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Weather-Related Fatalities in Australia between 2006 and 2019: Applying an Equity Lens

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Abstract: Extreme weather events can cause significant human, economic and infrastructure losses. Within a changing climate, heatwaves, droughts, and floods are becoming more frequent and severe. Unfortunately, those who are most vulnerable are often disproportionately impacted. In this study, we examined the epidemiology of weather-related fatalities due to excessive heat (International Classification of Diseases [ICD]-10 codes X30); excessive cold (X31); storm and flood (X37; X38); and other causes (X32, X33, X39) in Australia between 2006–2019. There were 682 deaths due directly to weather-related events (41% excessive cold; 37% excessive heat; 15% storms and floods). The mean age of a weather-related victim in Australia was 60.8 years (SD = 24.1), with people aged 65+ years 12.8 times (95% confidence interval [CI]: 9.23–17.6) more likely to die due to a weather-related event. As the planet warms our study identifies declining excessive cold-related deaths, while other types of weather events remain steady or increase. In the context of climate change we must protect those most at risk; children and adolescents due to storms and floods, those with co-morbidities (particularly circulatory system disorders) and the elderly. Special attention should be paid to preventing excessive heat-related death among Aboriginal and Torres Strait Islander Peoples and international visitors.

Keywords: extreme weather; climate change; heat; cold; flood; storm; resilience; preparedness; co-morbidities; mortality

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1. Introduction

Climate change has numerous and wide-reaching impacts on human health, including respiratory and cardiovascular disease, injuries and premature death, food and water-borne illness and other infectious disease and mental health issues [1]. Disaster events, such as floods and storms are predicted to increase in frequency and severity due to the effects of climate change [2], as are the frequency and intensity of heatwaves [3]. Action on climate change, such as those measures outlined by the global community as part of the 2021 United Nations Climate Change Conference (COP26), including delivering on climate finance, stepping up support for adaptation and moving away from fossil fuels [4], are vital to reducing mortality, morbidity, infrastructure damage and economic harm due to extreme weather events. The need for action is pressing, as scientists predict Europe's death toll from weather disasters could rise 50-fold by the end of the 21st century [5]. Without action, a predicted 1.5 million people could die due to extreme heat alone per year within the same timeframe [5].

Australia as a continent is highly vulnerable to climate change and is regularly impacted by extreme weather events including floods, drought and heatwave exacerbating bushfires emergencies. Recent significant loss of life in Australia was experienced during the devastating Queensland floods, which resulted in the deaths of 33 people [6] and occurred in the context of prolonged drought [7]. Devastating bushfire emergencies have been experienced in Australia several times in recent years, with the 2019/20 bushfires burning through 46 million acres of land, destroying 3500 building and killing at least 34 people [8]. In this study an exploration of weather-related events as a cause of deaths is used to understand the impact of extreme weather on human health [9]. Such causes of death include heatwave, bushfire, drought, floods, storms, cyclones and excessive cold [10,11]. Weather-related events can have immediate physical and mental health impacts (such as injury and trauma incurred during the event) resulting in premature mortality and morbidity, and ongoing physical and mental health impacts leading to excess mortality and health system burden [12,13]. Researchers warn that further escalation to Australia's hot and erratic climate will lead to more extreme weather-related events, as well as shifts in disease burden [9]. These include a rise in infectious disease outbreaks following extreme rainfall events and climate-sensitive vector borne diseases impacted by rainfall and temperature changes [9].

Despite this vulnerability, there has been limited prior research on the topic of all-cause mortality due to extreme weather events in Australia. Studies have explored the impact of temperature on mortality, including extreme heat at a sub national level [14,15], and nationally to 2009 [16], as well as comparing heat- and cold-related mortality between Australia and the United Kingdom [17], however updated analyses, which includes other extreme weather events are required to inform preparation of plans to increase the community awareness and preparedness in the context of a changing climate. Such research can support recent calls for climate-health action plans [18] and, more broadly, action to reduce human and environmental impacts due to climate change [19].

Given Australia's vulnerability to extreme weather events, this study aimed to explore the epidemiology of weather-related fatalities in Australia to inform future risk reduction measures. This analysis examines both fatalities directly due to weather-related events (i.e., those where weather-related events were coded as the underlying cause of death) and fatalities where weather-related disasters were coded as having contributed to the fatality (i.e., a death with a primary code of ischaemic heart disease which was also coded as having occurred in the context of excessive heat). In conducting this analysis, we took an equity lens, given the impact that determinants of health can have on human health [20] and injury risk [21]. To that end, we also aimed to examined how risk of weather-related death varies by socio-demographic factors, namely geographical remoteness and socio-economic status.

2. Materials and Methods

This study explores underlying and contributory causes of death (up to 12 causes in the cause hierarchy from cause 1a) of Australian residents coded as weather-related events from 1 January 2006 to 31 December 2019. De-identified data on all-cause mortality was supplied by the Australian Bureau of Statistics (ABS; International Classification of Diseases [ICD]-10: A00-Z99). The dataset included information on usual area of residence, age, sex, Aboriginal and Torres Strait Islander Peoples, date of death, country of birth, length of stay in Australia, underlying cause of death and other causes of death. Usual area of residence was provided at the Statistical Areas Level 2 level (SA2) which is defined by the ABS as a functional area with an average of approximately 10,000 people, with a minimum of 3000 and a maximum of 25,000 people and represent communities that interact together economically and socially, with codes for those who do not reside (i.e., visitors) in Australia [22]. SA2 is then also used to describe remoteness, visitor status and socio-economic status.

Rurality was derived from SA2 level information using the Australian Statistical Geography Standard (ASGS), a measure based on relative access to services [23]. SA2 regions were categorized as Major Cities, Inner Regional, Outer Regional, Remote, or Very Remote [23]. Similarly, socioeconomic status was determined on the SA2 level based on the Index of Socio-economic Advantage and Disadvantage (IRSAD), a measure that is determined by a range of factors such as an individual's income, qualifications, and occupation [24]. Those in the 8–10th decile were considered highly advantaged, those in the 4–7th decile were considered middle advantage, and those in the 1–3rd decile were considered to be from a low level of advantage [24].

As the data were collected over a 14-year period, there were some changes in SA2 designation. SA2 regions that had a change in rurality designation were coded as their most current designation according to the ASGS.

Weather-related fatalities were defined via ICD-10 codes adopting the approach outlined by Thacker et al. [25] with some modification. Deaths due to earth movements (ICD-10 codes X34, X35) were excluded due to not being weather-related. There were only a small number of deaths during the study period in Australia where landslides and mudslides (X36) were an underlying or contributory cause (n = 4); these were not included as we could not determine if they were weather-related. Secondly, due to small numbers, deaths due to lightning (X33) and weather event not specified (X32, X39) were combined into an 'Other weather-related' category for analysis. These codes and categories are depicted in Table 1.

Table 1. International Classification of Diseases (ICD)-10 codes for classification of death associated with weather-related events, adapted from Thacker et al. [25].

Disaster Event	ICD-10 Codes	Categories Used for Analysis
Heat	X30 exposure to excessive natural heat	Heat
Cold	X31 exposure to excessive natural cold	Cold
Weather event not specified	X32 exposure to sunlight X39 exposure to other and unspecified forces of nature	Other
Lightning	X33 victim of lightning	Other
Storms and floods	X37 victim of cataclysmic storms (includes blizzards, tornadoes, and hurricanes) X38 victim of flood	Storms and Floods

For our analysis, we first looked for external cause codes that identified weather-related events (Table 1) in the underlying cause of death column and performed analysis on this grouping. We subsequently identified any additional fatalities (excluding those where weather-related codes were coded as the underlying cause of death) where weather-related codes appeared as a contributory cause of death (i.e., levels 2–12). There was only one case (n = 1) where two weather-related disaster codes appeared as contributory causes of death. In this instance, the first code which appeared was used for analysis.

Data were analysed using IBM Statistical Package for Social Sciences SPSS Version 25 [26]. Analysis comprised descriptive statistics and chi square tests of association, where significance was defined as $p < 0.05$ and $p < 0.001$ where a Bonferroni correction was applied, which corrects for cumulative Type 1 error [27]. Linear trends over time were calculated using Microsoft Excel. Relative risk (RR) and 95% confidence intervals were calculated using crude annual fatality rates per 100,000 population by sex and age group. Rates were calculated for residents only (excluding international visitors) using the Australian national population as at June of each included by year (2006–2019) by sex and age group [28] and by remoteness [29]. Population data for Aboriginal and Torres Strait Islander Peoples were sourced for 2006–2016 from census data [30] and from population projections for 2017–2019 [31] and combined. When RR was calculated, the group within the variable of interest with the lowest rate was used as the reference group.

Ethical approval was obtained from the Human Research Ethics Committee of James Cook University (Ethics Approval Number H6136). Due to ethical constraints and privacy concerns, cell counts <5 are not presented (NP).

3. Results

In total there were 1083 deaths due weather-related events in Australia across the study period; 484 (44.7%) due to excessive cold, 422 (39.0%) due to excessive heat, 103 (9.5%) due to storms and floods, and 74 (6.8%) due to other extreme-weather-related events. Of the 1083 deaths, 682 (63.0%) weather-related incidents were deemed to be the underlying cause of death and 401 (37.0%) where a weather-related code appeared as a contributory cause of death.

3.1. Fatalities Where Weather-Related Events Were the Underlying Cause of Death

Weather-related events accounted for 0.03% of all cause-mortality across the study period. The 682 deaths where a weather-related incident was an underlying cause equate to an annual average of 49 deaths per year. Temporal trends are depicted in Figure 1, with linear trend lines indicating that numbers of excessive heat-related deaths are steady across the study period (y = 0.022x + 17.835; $R^2 < 0.001$), the number of excessive cold-related deaths are declining (y = −2.0725x + 35.615; $R^2 = 0.626$), the number of storm and flood-related deaths have slightly declined (y = −0.1253x + 8.2967; $R^2 = 0.0039$) and the number of other weather-related deaths are steady (y= 0.0176x + 3.1538; R^2= 0.0009). (Figure 1)

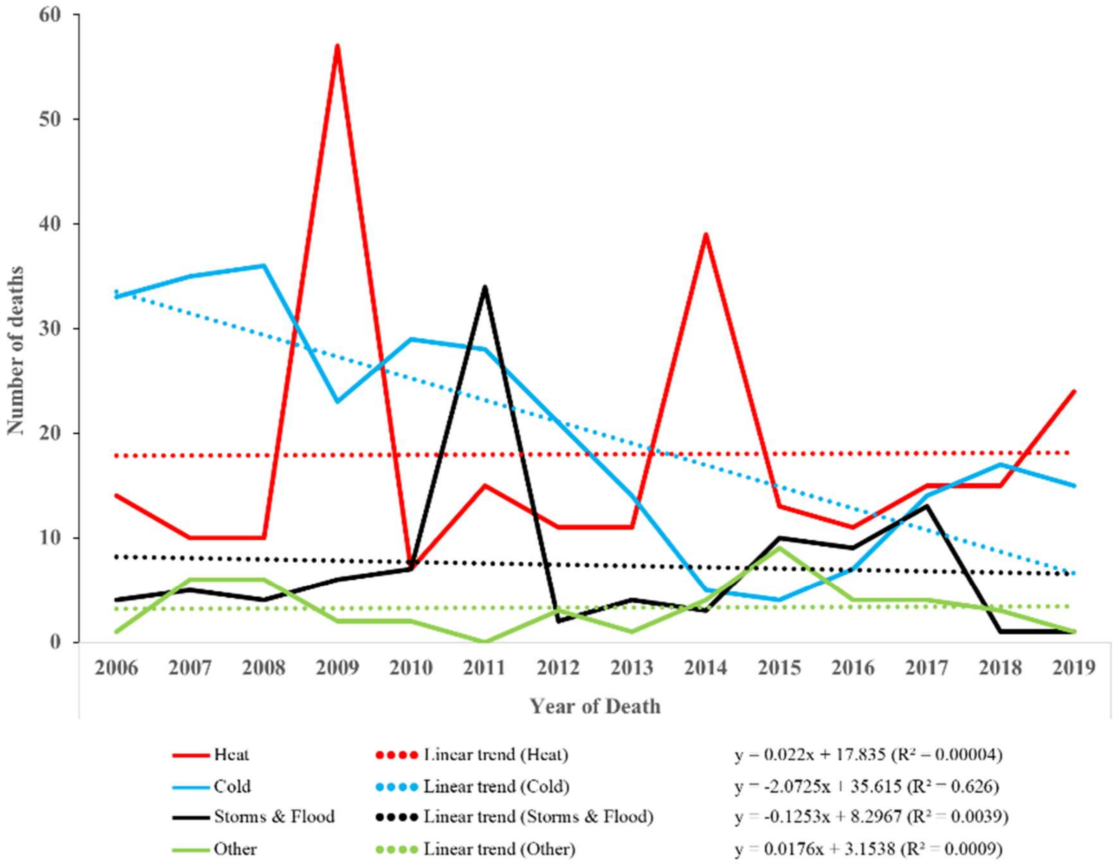

Figure 1. Temporal trends in deaths coded with weather-related codes as the underlying cause, Australia 2006–2019.

The largest proportion of deaths were due to excessive cold (41.2%; *n* = 281), followed by excessive heat (37.0%; *n* = 252), storms and floods (15.1%; *n* = 103) and other (6.7%; *n* = 46). Males accounted for 62.3% (*n* = 425) of all underlying cause weather-related deaths in Australia across the study period. Statistically significant differences were seen by sex and type of weather-related events, with males at greater risk of deaths due to storms and floods and other weather-related events when compared to females, and females more likely to die due to excessive heat and excessive cold ($X^2 = 8.922$; $p = 0.030$) than males (Table 2).

Table 2. Characteristics of underlying cause weather-related fatalities by category of weather X^2 (*p* value), Australia, 2006–2019.

Variable	Total (*n* = 682)	Heat (*n* = 252)	Cold (*n* = 281)	Storms & Flood (*n* = 103)	Other (*n* = 46)	X^2 (*p* Value)
Sex						
Female	257	99	115	34	9	8.922
Male	425	153	166	69	37	($p = 0.030$)
Age group						
0–17 years	43	24	0	18	NP	
18–39 years	92	43	15	19	15	116.204
40–64 years	203	79	71	34	19	($p < 0.001$)
65+ years	344	106	195	32	11	
Aboriginal and Torres Strait Islander Peoples						
Aboriginal and/or Torres Strait Islander	46	25	NP	13	5	25.542
Non-Indigenous	622	224	272	86	40	($p < 0.001$)
Not Stated	14	NP	6	NP	NP	-
Visitor Status						
Death in state of residence	633	217	276	101	39	43.419
Interstate Death	22	13	5	NP	NP	($p < 0.001$)
International visitor	27	22	0	0	5	
Remoteness classification of decedent resident location						
Major Cities	386	132	215	20	19	
Inner Regional	138	35	44	49	10	
Outer Regional	68	29	16	18	5	131.723
Remote	28	12	NP	9	NP	($p < 0.001$)
Very Remote	30	20	0	7	NP	
Usual residence overseas	27	22	0	0	5	
Usual residence unknown	5	NP	NP	0	NP	-
Index of Relative Socio-economic Advantage and Disadvantage (IRSAD) of decedent resident location						
Low	196	82	62	38	14	39.470
Mid	260	84	101	55	20	($p < 0.001$)
High	147	50	86	6	5	
Missing	79	36	32	NP	7	-
Season						
Summer (December–February)	283	185	14	62	22	
Autumn (March–May)	106	17	57	23	9	349.900
Winter (June–August)	182	7	157	14	NP	($p < 0.001$)
Spring (September–November)	111	43	53	NP	11	

The average age of a person who died due to a weather-related event in Australia was 60.8 years (SD = 24.1 years). There were significant between group differences seen in the mean ages of decedents by type of weather-related event (46.122; df = 3; $p < 0.001$), with decedents due to excessive cold significantly older (M = 72.2 years; SD = 17.1 years) than decedents who died due to excessive heat (M = 55.6 years; SD = 26.1), storms and floods (M = 47.5 years; SD= 23.6) and other weather-related events (M = 49.9 years; SD = 20.2).

Half of all underlying cause weather-related deaths occurred in those aged 65 years and older (50.4%; $n = 344$). People aged 65 years and over were significantly more likely to die due to excessive cold compared to those of other age groups, whereas younger people (0–17 years and 18–39 years) were more at risk due to excessive heat and floods and storms ($X^2 = 116.204$; $p < 0.001$). When compared to non-Indigenous people, Aboriginal and Torres Strait Islander Peoples were more likely to die due to excessive heat, while non-Indigenous people were identified as being at increased risk of dying due to excessive cold (X^2 = 25.542; $p < 0.001$). (Table 2)

The vast majority of weather-related decedents died in their Australian state or territory of residence (92.1%), with just 4.0% (n = 27) of decedents being international visitors. Those visiting from overseas were significantly more likely to die due to excessive heat compared to other categories, whereas local residents were more at risk of dying due to excessive cold and storms and floods (X^2 = 43.419; $p < 0.001$). (Table 2)

Risk of excessive cold related death was significantly higher in Major Cities compared to other remoteness classifications. The risk of death due to excessive heat was more common in Outer Regional, Remote and Very Remote areas, while risk of death due to storms and floods was more common in all remoteness classifications outside of Major Cities (X^2 = 175.053; $p < 0.001$). (Table 2)

Deaths due to excessive heat were more common in low IRSAD areas compared to areas classified as mid and high IRSAD, whereas deaths due to excessive cold were significantly more common in high IRSAD areas. Death due to storms and floods were more common in low and mid IRSAD areas (X^2 = 49.244; $p < 0.001$). (Table 2)

The largest proportion of underlying cause weather-related deaths occurred in the Summer months (n = 283; 41.5%), followed by Winter (n = 182; 26.7%). Unsurprisingly, excessive heat deaths were most common in Summer when compared to other seasons and excessive cold deaths most common in Winter (X^2 = 349.900; $p < 0.001$). There were, however, a small number of deaths due to excessive heat in Winter (n = 7) and excessive cold in Summer (n = 14). Sixty percent (60.2%) of all deaths due to storms and floods occurred in Summer (n = 62). (Table 2)

3.2. Fatality Rates of Australian Residents Where Weather-Related Events Were the Underlying Cause of Death

Of the 655 deaths of Australian residents where the underlying cause was an extreme weather-related event, the overall fatality rate was 0.21 per 100,000 population. Compared to females (who died due to a weather-related event at a rate of 0.15 per 100,000 population), males were 1.43 times more likely to die in a weather-related event (95%CI: 1.22–1.68). (Table 3)

Table 3. Number and crude rate per 100,000 resident population of Australian resident deaths due to weather-related events, Australia, 2006–2019.

Variable	Number of Resident Deaths	Rate/ 100,000 Population	RR (95% Confidence Interval [CI])
Sex			
Female	248	0.15	1
Male	407	0.22	1.43 (1.22–1.68)
Age group			
0–17 years	42	0.06	1
19–39 years	83	0.08	1.44 (0.99–2.09)
40–64 years	191	0.19	3.27 (2.34–4.57)
65+ years	339	0.74	12.78 (9.28–17.62)
Indigenous status			
Aboriginal and/or Torres Strait Islander Peoples	46	0.44	2.31 (1.71–3.11)
Non-Indigenous	595	0.19	1
Remoteness classification of decedent resident location			
Major Cities	386	0.17	1
Inner Regional	138	0.24	1.39 (1.14–1.69)
Outer Regional	68	0.24	1.43 (1.11–1.86)
Remote	28	0.67	3.97 (2.71–5.83)
Very Remote	30	1.06	6.23 (4.30–9.04)

Compared to the reference group (0–17 year-olds; crude weather-related fatality rate of 0.06 per 100,000 population), risk of death due to a weather-related events increased as people aged. The greatest risk was for those aged 65 years and older (a rate of 0.74 per 100,000 population) with a fatality rate almost 13 times higher (RR = 12.78; 95%CI: 9.28–17.62) than 0–17 year-olds. (Table 3)

Aboriginal and Torres Strait Islander Peoples died due to weather-related incidents at a rate of 0.44 / 100,000 population, double that of non-Indigenous Australians (RR = 2.31; 95%CI: 1.71–3.11). Fatality rates for weather-related events increased, the further decedents resided from major cities, with the risk greatest for residents of very remote areas (1.06 per 100,000 population; RR = 6.23; 95%CI: 4.30–9.04). (Table 3)

3.3. Fatalities Where Weather-Related Events Were a Contributory Cause of Death

There were a further 401 fatalities in Australia across the study period where a weather-related code appeared within any of the contributory causes of death. Among this, excessive cold-related codes appeared most commonly in 203 deaths, followed by excessive heat (n = 170). There were no deaths where storms and flood codes appeared in the contributory causes. Excessive heat was indicated as a contributory cause in 125 (61.9%) deaths due to disorders in the circulatory system. Of deaths due to external causes, 72.1% (n = 44) had a contributory cause of excessive cold. (Table 4)

Table 4. Weather-related contributory cause of death codes by category of condition of underlying cause of death, Australia, 2006–2019.

Category of Condition	Total (n = 401)	Heat (n = 170)	Cold (n = 203)	Storms & Flood (n = 0)	Other (n = 28)
Circulatory system	202	125	72	0	5
Digestive system	15	NP	12	0	0
Endocrine and metabolic	20	7	13	0	0
External cause	61	10	44	0	7
Genitourinary system	9	0	9	0	0
Infectious and parasitic	18	NP	16	0	0
Mental and behavioural	10	5	NP	0	NP
Musculoskeletal	NP	NP	NP	0	NP
Neoplasms	27	5	11	0	11
Nervous system	10	NP	6	0	NP
Respiratory system	22	9	12	0	NP
Skin	NP	0	NP	0	0

4. Discussion

Australia is a nation which is vulnerable to climate change and weather-related disasters [9], which impact physical and mental health, infrastructure and health system burden, while also resulting in economic harm [9]. This vulnerability has seen calls for climate-health action plans [18,19]. To inform risk reduction efforts, this study conducted an epidemiological analysis of weather-related fatalities in Australia between 2006 and 2019 and examined the impacts of equity on weather-related fatalities. We found mortality directly due to weather-related events is low in Australia, but greatest due to the effects of excessive cold and heat, with particular populations at increased risk.

Our analysis indicated that older people were most at risk than other age groups of weather-related disaster deaths in Australia, with people aged 65+ years or older almost 13 times more likely to die due to a weather-related event than children and young people aged 0–17 years. Evidence post-millennium from other disasters globally such as heatwaves, tsunamis, hurricanes and typhoons also indicate older people are disproportionately affected by disasters [32,33], as well as injury-related causes of death such as drowning [34] and falls [35]. Globally, previously published literature has pointed to poverty, chronic illness and psychological issues as underlying the vulnerability of older people to disasters [36]. With a globally aging population, there is a need to ensure weather-related event preparedness and mitigation strategies are developed which are specifically relevant to older people [37], who may have specific health needs, as well as challenges around mobility and technology [38].

The topic of technology raises important considerations regarding the most effective means of increasing community awareness around weather risks including early warning systems. Technology used includes traditional media, social media, radar, modelling and unmanned aerial vehicles (UAVs) [39,40]. While technology has no doubt advanced preparedness, there remains disparities in access and digital literacy between urban and rural areas [41], and also between young and older people [42]. A truly equitable approach to weather-related deaths in Australia must ensure those at-risk groups are adequately considered and planned for [32].

Despite age-related challenges facing older people, this cohort may also possess specific strengths which can assist in preparing for and dealing the aftermath of extreme weather events. Older age has been found to positively correlate with resilience [37,43]. Social capital and skills in community outreach have also been identified as contributing to resilience in face of weather-related disasters [44,45], including in research from rural Australia [46].

Those with poorer health are also more vulnerable to extreme weather [47]. Pre-existing medical conditions are likely to contribute to our finding of increased risk of death due to a weather-related event among those of older ages. Similarly, our exploratory analysis of deaths due to other causes where weather-related events were implicated as contributory highlights the role of poor health during times of extreme weather. The most common conditions were circulatory system disorders (often co-occurring with excessive heat) and external causes associated with excessive cold. In particular, the predominance of circulatory system disorders is seen in non-weather-related deaths in Australia [48] and indicates a group that may need targeted risk reduction measures, particularly in times of heat and heatwave [12]. Of note, there were no cases where storm and flood was a contributory cause indicating risk (and therefore prevention) of storm and flood deaths likely occurs outside the context of co-morbidities.

Aboriginal and Torres Strait Islander Peoples were identified as being at increased risk of death due to excessive heat in the present study, with 54.3% of all Indigenous deaths due to weather-related events being heat-related. Previous research has indicated that Aboriginal populations are disproportionately exposed to a range of climate extremes, including heat but also rainfall and drought [49]. However, Indigenous Australians also possess strong connection to country which may result in unique nature-based approaches to resilience and preparedness. Future weather-related deaths mitigation should consider Indigenous knowledge and ensure culturally appropriate and locally relevant approaches.

It is also known that socio-economic disadvantage, for Indigenous and non-Indigenous people alike, impacts capacity to adapt to climate change and associated weather-related events [49]. In light of this, our analysis took an equity lens to examine how risk of weather-related fatalities and excess mortality during weather-related events is impacted by the determinants of health of geographical remoteness and socioeconomic status [20]. We found elevated weather-related fatality rates as remoteness increased, with residents of very remote areas 6 times more likely to die in a weather-related event than residents of major cities. This increased risk for regional and remote residents in Australia is seen in other causes of mortality and morbidity [50,51] and likely indicates challenges in timely implementation of risk preparedness, mitigation and response across large distances and disparate populations. With Australia experiencing significant relocation of people during the COVID-19 pandemic from urban to regional and rural areas [52] there is a need to better understand the population impact in these areas and develop strategies for sustainability that do not place people in areas likely to be more susceptible to weather events, such as flooding.

Previous literature has reported urban area vulnerability to excessive heat and the impacts excessive heat has on residents of major city areas in Australia [33,53]. On the contrary to much of this research, our study identified significantly increased risk of death due to excessive cold in areas classified as major cities, while regional and remote Australia sees increased risk of death due to excessive heat. Of concern, much of the published literature regarding heat mitigation strategies appears to focus on urban areas [54,55] and the urban heat island phenomenon [56,57]. There remains an evidence gap on effective heat mitigation strategies for rural and remote Australia, with emerging evidence indicating poor housing design in new builds and a reliance on air conditioning [58]. In the context of increased frequency, severity and duration of heatwaves in Australia [59], this evidence is urgently needed.

Disproportionate risk of death due to weather-related events in regional and remote locations can often be compounded by socio-economic disadvantage [50]. In the current study, we found residents of low IRSAD areas (that is those areas experiencing higher socio-economic disadvantage) were more likely to die due to excessive heat, and, also at increased risk of death due to storms and floods. This mirrors research into health impacts from heatwave [12] and epidemiological studies of flood-related drowning and injury risk among children and young people in Australia [51,60]. Unsurprisingly, research has indicated that an individuals' disaster preparedness is defined by their ability to meet the costs of the disaster and their insurance coverage for damage sustained [61]. Therefore, those better able to prepare for disasters are those with greater financial capacity, regardless of disaster type. This can compound low socio-economic individual's vulnerability to disaster events. It is likely that other factors, such as ethnicity, gender, disability, and age, exist in tandem with low financial capacity, also contributing to increased risk in times of disaster [62]. As such, there is a need to ensure that those most at risk are supported, particularly during times of extreme weather. Working towards a sustainable future which reduces the impact of humans on climate is essential, noting the flow on effects to food, fiber and production [63].

There is a clear link between factors which impact equity such as economic, social, geographic, demographic, and cultural factors and exposure, and thus vulnerability, to weather-related deaths [64,65]. At a whole-of-population level, these links were clear in the findings of the current research, with greater risk seen in rural and low socioeconomic areas. There is, however, a need to better understand variance in exposure to weather-related events in Australia at a sub-national level, and by type of weather-related event. Such information is vital to designing and implementing effective adaptation and risk management strategies at the local level.

While international visitors accounted for only 4% of deaths due to weather-related events in Australia, our analysis indicated they were at significantly greater risk of death due to excessive heat. Tourists have been identified as an at-risk group for a range of injuries [66] and the field of travel medicine has been identified as a sector which can assist in tourist safety [67]. However, it is not well understood what advice is provided to tourists traveling to Australia regarding weather-related events. In the context of a warming climate [1], and as Australian international borders reopen to tourists post the relaxing of COVID-19 pandemic suppression strategies [68], now is an opportune time to conduct an audit of weather-related disaster information provided to tourists and ensure they are receiving sufficient information. The provision and content of such information may vary by tourist home continent (and susceptibility to heat), as well as location (such as tropical or cooler climates) and choice of activities in Australia.

This study could be seen as an indication of deaths due to weather-related disasters, however there is no disaster flag in the dataset. As such we have used the more cautious term of weather-related fatalities. We note that under the United Nations Office for Disaster Risk Reduction a disaster needs to disrupt the functioning of a community which leads to human, material, economic or environmental losses and impacts [69]. All of the deaths examined in this study could be considered disasters however without this flag, or more detail about the incident, we are unable to make this determination. There are opportunities for further research in this space, both to examine if misattribution of cause of death, or failure to include heat/weather as contributory factors are resulting in under-reporting. We recommend further work on weather-related excess mortality in order to more fully understand impacts on human health.

Strengths and Limitations

This study is the first to explore weather-related fatalities on a national scale in Australia and provides important insights about those at increased risk of death due to weather-related events in Australia, as well as excess mortality due to weather-related events. It provides useful information for future preparedness and mitigation in Australia. However, the findings must be considered in light of some limitations. The data presented within the study do not include deaths due to bushfires, a common weather-related hazard in Australia, nor deaths due to landslides as there were only a small number which occurred during the study period (n = 4) and we could not determine if they were weather-related or not. Analysis examining deaths where weather-related events were deemed to have contributed is interim in nature. Due to delays in death registration, there may be some deaths which occurred in the later months of 2019 which would have been registered in the 2020 year and are therefore not included in this study. Remoteness and IRSAD classifications are based on decedent's usual residence and do not reflect where the death occurred. Population data by IRSAD classification were not able to be located to include analyses on rates and RR by IRSAD. As previously indicated, further work is required to identify weather-related disasters in Australia, using standardized definitions, as well as quantify any misattribution leading to underreporting. Australia as a continent experiences a range of different climactic conditions [70] however, our analysis did not consider the differences in weather-elated mortality by climactic zones. This important topic represents an opportunity for further research. Additionally, although beyond the scope of this study, a geospatial analysis of weather-related fatalities may assist in preparedness planning at the community level.

5. Conclusions

There is an opportunity to better prevent weather-related disaster fatalities in Australia. This study has identified those at increased risk of weather-related disaster death, including people of older age, Aboriginal and Torres Strait Islander Peoples and residents of Very Remote areas. These findings highlight the need for an equity lens in developing weather-related preparedness and mitigation approaches for these populations. Within the context of a changing climate, preventing weather-related harms to human health has never been more important.

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References

1. Watts, N.; Amann, M.; Ayeb-Karlsson, S.; Belesova, K.; Bouley, T.; Boykoff, M.; Byass, P.; Cai, W.; Campbell-Lendrum, D.; Chambers, J.; et al. The Lancet Countdown on health and climate change: From 25 years of inaction to a global transformation for public health. *Lancet* **2018**, *391*, 581–630. [CrossRef] [PubMed]
2. Arias, P.; Dereczynski, C.; Alves, L.; Ruiz-Carrascal, D.; Rojas, M.; Sorensson, A.; Ruiz, L.; Vera, C. Climate change in South America: New insights from the most recent IPCC assessment report. *AGU Fall Meet.* **2021**, *2021*, GC51B-05.
3. Matthews, T.K.R.; Wilby, R.L.; Murphy, C. Communicating the deadly consequences of global warming for human heat stress. *Proc. Natl. Acad. Sci. USA* **2017**, *114*, 3861–3866. [CrossRef] [PubMed]
4. World Health Organization. COP26 Special Report on Climate Change and Health: The Health Argument for Climate Action. Available online: https://apps.who.int/iris/bitstream/handle/10665/346168/9789240036727-eng.pdf?sequence=1 (accessed on 29 September 2022).
5. Akhtar, R. Introduction: Extreme Weather Events and Human Health: A Global Perspective. In *Extreme Weather Events and Human Health: International Case Studies*; Akhtar, R., Ed.; Springer International Publishing: Cham, Switzerland, 2020; pp. 3–11.
6. Queensland Floods Commission of Inquiry. *Queensland Floods Commission of Inquiry—Final Report*; Government of Queensland: Queensland, Australia, 2012.
7. Ben Smee and agencies. Up to 500,000 drought-stressed cattle killed in Queensland floods. *The Guardian*, 11 February 2019.
8. Center for Disaster Philanthropy. 2019–2020 Australian Bushfires. Available online: https://disasterphilanthropy.org/disasters/2019-australian-wildfires/ (accessed on 26 November 2022).
9. Hanna, E.G.; McIver, L.J. Climate change: A brief overview of the science and health impacts for Australia. *Med. J. Aust.* **2018**, *208*, 311–315. [CrossRef]
10. Borchers Arriagada, N.; Bowman, D.M.J.S.; Palmer, A.J.; Johnston, F.H. Climate Change, Wildfires, Heatwaves and Health Impacts in Australia. In *Extreme Weather Events and Human Health: International Case Studies*; Akhtar, R., Ed.; Springer International Publishing: Cham, Switzerland, 2020; pp. 99–116.
11. Ashcroft, L.; Karoly, D.J.; Dowdy, A.J. Historical extreme rainfall events in southeastern Australia. *Weather Clim. Extrem.* **2019**, *25*, 100210. [CrossRef]
12. Mason, H.; King, J.C.; Peden, A.E.; Franklin, R.C. Systematic review of the impact of heatwaves on health service demand in Australia. *BMC Health Serv. Res.* **2022**, *22*, 960. [CrossRef]
13. Reifels, L.; Mills, K.; Dückers, M.L.A.; O'Donnell, M.L. Psychiatric epidemiology and disaster exposure in Australia. *Epidemiol. Psychiatr. Sci.* **2019**, *28*, 310–320. [CrossRef]
14. Yu, W.; Vaneckova, P.; Mengersen, K.; Pan, X.; Tong, S. Is the association between temperature and mortality modified by age, gender and socio-economic status? *Sci. Total Environ.* **2010**, *408*, 3513–3518. [CrossRef]
15. Schaffer, A.; Muscatello, D.; Broome, R.; Corbett, S.; Smith, W. Emergency department visits, ambulance calls, and mortality associated with an exceptional heat wave in Sydney, Australia, 2011: A time-series analysis. *Environ. Health* **2012**, *11*, 3. [CrossRef]
16. 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**, *651*, 2558–2565. [CrossRef]
17. Vardoulakis, S.; Dear, K.; Hajat, S.; Heaviside, C.; Eggen, B.; McMichael, A.J. Comparative assessment of the effects of climate change on heat-and cold-related mortality in the United Kingdom and Australia. *Environ. Health Perspect.* **2014**, *122*, 1285–1292. [CrossRef] [PubMed]
18. AAP. 'Climate Change is Already Killing Australians': Calls for Urgent Rollout of Climate-Health Action Plan. Available online: https://www.sbs.com.au/news/article/climate-change-is-already-killing-australians-calls-for-urgent-rollout-of-climate-health-action-plan/90ydswgl7 (accessed on 13 December 2022).
19. Royal Australasian College of Physicians. Climate Change and Health. Available online: https://www.racp.edu.au/advocacy/policy-and-advocacy-priorities/climate-change-and-health (accessed on 13 December 2022).
20. Marmot, M. Social determinants and the health of Indigenous Australians. *Med. J. Aust.* **2011**, *194*, 512–513. [CrossRef] [PubMed]
21. Peden, A.E.; Franklin, R.C. Child Injury Prevention: It Is Time to Address the Determinants of Health. *Children* **2021**, *8*, 46. [CrossRef]
22. Australian Bureau of Statistics. Statistical Area Level 2 (SA2). Available online: 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 (accessed on 15 September 2022).
23. Australian Bureau of Statistics. The Australian Statistical Geography Standard (ASGS) Remoteness Structure. Available online: https://www.abs.gov.au/websitedbs/d3310114.nsf/home/remoteness+structure (accessed on 15 February 2022).

24. Australian Bureau of Statistics. 2033.0.55.001—Census of Population and Housing: Socio-Economic Indexes for Areas (SEIFA), Australia. 2016. Available online: https://www.abs.gov.au/ausstats/abs@.nsf/Lookup/by%20Subject/2033.0.55.001~{}2016~{}Main%20Features~{}IRSAD~{}20 (accessed on 15 September 2022).
25. Thacker, M.T.F.; Lee, R.; Sabogal, R.I.; Henderson, A. Overview of deaths associated with natural events, United States, 1979–2004. *Disasters* **2008**, *32*, 303–315. [CrossRef] [PubMed]
26. IBM Corp. *IBM SPSS Statistics for Windows Version 25*; IBM Corp.: Armonk, NY, USA, 2020.
27. Keppel, G. *Design and Analysis: A Researcher's Handbook*, 3rd ed.; Prentice Hall: Englewood Cliffs, NJ, USA, 1991.
28. Australian Bureau of Statistics. Population—Australia by Sex and Single Year of Age. Available online: https://www.abs.gov.au/statistics/people/population/national-state-and-territory-population/mar-2022/3101059.xlsx (accessed on 14 October 2022).
29. Australian Bureau of Statistics. Population Estimates by Significant Urban Area and Remoteness Area (ASGC2016), 2001 to 2021. Available online: https://www.abs.gov.au/statistics/people/population/regional-population/2021/32180DS0004_2001-21.xlsx (accessed on 14 October 2022).
30. Australian Bureau of Statistics. Table 1: Estimated Resident Population, Aboriginal and Torres Strait Islander Australians, Australia, States and Territories by Sex—2006 to 2016. Available online: https://www.abs.gov.au/statistics/people/aboriginal-and-torres-strait-islander-peoples/estimates-and-projections-aboriginal-and-torres-strait-islander-australians/2006-2031#data-download (accessed on 14 October 2022).
31. Australian Bureau of Statistics. Stat Data Explorer—Projected Population, Aboriginal and Torres Strait Islander Australians, Australia, State and Territories, 2016 to 2031. Available online: https://explore.data.abs.gov.au/vis?fs[0]=People%2C0%7CAboriginal%20and%20Torres%20Strait%20Islander%20Peoples%23ATSIP%23&pg=0&fc=People&df[ds]=PEOPLE_TOPICS&df[id]=ABORIGINAL_POP_PROJ&df[ag]=ABS&df[vs]=1.0.0 (accessed on 14 October 2022).
32. International, H. Older People in Emergencies: Identifying and Reducing Risks. Available online: https://www.humanitarianlibrary.org/resource/older-people-emergencies-%E2%80%93-identifying-and-reducing-risks (accessed on 14 October 2022).
33. Vaneckova, P.; Beggs, P.J.; Jacobson, C.R. Spatial analysis of heat-related mortality among the elderly between 1993 and 2004 in Sydney, Australia. *Soc. Sci. Med.* **2010**, *70*, 293–304. [CrossRef]
34. Clemens, T.; Peden, A.E.; Franklin, R.C. Exploring a Hidden Epidemic: Drowning Among Adults Aged 65 Years and Older. *J. Aging Health* **2021**, *33*, 8982643211014770. [CrossRef]
35. James, S.L.; Castle, C.D.; Dingels, Z.V.; Fox, J.T.; Hamilton, E.B.; Liu, Z.; Roberts, N.L.S.; Sylte, D.O.; Henry, N.J.; LeGrand, K.E.; et al. Global injury morbidity and mortality from 1990 to 2017: Results from the Global Burden of Disease Study 2017. *Inj. Prev.* **2020**, *26*, i96–i114. [CrossRef]
36. Evans, J. Mapping the vulnerability of older persons to disasters. *Int. J. Older People Nurs.* **2010**, *5*, 63–70. [CrossRef]
37. Kwan, C.; Walsh, C.A. Seniors' disaster resilience: A scoping review of the literature. *Int. J. Disaster Risk Reduct.* **2017**, *25*, 259–273. [CrossRef]
38. Chan, E.Y.Y. *Disaster Public Health and Older People*; Routledge: Abingdon, Oxfordshire, UK, 2019.
39. Sakurai, M.; Murayama, Y. Information technologies and disaster management—Benefits and issues. *Prog. Disaster Sci.* **2019**, *2*, 100012. [CrossRef]
40. Khan, A.; Gupta, S.; Gupta, S.K. Emerging UAV technology for disaster detection, mitigation, response, and preparedness. *J. Field Robot.* **2022**, *39*, 905–955. [CrossRef]
41. Lai, C.-H.; Chib, A.; Ling, R. Digital disparities and vulnerability: Mobile phone use, information behaviour, and disaster preparedness in Southeast Asia. *Disasters* **2018**, *42*, 734–760. [CrossRef] [PubMed]
42. Brockie, L.; Miller, E. Older adults' disaster lifecycle experience of the 2011 and 2013 Queensland floods. *Int. J. Disaster Risk Reduct.* **2017**, *22*, 211–218. [CrossRef]
43. Timalsina, R.; Songwathana, P. Factors enhancing resilience among older adults experiencing disaster: A systematic review. *Australas. Emerg. Care* **2020**, *23*, 11–22. [CrossRef]
44. Brockie, L.; Miller, E. Understanding older adults' resilience during the Brisbane floods: Social capital, life experience, and optimism. *Disaster Med. Public Health Prep.* **2017**, *11*, 72–79. [CrossRef]
45. Lin, P.-S.S.; Chen, S.-S. Social networks for older people's resilient aging-in-place: Lessons from the post-landslide Ksunu tribe in Taiwan. *Int. J. Disaster Risk Reduct.* **2022**, *82*, 103336. [CrossRef]
46. Howard, A.; Blakemore, T.; Bevis, M. Older people as assets in disaster preparedness, response and recovery: Lessons from regional Australia. *Ageing Soc.* **2017**, *37*, 517–536. [CrossRef]
47. Benevolenza, M.A.; DeRigne, L. The impact of climate change and natural disasters on vulnerable populations: A systematic review of literature. *J. Hum. Behav. Soc. Environ.* **2019**, *29*, 266–281. [CrossRef]
48. Australian Bureau of Statistics. Underlying Causes of Death (Australia). Available online: https://www.abs.gov.au/statistics/health/causes-death/causes-death-australia/latest-release#data-download (accessed on 13 November 2020).
49. Standen, J.C.; Spencer, J.; Lee, G.W.; Van Buskirk, J.; Matthews, V.; Hanigan, I.; Boylan, S.; Jegasothy, E.; Breth-Petersen, M.; Morgan, G.G. Aboriginal Population and Climate Change in Australia: Implications for Health and Adaptation Planning. *Int. J. Environ. Res. Public Health* **2022**, *19*, 7502. [CrossRef]
50. Taylor, D.H.; Peden, A.E.; Franklin, R.C. Disadvantaged by More Than Distance: A Systematic Literature Review of Injury in Rural Australia. *Safety* **2022**, *8*, 66. [CrossRef]

51. Peden, A.E.; Franklin, R.C. Exploring Flood-Related Unintentional Fatal Drowning of Children and Adolescents Aged 0–19 Years in Australia. *Safety* **2019**, *5*, 46. [CrossRef]
52. Nygaard, C.A.; Parkinson, S. Analysing the impact of COVID-19 on urban transitions and urban-regional dynamics in Australia*. *Aust. J. Agric. Resour. Econ.* **2021**, *65*, 878–899. [CrossRef] [PubMed]
53. Santamouris, M.; Paolini, R.; Haddad, S.; Synnefa, A.; Garshasbi, S.; Hatvani-Kovacs, G.; Gobakis, K.; Yenneti, K.; Vasilakopoulou, K.; Feng, J.; et al. Heat mitigation technologies can improve sustainability in cities. An holistic experimental and numerical impact assessment of urban overheating and related heat mitigation strategies on energy consumption, indoor comfort, vulnerability and heat-related mortality and morbidity in cities. *Energy Build.* **2020**, *217*, 110002. [CrossRef]
54. Chen, D.; Wang, X.; Thatcher, M.; Barnett, G.; Kachenko, A.; Prince, R. Urban vegetation for reducing heat related mortality. *Environ. Pollut.* **2014**, *192*, 275–284. [CrossRef] [PubMed]
55. Yenneti, K.; Ding, L.; Prasad, D.; Ulpiani, G.; Paolini, R.; Haddad, S.; Santamouris, M. Urban Overheating and Cooling Potential in Australia: An Evidence-Based Review. *Climate* **2020**, *8*, 126. [CrossRef]
56. Imran, H.M.; Kala, J.; Ng, A.; Muthukumaran, S. Effectiveness of green and cool roofs in mitigating urban heat island effects during a heatwave event in the city of Melbourne in southeast Australia. *J. Clean. Prod.* **2018**, *197*, 393–405. [CrossRef]
57. Yang, J.; Santamouris, M. Urban Heat Island and mitigation technologies in Asian and Australian Cities—Impact and mitigation. *Urban Sci.* **2018**, *2*, 74. [CrossRef]
58. Loughnan, M.; Carroll, M.; Tapper, N.J. The relationship between housing and heat wave resilience in older people. *Int. J. Biometeorol.* **2015**, *59*, 1291–1298. [CrossRef]
59. Adnan, M.S.G.; Dewan, A.; Botje, D.; Shahid, S.; Hassan, Q.K. Vulnerability of Australia to heatwaves: A systematic review on influencing factors, impacts, and mitigation options. *Environ. Res.* **2022**, *213*, 113703. [CrossRef]
60. Peden, A.; Franklin, R.C. Exploring the Impact of Remoteness and Socio-Economic Status on Child and Adolescent Injury-Related Mortality in Australia. *Children* **2021**, *8*, 5. [CrossRef]
61. Boon, H. Preparedness and vulnerability: An issue of equity in Australian disaster situations. *Aust. J. Emerg. Manag.* **2013**, *28*, 12–16.
62. Howard, A.; Agllias, K.; Bevis, M.; Blakemore, T. How Social Isolation Affects Disaster Preparedness and Response in Australia: Implications for Social Work. *Aust. Soc. Work* **2018**, *71*, 392–404. [CrossRef]
63. Lade, S.J.; Steffen, W.; de Vries, W.; Carpenter, S.R.; Donges, J.F.; Gerten, D.; Hoff, H.; Newbold, T.; Richardson, K.; Rockström, J. Human impacts on planetary boundaries amplified by Earth system interactions. *Nat. Sustain.* **2020**, *3*, 119–128. [CrossRef]
64. Cardona, O.D.; Van Aalst, M.K.; Birkmann, J.; Fordham, M.; Mc Gregor, G.; Rosa, P.; Pulwarty, R.S.; Schipper, E.L.F.; Sinh, B.T.; Décamps, H. Determinants of risk: Exposure and vulnerability. In *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation: Special Report of the Intergovernmental Panel on Climate Change*; Cambridge University Press: Cambridge, UK, 2012; pp. 65–108.
65. Lindsay, J.R. The Determinants of Disaster Vulnerability: Achieving Sustainable Mitigation through Population Health. *Nat. Hazards* **2003**, *28*, 291–304. [CrossRef]
66. Franklin, R.C.; Miller, L.; Watt, K.; Leggat, P.A. Tourist injury. In *Tourist Health, Safety and Wellbeing in the New Normal*; Springer: New York, NY, USA, 2021; pp. 189–218.
67. Leggat, P.A. Travel medicine and tourist health. In *Tourist Health, Safety and Wellbeing in the New Normal*; Springer: New York, NY, USA, 2021; pp. 25–46.
68. Grozinger, P.; Parsons, S.J.B. *The COVID-19 Outbreak and Australia's Education and Tourism Exports*; RBA Bulletin; Reserve Bank of Australia: Canberra, Australia, December 2020.
69. United Nations Office for Disaster Risk Reduction. Terminology—Disaster. Available online: https://www.undrr.org/terminology/disaster (accessed on 31 October 2022).
70. Bureau of Meterology. Map of Climate Zones of Australia. Available online: http://www.bom.gov.au/climate/how/newproducts/images/zones.shtml (accessed on 26 November 2022).