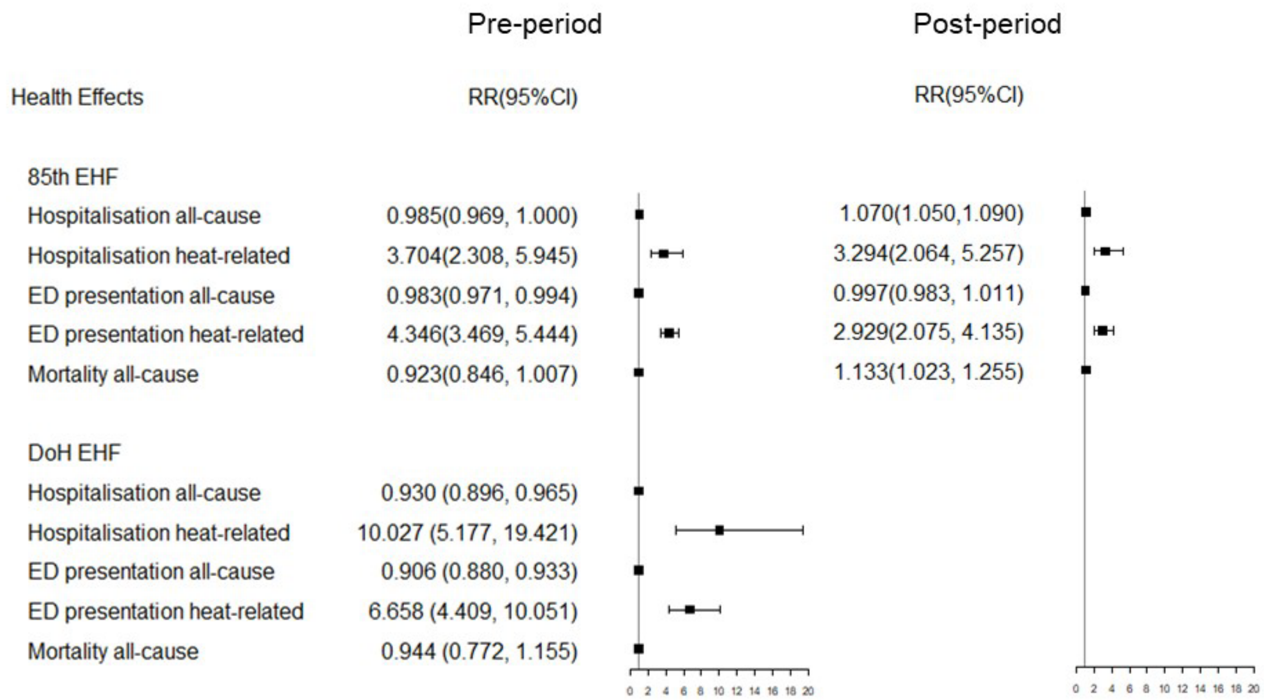

Figure 2. Health effects during HW days compared with NHW days by the Bureau's 85th percentile EHF and DOH's 3DAT in the pre- and post-periods

RR = rate in HW days /rate in NHW days

3.4.3 Effects of HW intensity on health service utilisation by the Bureau's 85th percentile of EHF

The effect of HW intensity on the RRs (rates in HW days/rates in NHW days) of the five health service utilisation indicators during the pre- and post-periods is depicted in Figure 3. Overall, most indicators showed increased RRs of health service utilisation indicators in MHW (left) and SHW (right) days during the pre- and post-period.

During the pre-period, compared with NHW days, there were significantly higher rates of all-cause hospitalisations, all-cause ED presentations, heat-related hospitalisations, and heat-related ED presentations in MHW days. The rates of heat-related hospitalisations and heat-related ED presentations were more than twice higher as those in NHW days. When HW intensity increased from MHW to SHW, the RR of heat-related ED presentations in SHW days (4.957, 95% CI: 3.951-6.220) was significantly higher than that in MHW days (2.457, 95% CI: 2.159-2.796). These results indicated significant dose-response relationships between HW intensity and heat-related health service indicators (hospitalisations and ED presentations). The higher the HW intensity, the higher the heat-related health service utilisation rates.

During the post-period, not only heat-related hospitalisations and heat-related ED presentations but also all-cause hospitalisations and all-cause mortality rates showed dose-response relationships with significantly increased rates during SHW days as compared with NHW days and MHW days as compared with NHW days.

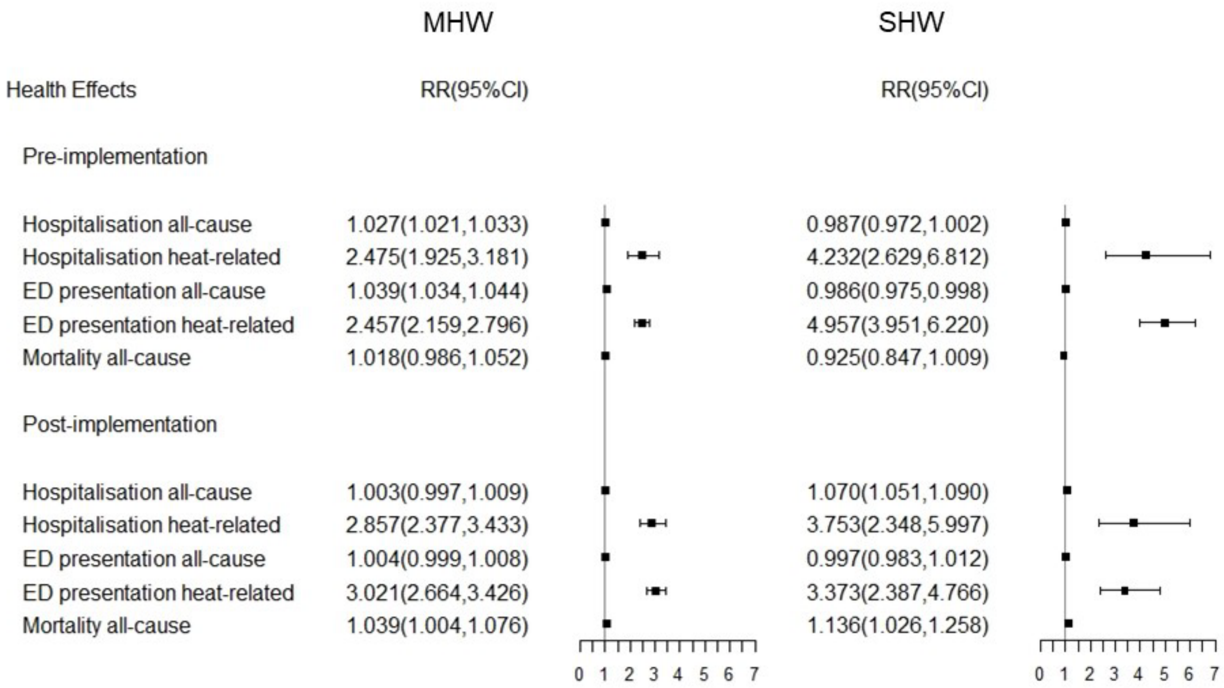

Figure 3. Effects of HW severity on health service utilisation indicators by the Bureau's 85th EHF in the pre- and post-periods

3.5 Identify vulnerable populations and locations for ED presentations

3.5.1 Results from Poisson regression models

Table 5 presents the significant impact of HW, age groups, Aboriginal status, and social economic status (SEIFA) on all-cause ED presentations after adjusting for other risk factors. During HW days, there was a 4.2 per cent (95% CI: 2.9, 5.6) increase in ED presentations compared to NHW days. The most vulnerable groups included those aged 0–4 years old and senior populations aged 60 and above, after adjusting for the other risk factors in the model.

Table 5. Impact of HW, age and other important risk factors on all cause ED presentations, Perth, WA, 2006–2015

Risk factors	Category	Joint effect	RR (95% CI)	P value
HW	HW day		1.042 (1.029,1.056)	<.0001
	Non HW day*			
Age group	0–4y		2.306 (2.297,2.315)	<.0001
	5–9y		1.072 (1.067,1.076)	<.0001
	15–59y		1.068 (1.065,1.072)	<.0001
	60+y		1.488 (1.483,1.494)	<.0001
	10–14y*			
Aboriginality	Aboriginal		1.901 (1.894,1.908)	<.0001
	Non-Aboriginal *			
SEIFA	Disadvantaged		1.712 (1.709,1.715)	<.0001
	Middle		1.295 (1.292,1.297)	<.0001
	Least disadvantaged*			

$PM_{2.5}$: particulate matter with aerodynamic diameter ≤2.5 micrometres; RR: relative risk; CI: confidence interval; SEIFA: socio-economic index for areas; * reference category
Other risk factors adjusted in the model but not included in the table: sex, weather zone, holiday and weekend, and air quality indicators

3.5.2 Results from machine learning models

Several models were performed using a machine learning approach to estimate which model predicted ED presentations well. Among all the models examined for all age groups and children aged 0-4 years, the random forest model outperformed other models with the lowest error (RMSE and MAE values) and the highest R^2 for all age groups and young children.

Further analysis was conducted using the random forest model and 2006–2014 ED presentation data for all age groups and predicting ED presentations for 2015. Validation was then conducted by comparing results between the predicted and actual 2015 ED presentation data (Figure 4). The ED presentation counts were adjusted for population in the model, and the goodness of fit measure R^2 for the model was 0.953, indicating the model fitted the data extremely well.

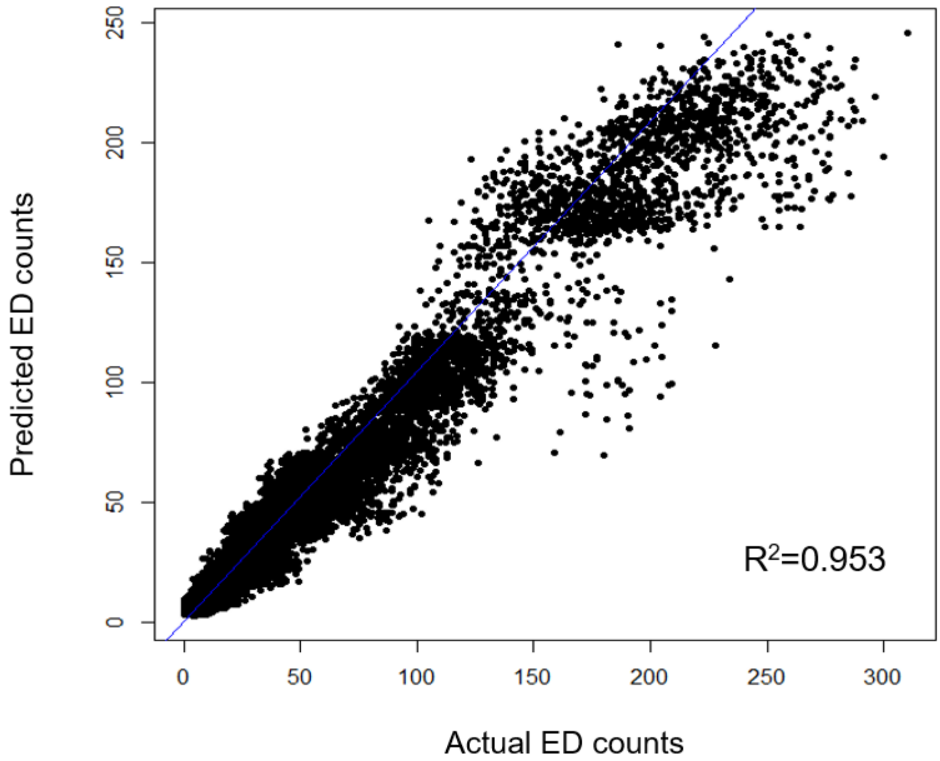

Figure 4. Comparison between predicted and actual values of ED presentation counts after adjusting for the 2015 population

Results of the variable importance ranking from the global random forest models for all age groups and young children (0–4 years) showed that age and socioeconomic status (SEIFA) were the two most important risk factors for predicting ED presentations. HWs also contributed to the increased ED presentations in both models.

Geographical random forest (GRF) is an extension of the global random forest that can identify spatial variations of the importance ranking for the risk factors in the model. Further analysis was conducted for young children using the eight risk factors (i.e., SEIFA, EHF, and six air quality indicators) by GRF models. The goodness of fit test revealed that the GRF model fitted the data relatively well with an R^2 value of 0.98. Overall, all the risk factors were relatively more important in the southern area than in other areas (Figure 5). HW and SEIFA were the two most important risk factors predicting ED presentations for children in the southern areas. There was a spatial interaction between EHF and SEIFA. Southern areas such as Mandurah, Serpentine–Jarrahdale and Kwinana were among the three areas most vulnerable to HW for all age groups, including children.

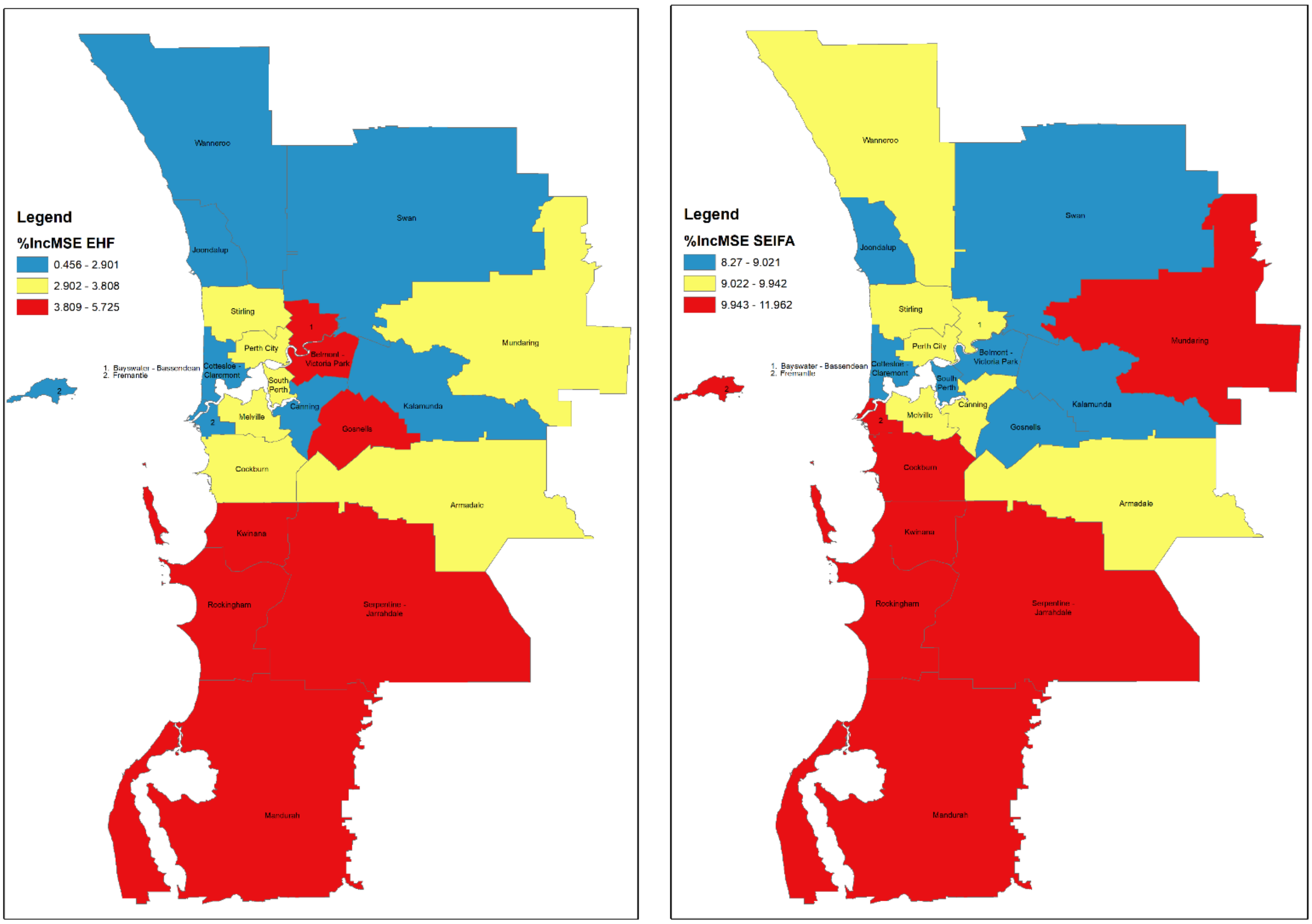

Figure 5. Important risk factors (HW & SEIFA) by SA3 for 0-4 years age group

%IncMSE= Percentage Increase in Mean Squared Error, the higher values imply increased importance.

4. Discussion

HW are becoming a common occurrence in Australia, more frequent and severe [1, 3, 4, 24]. Associated with these HW events is the anticipated rise in the number of heat-related health service utilisations such as hospitalisations, ED presentations, and deaths, and the consequential impacts on the community, infrastructure, and government services.

By using the WA DOH's 3DAT, only one HW event was identified in the pre-period (2009–2011) and no HW events were identified in the post-period (Table 2). However, using the Bureau's EHF definition, 58 HW events were identified in the pre-period and 45 HW events in the post-period. When compared with those identified by the Bureau's EHF, the HW severity level of the current 3DAT was similar to the Bureau's 98th or 99th EHF level. That means, on very rare occasions, the WA HW activation would be activated. However, the majority of HW events were mild (<85th EHF as defined by the Bureau). Therefore, the current HW activation trigger defined by 3DAT in the SHP-HW is not sensitive. It could not identify additional health service utilisation related to mild HW events.

Sensitivity analysis using the Bureau's EHF measurement showed that compared to the pre-period, the rates of the majority of health service indicators significantly increased (i.e., rates for all-cause ED presentations, all-cause hospitalisations, heat-related hospitalisations, and mortality) in the post-period (Table 3). Given that these health service indicators increased in the post-period and no HW events could be identified using the 3DAT trigger, it is obvious that HW management for the post-period would be problematic when the current trigger was applied.

Results from Table 3 also show comparison results for different cut-offs of EHF for the five health service indicators by the Bureau's HW measurement between the pre- and post-period. Among the chosen cut-offs, the 80th or 85th EHF is most suitable as a new trigger for activation of the SHP-HW Plan. Using these two percentiles, not only were significant differences in all-cause ED presentation rates and all-cause hospitalisation rates detected, but significant differences in heat-related ED presentation rates and all-cause mortality rates between the pre- and post-periods were also identified. Therefore, these two percentiles are more sensitive to detecting additional health service utilisation related to HW exposure.

There were significant dose-response relationships between HW severities and health service indicators displayed in Table 4, in particular, for heat-related ED presentations and heat-related hospitalisations. At the 85th percentile EHF, all-cause mortality showed clear dose-response relationships at all levels. These results provided further evidence for selecting the most suitable triggers for the HW response plan.

Because the 85th percentile of all positive EHF was suggested by the Bureau as a representative cut-off point at which a HW event is considered severe [25], we did further analysis on RRs using the Bureau's 85th percentile EHF and compared it with DOH's EHF. During the pre-period, compared to NHW days, significantly higher rates of heat-related hospitalisations and heat-related ED presentations were found during HW days using both definitions, although using DOH's EHF resulted in wider CI ranges. During the post-period, by using the Bureau's 85th percentile EHF, significantly higher rates of all-cause hospitalisations, heat-related health outcomes, and all-cause mortality were observed compared with NHW days (Figure 2). The Bureau's EHF was also sensitive to detecting significantly higher risks when the HW days were classified either as mild or severe (Figure 3). The dose-response relationship results using the 85th EHF further suggested its usefulness as the recommended trigger for SHP-HW activation.

Based on the above outcomes, using the new trigger (the Bureau's 85th EHF) could effectively predict HW events that would have significant impacts on the WA health system. Using this new trigger, the WA DOH could be well prepared for the likelihood of increased health service utilisation related to HW. This would help manage and reduce the adverse impacts of HW on WA residents.

In previous heat-related health studies, age was identified as one of the important demographic factors [26, 27]. In the SHP-HW Plan, only people over 65 years old were listed as vulnerable populations to HW on the list of vulnerable locations "impacted by environmental factors". The Poisson regression and machine learning approaches used in the current study showed that age was the most important risk factor for predicting ED presentations. Vulnerable populations include people aged 60 years and over and children aged 0–4 years. As confirmed in the global and local random forest models, another important demographic risk factor, SEIFA, was missed from the list of vulnerable locations "impacted by environmental factors" in the SHP-HW Plan.

The geographical random forest (GRF) model (an extension of the random forest algorithm) is a novel method to assess local variations of outcomes. To our knowledge, this is the first study using this method to assess the impact of HW and other risk factors on health and to predict geographic variation in ED service demand. Using various GRF models, HW was identified as the second most important risk factor after SEIFA. Mandurah, Serpentine–Jarrahdale and Kwinana were identified as the three areas most vulnerable to HW (Figure 5). Moreover, there was a spatial interaction between HW, $PM_{2.5}$, and SEIFA.

Currently, the national HW forecasting system (http://www.bom.gov.au/australia/heatwave/) is in the operation phase. This new HW forecast service runs each year from October to the end of March and provides town based HW data and HW assessment raster data via map services on a daily basis. The map shows the location of HW and the level of intensity, including NHW, low-intensity HW, severe HW, and extreme HW. It uses a simple method where HW can be determined empirically from observation of the severity category. WA DOH can benefit from using such an available free resource to identify HW timely and notify the affected local government areas in WA.

5. Conclusions and recommendations

Conclusions

Based on the findings of the project we conclude:

1. The current HW trigger defined in the SHP-HW for the Perth metropolitan area (i.e., a 3-day average daily temperature (3DAT) at 32 degrees Celsius and above) could only identify very rare extreme HW events.
2. The Bureau's EHF was more sensitive compared with the WA DOH's. During the pre-period, it could identify more HW events and additional heat-related health service utilisation than the one by WA DOH. During the post-period, HW events reduced but still could be identified by the Bureau's HW measurement.
3. The majority of HW events were mild. These mild HW events were identified as being associated with significant increases in ED presentations and hospitalisations. Severe HW events were even more strongly linked to increased health service utilisation.
4. When the Bureau's 85th EHF trigger was applied, not only did ED presentations and hospitalisations increase significantly, but also mortalities increased significantly.
5. The most significant lag effect of HW on health service utilisation was on day 3 of a HW event, but it can be longer than 3 days.
6. The study identified vulnerable populations and locations, including children aged 0–4 years, adults aged 60 years and over, Aboriginal people, those living in socio-economically disadvantaged areas, and southern areas (i.e. Mandurah, Kwinana, and Serpentine–Jarrahdale).
7. The Bureau's HW forecasting warning service is a good resource that can be used for WA to timely identify HW hotspots and severity.

Recommendations

To improve HW management and prevent HW related adverse health effects, we recommend the following:

1. Agencies responsible for HW management can consider the use of the Bureau's HW measurement, the Bureau's HW severity classifications, and the Bureau's 85th percentile EHF cut-off as the trigger for activation for effectively managing and preventing HW related adverse health effects in WA.
2. The health effects of HW exposure may appear and exist for longer periods than the HW days and may occur a few days after an HW event. This information is important for allocating sufficient resources (i.e., education, training, and infrastructure) for vulnerable populations and locations.
3. Agencies responsible for HW management can consider the inclusion of children aged 0–4 years old and those living in socio-economically disadvantaged areas in the "At Risk Population List".
4. The Bureau's HW forecasting operational resource—HW service for Australia can be used during warm months to timely and cost-effectively monitor HW hot spots, identify HW severity levels, activate responses and recovery plans in WA. It also has the potential to be used for predicting additional health service utilisation related to HW.

6. References

1. Commonwealth Scientific and Industrial Research Organisation (CSIRO). *The report-state of the climate 2014*. 2014 accessed 12.07.16]; Commonwealth Scientific and Industrial Research Organisation]. Available from: http://www.csiro.au/en/Research/OandA/Areas/Assessing-our-climate/State-of-the-Climate/2014-SoC-Report.
2. Steffen, W.L., L. Hughes, and S. Perkins, *Heatwaves: Hotter, Longer, More Often*. 2014: Climate Council of Australian.
3. Nairn, J.R., R.G. Fawcett, and K.A. Day, *Defining heatwaves: heatwave defined as a heat-impact event servicing all community and business sectors in Australia*. 2013, Melbourne: Centre for Australian Weather and Climate Research.
4. Coates, L. *An overview of fatalities from some natural hazards in Australia*. 1996. Barton, A.C.T.: Institution of Engineers, Australia.
5. Guo, Y., *Hourly associations between heat and ambulance calls.* Environmental Pollution, 2017. **220**: p. 1424-1428.
6. Linares, C., et al., *Effect of heat waves on morbidity and mortality due to Parkinson's disease in Madrid: A time-series analysis.* Environment International, 2016. **89-90**: p. 1-6.
7. Song, X., et al., *The impact of heat waves and cold spells on respiratory emergency department visits in Beijing, China.* Sci. Total Environ., 2018. **615**: p. 1499-1505.
8. Azhar, G.S., et al. *Heat-related mortality in India: excess all-cause mortality associated with the 2010 Ahmedabad heat wave*. PLoS ONE, 2014. **9**, e91831 DOI: 10.1371/journal.pone.0091831.
9. Yang, J., et al., *Impact of heat wave in 2005 on mortality in Guangzhou, China.* Biomed Environ Sci, 2013. **26**(8): p. 647-54.
10. Tong, S., et al. *The impact of heatwaves on mortality in Australia: a multicity study*. BMJ Open, 2014. **4**, e003579 DOI: 10.1136/bmjopen-2013-003579.
11. Boyson, C., S. Taylor, and L. Page, *The national heatwave plan - a brief evaluation of issues for frontline health staff.* PLoS currents, 2014. **6**.
12. Hess, J.J., et al., *Building Resilience to Climate Change: Pilot Evaluation of the Impact of India's First Heat Action Plan on All-Cause Mortality.* Journal of Environmental and Public Health, 2018. **2018**: p. 8.

13. Nitschke, M., et al., *Evaluation of a heat warning system in Adelaide, South Australia, using case-series analysis.* Bmj Open, 2016. **6**(7).
14. Scalley, B.D., et al., *Responding to heatwave intensity: Excess Heat Factor is a superior predictor of health service utilisation and a trigger for heatwave plans.* Aust N Z J Public Health, 2015. **39**(6): p. 582-587.
15. Kunst, A. and R. Britstra, *Implementation evaluation of the Dutch national heat plan among long-term care institutions in Amsterdam: a cross-sectional study.* BMC Health Services Research, 2013. **13**(1): p. 135.
16. DPMU Western Australian Department of Health, *State Emergency Management Plan for Heatwave*, The Western Australian Department of Health, Editor. 2012, Western Australian Department of Health: Perth.
17. DPMU Department of Health, *State Hazard Plan - Heatwave*, Department of Health (DPMU), Editor. 2021: Perth. p. 30.
18. Australian Bureau of Statistics (ABS). *Year book Australia, 2012*. 2012; Available from: http://www.abs.gov.au/ausstats/abs@.nsf/Lookup/by%20Subject/1301.0~2012~Main%20Features~Australia's%20climate~143.
19. Australian Bureau of Statistics (ABS). *Population by age and sex, regions of Australia, 2015*. 2016; Available from: http://www.abs.gov.au/AUSSTATS/abs@.nsf/Previousproducts/3235.0Main%20Features352015?opendocument&tabname=Summary&prodno=3235.0&issue=2015&num=&view=.
20. Australian Bureau of Statistics (ABS). *Australian Statistical Geography Standard (ASGS): Volume 1 - Main Structure and Greater Capital City Statistical Areas, July 2016*. 2016; Available from: https://www.abs.gov.au/ausstats/abs@.nsf/Lookup/by%20Subject/1270.0.55.001~July%202016~Main%20Features~Statistical%20Area%20Level%202%20(SA2)~10014.
21. Patel, D., et al., *Joint effect of heatwaves and air quality on emergency department attendances for vulnerable population in Perth, Western Australia, 2006 to 2015.* Environmental Research, 2019. **174**: p. 80-87.
22. Mesnard, L., *Pollution models and inverse distance weighting: Some critical remarks.* Computers and Geosciences, 2013. **52**: p. 459-469.
23. Wong, D.W., L. Yuan, and S.A. Perlin, *Comparison of spatial interpolation methods for the estimation of air quality data.* Journal of Exposure Science and Environmental Epidemiology, 2004. **14**(5): p. 404-415.

24. Coopers, P.W., *Protecting human health and safety during severe and extreme heat events: A national framework.* Commonwealth Government Report, Australia, 2011.
25. Nairn, J.R. and R.J.B. Fawcett, *The Excess Heat Factor: A Metric for Heatwave Intensity and Its Use in Classifying Heatwave Severity.* International Journal of Environmental Research and Public Health, 2015. **12**(1): p. 227-253.
26. Knowlton, K., et al., *The 2006 California heat wave: Impacts on hospitalizations and emergency department visits.* Environmental Health Perspectives, 2009. **117**(1): p. 61-67.
27. Schaffer, A., et al. *Emergency department visits, ambulance calls, and mortality associated with an exceptional heat wave in Sydney, Australia, 2011: a time-series analysis*. Environmental Health, 2012. **11**, DOI: 10.1186/1476-069X-11-3.

7. Appendices

Appendix 1: HW definitions

Heatwave definition	Inclusion criteria
DOH EHF	DOH EHF ≥32°C = HW day DOH EHF <32°C = NHW day
BOM EHF	BOM EHF >0 = HW day BOM EHF ≤0 = NHW day
70th EHF	BOM EHF ≥8.28 = HW day BOM EHF <8.28 = NHW day
75th EHF	BOM EHF ≥9.91 = HW day BOM EHF <9.91 = NHW day
80th EHF	BOM EHF ≥11.43 = HW day BOM EHF <11.43 = NHW day
85th EHF	BOM EHF ≥14.0 = HW day BOM EHF <14.0 = NHW day
95th EHF	BOM EHF ≥27.14 = HW day BOM EHF <27.14 = NHW day
70th EHF (3 levels severity)	BOM EHF ≥8.28 = SHW day BOM EHF >0 –< 8.28 = MHW day BOM EHF ≤0 = NHW day
75th EHF (3 levels severity)	BOM EHF ≥9.91 = SHW day BOM EHF >0 –< 9.91 = MHW day BOM EHF ≤0 = NHW day
80th EHF (3 levels severity)	BOM EHF ≥11.43 = SHW day BOM EHF >0 – <11.43 = MHW day BOM EHF ≤0 = NHW day
85th EHF (3 levels severity)	BOM EHF ≥14.0= SHW day BOM EHF> 0 – <14.0 = MHW day BOM EHF ≤0 = NHW day
95th EHF (3 levels severity)	BOM EHF ≥27.14 = SHW day BOM EHF >0 – <27.14 = MHW day BOM EHF ≤0 = NHW day

BOM: Bureau of meteorology; DOH: department of health; EHF: excess heat factor; HW: heatwave; NHW: non-heatwave

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