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Causal Pathways of Flood Related River Drowning Deaths in Australia

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Citation

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Abstract

Introduction: Globally, flooding is the most common of all natural disasters and drowning is the leading cause of death during floods. In Australia, rivers are the most common location of drowning and experience flooding on a regular basis.

Methods: A cross-sectional, total population audit of all known unintentional river flood related fatal drownings in Australia between 1-July-2002 and 30-June-2012 was conducted to identify trends and causal factors.

Results: There were 129 (16.8%) deaths involving river flooding, representing a crude drowning rate of 0.06 per 100,000 people per annum. Half (55.8%) were due to slow onset flooding, 27.1% flash flooding and the type of flooding was unknown in 17.1% of cases. Those at an increased risk were males, children, driving (non-aquatic transport) and victims who were swept away ($p<0.01$). When compared to drownings in major cities, people in remote and very remote locations were 79.6 and 229.1 times respectively more likely to drown in river floods. Common causal factors for falls into flooded rivers included being alone and a blood alcohol content ≥0.05% (for adults). Non-aquatic transport incident victims were commonly the drivers of four wheel drive vehicles and were alone in the car, whilst attempting to reach their own home or a friend's.

Discussion: Flood related river drownings are preventable. Strategies for prevention must target causal factors such as being alone, influence of alcohol, type/size of vehicle, and intended destination. Strategies to be explored and evaluated include effective signage, early warning systems, alternate routes and public awareness for drivers.

Funding Statement

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Introduction

Floods are the most common of all natural disasters, and the leading cause of natural disaster deaths worldwide [1].The World Health Organization (WHO) estimates that globally, between 1980 and 2009, floods have claimed the lives of over 500,000 people [2]. Drowning is the leading cause of death during flood events [3], accounting for two-thirds of all deaths, followed by trauma [4].

Drowning risk changes during floods due to characteristics [5] such as: water depth, flow velocities and the rate of rising waters [6,7]; roadways being covered or cut off by water and debris [8]; and an increased amount of water in storm water drains and irrigation channels [9,10]. There is a need for prevention strategies to minimise risk of drowning during times of flood. Strategies proposed include: engineering measures to restrict access to floodwaters, particularly by motorists [11] and the use of public awareness and education measures [11]; as well as predictive modelling and early warning and evacuation procedures [5].

Australia has experienced significant flood events. One of the most devastating recent events was the Queensland floods of 2010/11 which affected 78% of the state and resulted in the deaths of 33 people, 21 in one flash flood event [12]. In Australia, rivers are the leading location for drowning [13] and slow onset floods from inland rivers are the most common, however most deaths occur due to flash flooding, often as a result of thunderstorms [14].

Rivers, with their variable environments [7] and significant contribution to the fatal drowning toll [13], require attention in order to develop effective prevention strategies. Unlike coastal waters, specifically rip currents [15,16,17], which have benefited from much research, flood related deaths (16.8% of all unintentional drowning deaths in rivers) have not benefited from such focus.

Population based research examining risk factors has been identified as a gap in the published literature for river drowning [18]. With the likelihood of floods increasing [1,19] there is a need to examine the epidemiology of river flood related drowning deaths in Australia. This paper represents the first total population cross-sectional study of all unintentional fatal river flood related drowning in Australia using coronial data.

Aims

This study aims to: Describe the incidence of unintentional fatal drowning during periods of river flooding in Australia between 1 July 2002 and 30 June 2012; discuss risk factors associated with river flood related drowning; and propose potential strategies for prevention.

Methods

Ethical approval for this study was provided by the Victorian Department of Justice and Regulation (Department of Justice and Regulation Human Research Ethics Committee – CF/15/13552) and James Cook University (James Cook University Human Research Ethics Committee – H6282). Informed consent has not been obtained as the human subjects involved in this research are deceased.

Unintentional fatal drowning in Australia is considered a 'reportable death' and cases of this nature are captured in the Australian National Coronial Information System (NCIS), an internet based data storage and retrieval system for Australian coronial cases. All cases of unintentional fatal river drowning between 1 July 2002 and 30 June 2012 were extracted from the NCIS and collated in a database. This includes populating a range of variables for each victim including sex, age, geographic location of drowning incident, residential location of drowning victim, activity being undertaken prior to drowning, involvement of alcohol and/or drugs, the presence of pre-existing medical conditions and ethnicity of the drowning victim. Cases in the NCIS remain open (i.e. under investigation) until a cause of death has been ruled by the coroner. At time of analysis, 93.4% of cases were closed (i.e. no longer under coronial investigation). For the open cases, data is correct as at 16 July 2016.

All cases within this study are either cases where the primary cause of death (Level 1a) was drowning or where drowning was a contributory cause of death (Level 1b to Level 3). Where an initial non-fatal drowning occurred and the victim subsequently died in hospital from the related effects of the immersion, these cases were included (no such victims in the flood-related cohort). Cases relate to unintentional drowning deaths that occurred in Australian rivers, creeks and streams only. Rivers, creeks and streams were defined as "A natural waterway that may be fed from other rivers or bodies of water draining water away from a 'catchment area' to another location…" and "can vary in water flow, length, width and depth…" [13].

Flooding for the purposes of this study was defined as comprising slow onset floods from inland rivers [7] and rapid on-set flash floods as a result of intense rainfall associated with thunderstorms [14]. The involvement of flooding was determined through information presented in the cause of death text field or narratives of the police report and/or coronial report (if available). Where available, cases coded to ICD-10 were also identified as being flood related if the external cause code X37.8 (other cataclysmic storms) and X38 (flood, sequela) was provided in the external data tab within the NCIS [20]. Data on the ICD10 code for deaths are identified by matching cases within the NCIS to the de-identified data provided through the Australian Bureau of Statistics (ABS) Causes of Death release [21]. Cases were identified as being flood-related with a 'yes' in the corresponding variable.

Drowning victims were coded into two groups (children or adults) based on their age. Children were defined as those aged 0-17 years and adults were defined as being aged 18 years and over. In Australia, 18 years is the age a child reaches adulthood for the purposes of the criminal law [22].

The remoteness classification of incident postcode was coded according to the Australian Standard Geographical Classification (ASGC) [23]. Postcodes are coded into one of five remoteness classifications based on a number of factors including distance from essential services [24].

Visitor status was calculated by determining the distance, in kilometres, between the residential and incident postcodes using Google Maps [25]. A distance of 100km or less was classified as 'Not A Visitor'; those who resided within the same State or Territory with a distance greater than 100km, were classified as an 'Intrastate Visitor'; those who drowned in a different State or Territory and were greater than 100km from where they resided were classified as 'Interstate Visitors'; and those with a residential postcode in the NCIS of 7777 (i.e. live overseas) were classified as 'Overseas Tourists'.

Time of day of drowning incident was coded into four groupings for analysis: morning (6:01am to 12pm), afternoon (12:01pm to 6pm), evening (6:01pm to 12am) and early morning (12:01am to 6am). For the time of incident variable, where time could not be determined a coding of 9999 (Unknown) was used.

Crude drowning rates per 100,000 population were calculated using population demographic data cubes from the Australian Bureau of Statistics (ABS) for the period June 2003 to June 2012 [26,27] and excluded international tourists. Drowning rates for people of Aboriginal or Torres Strait Islander descent were calculated using population estimates for 2002-2011 from the ABS [28]. Rates for country of birth and remoteness classification of incident location were calculated using a three yearly average from population data available from the three Australian population Census years 2001 [29], 2006 [30] and 2011 [31] and averaged to determine population and yearly drowning rate.

Due to difficulties around interpreting blood alcohol content (BAC) for drowning victims [32], alcohol involvement was deemed where a BAC was available (either in the autopsy or toxicology report) and was ≥0.05% (that is 0.05 grams of alcohol in every 100 millilitres of blood). Cases where alcohol was known to be consumed but no BAC was available were deemed Unknown for alcohol involvement.

Data coding and analysis was conducted in SPSS V20 [33]. Descriptive statistics were utilised, as well as chi squared analysis. A modified Bonferroni test suggested by Keppel [34] has been applied and statistical significance is deemed $p<0.03$. Relative risk (RR) was calculated, along with a 95% Confidence Interval (CI). Relative risk and chi squared analyses were conducted without the 'unknown' variable as it was assumed that this information was missing and no systematic bias was likely – e.g. presence of alcohol was calculated using the 'yes' and 'no' variables only. Where variable analysis presents cases of four or less, the term NP (not presented) has been used in the tables. Non-parametric chi squared analysis was also conducted using the proportional basis of the population as the assumed outcome numbers.

Causal factor analysis was conducted for river flood related drowning deaths as a result of the top three activities (falls, non-aquatic transport incidents, swept away; 83.7%). The narrative of the incident was analysed from the coronial finding. If the finding was unavailable, the police report narrative was used. If this was not available the autopsy report was used. The following new variables were added and coded from available data: For all cases – type of flood (flash or slow onset), if the victim was alone or with company and if the victim entered floodwaters intentionally or unintentionally. For drowning deaths due to falls into flooded rivers – what the victim fell from. For drownings as a result of being swept away by river floods – what the victim was swept from. For drowning deaths as a result of non-aquatic transport incidents involving river floods – if the victim was a driver or passenger, if the road was open or closed at the time of the incident, the victim's intended destination and the type of vehicle the victim was in when they drowned. The data was then visually depicted using flow charts developed with the assistance of a graphic designer. Initial coding was conducted by AEP, and then reviewed by RCF with cross-checking to ensure consistency by PAL.

Rates of non-aquatic transport flood related drowning per 100,000 registered vehicles were calculated using Australian vehicle registration data. Using the ABS Motor Vehicle Census [35], a 10 year average of registrations by vehicle type was calculated using data from 1-March-2003 to 1-March-2012 inclusive. Rates were calculated for passenger vehicles (car, four wheel drives (4WD)), light commercial vehicles (utilities), rigid trucks (heavy vehicles, machinery) and motorcycles (motorbikes, All Terrain Vehicles (ATVs)).

Results

Between 1 July 2002 and 30 June 2012, there were 770 drowning deaths in rivers, of which 129 (16.8%) were river flood related (Table 1). This represents a 10 year average drowning rate of 0.06 per 100,000 people per year (Figure 1). The number of deaths vary from a low of five deaths in 2002/03 to a high of 45 deaths in 2010/11, of which 21 (46.7%) occurred in a single flash flooding incident in the state of Queensland.

	Total		Flooding – Yes		Flooding – No		Flooding – Unknown		X^2 (p value) comparing flooding – yes to flooding – no
	N	%	N	%	N	%	N	%	
Total	770	100.0	129	16.8	485	63.0	156	20.3	
Sex									
Male	619	80.4	82	13.2	406	65.6	131	21.2	25.4 (p<0.001)
Female	151	19.6	47	31.1	79	52.3	25	16.6	
Age Group									
Children	113	14.7	30	26.5	65	57.5	18	15.9	7.6 (p=0.006)
Adults	657	85.3	99	15.1	420	63.9	138	21.0	
People of Aboriginal or Torres Strait Islander descent *									
Yes	82	10.6	15	18.3	46	56.1	21	25.6	0.5 (p=0.469)
No	688	89.4	114	16.6	439	63.8	135	19.6	
Visitor Status									
Not A Visitor	570	74.0	105	18.4	355	62.3	110	19.3	2.2 (p=0.140)
Visitor – Intrastate	110	14.3	21	19.1	68	61.8	21	19.1	0.3 (p=0.598)
Visitor – Interstate	46	6.0	NP	NP	29	63.0	15	32.6	4.4 (p=0.036)
Visitor – Overseas	21	2.7	0	0.0	16	76.2	5	23.8	
Visitor Status - Unknown	23	3.0	NP	NP	17	73.9	5	21.7	
Activity Immediately Prior to Drowning									
Falls	164	21.3	15	9.1	121	73.8	28	17.1	16.5 (p<0.001)
Non-aquatic Transport	140	18.2	71	50.7	47	33.6	22	15.7	110.0 (p<0.001)
Swept Away	23	3.0	22	95.7	0	0.0	NP	NP	73.3 (p<0.001)
Swimming and Recreating	125	16.2	9	7.2	91	72.8	25	20.0	14.9 (p<0.001)
Watercraft	123	13.9	5	4.1	84	68.3	18	14.6	19.5 (p<0.001)
Other	88	11.4	6	6.8	66	75.0	16	18.2	3.7 (p=0.054)
Unknown	107	16.0	NP	NP	76	71.0	46	43.0	
Presence of Alcohol (BAC ≥0.05%)									
Yes	196	25.5	26	13.3	132	67.3	38	19.4	3.2 (p=0.073)
No	321	41.7	64	19.9	205	63.9	52	16.2	
Unknown	253	32.9	39	15.4	148	58.5	66	26.1	
Time of Day									
Morning	147	19.1	26	17.7	91	61.9	30	20.4	0.6 (p=0.452)
Afternoon	321	41.7	52	16.2	220	68.5	49	15.3	0.1 (p=0.715)
Evening	160	20.8	27	16.9	95	59.4	38	23.8	0.6 (p=0.457)
Early Morning	77	10.0	8	10.4	53	68.8	16	20.8	1.9 (p=0.168)
Unknown	65	8.4	16	24.6	26	40.0	23	35.4	

^ compares flooding yes to flooding no; * 'Persons of Aboriginal or Torres Strait Islander descent – unknown have been combined with 'persons of Aboriginal or Torres Strait Islander descent – no' for the purposes of analysis. A modified Bonferroni test has been applied meaning statistical significance is deemed at p<0.03.

Table 1: River drowning deaths and flood related drowning deaths by sex, age group, people of Aboriginal or Torres Strait Islander descent, visitor status, activity immediately prior to drowning, remoteness classification of incident location, presence of alcohol (≥0.05mg/L) and time of day of drowning incident, Chi Squared (p value), Australia, 2002/03 to 2011/12 (N=770)

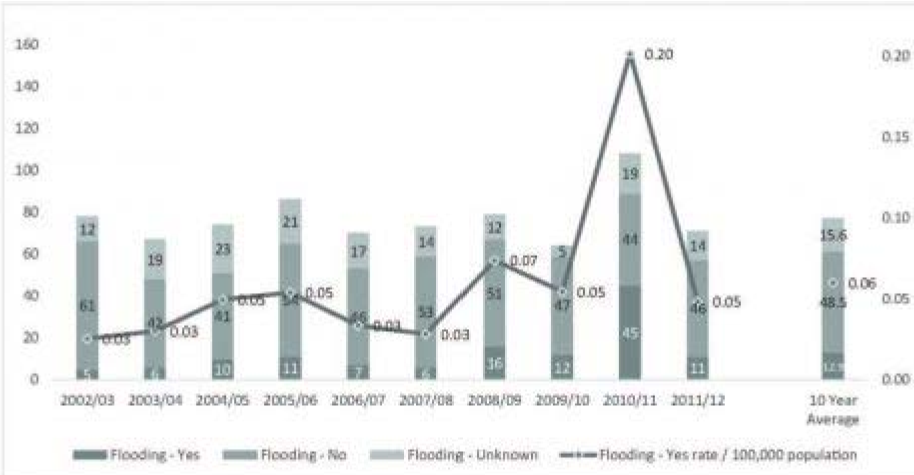

Fig. 1: Unintentional fatal drowning in rivers by flood status and financial year, number and crude rate per 100,000 population, Australia, 2002/03 to 2011/12 (N=770)

Slow onset flooding was involved in half (55.8%) of all river flood drowning deaths, 27.1% were as a result of flash flooding and type of flood was unknown in the remaining 22 cases. Males were significantly more likely to drown in river floods than females (χ^2= 9.9; p=0.002), accounting for almost two thirds (63.6%) of all drownings during river flooding (Table 2). Although a larger number of adults (n=99) drowned compared to children (n=30), children were significantly more likely to drown as a result of flooding (χ^2= 7.6; p=0.006). (Table 1) The 55-64 years age group recorded the largest number of river flood related drowning victims (n=20), however those aged 75+ years were 2.24 (CI: 0.13-38.24) times more likely to drown when compared to those aged 0-4 years. (Table 2)

	Flooding - Yes		Australian Population		RR (CI)	X^2 (p-value)
	Average per annum (n)	%	Annual population per annum over 10 years	Crude rate per 100,000 per annum		
Total	12.9	100.0	21114977	0.06		
Sex						
Male	8.2	63.6	10498797	0.08	1.76 (0.57-5.48)	9.9 (p=0.002)
Female	4.7	36.4	10616180	0.04	1	
Age Group						
0-4 years	0.7	5.4	1365812	0.05	1	15.9 (p=0.104)
5-9 years	0.7	5.4	1347529	0.05	1.01 (0.04-27.84)	
10-14 years	1.1	8.5	1383490	0.08	1.55 (0.08-31.06)	
15-17 years	0.5	3.9	843606.2	0.06	1.16 (0.03-43.58)	
18-24 years	0.6	4.7	2079371	0.03	0.56 (0.02-17.70)	
25-34 years	1.4	10.9	2992752	0.05	0.91 (0.05-16.08)	
35-44 years	1.8	14.0	3073163	0.06	1.14 (0.07-18.07)	
45-54 years	1.4	10.9	2894025	0.05	0.94 (0.05-16.63)	
55-64 years	2.0	15.5	2328123	0.09	1.68 (0.11-25.49)	
65-74 years	1.2	9.3	1500780	0.08	1.56 (0.08-29.74)	
75+ years	1.5	11.6	1306326	0.11	2.24 (0.13-38.24)	
People of Aboriginal or Torres Strait Islander descent * ^						
Yes	1.5	11.6	532309	0.28	5.25 (0.94-29.24)	37.3 (p<0.001)
No	9.9	76.7	18447158	0.05	1	
State or Territory of Drowning Death						
ACT	0.0	0.0	347360			183.5 (p<0.001)
NSW	2.9	22.5	6920872	0.04	1	
NT	1.2	9.3	217595	0.55	13.16 (1.57-110.47)	
QLD	6.9	53.5	4160860	0.17	3.96 (1.00-15.60)	
SA	0.0	0.0	1583108			
TAS	0.4	3.1	496584	0.08	1.92 (0.07-52.43)	
VIC	1.0	7.8	5226474	0.02	0.46 (0.05-4.43)	
WA	0.5	3.9	2159441	0.02	0.55 (0.03-11.11)	
Country of Birth ** ^^						
Australia	9.5	73.6	15216855	0.07	2.60 (0.39-17.39)	10.5 (p=0.001)
Outside Australia	1.2	9.3	5003784	0.02	1	
Remoteness Classification of Incident location						
Major Cities	1.0	7.8	13700034	0.02	1	996.9 (p<0.001)
Inner Regional	4.2	32.6	3926730	0.36	14.65 (1.65-129.74)	
Outer Regional	2.9	22.5	1937273	0.50	20.51 (2.11-199.09)	
Remote	1.8	14.0	309826	1.94	79.59 (6.91-917.33)	
Very Remote	3.0	23.3	179434	5.57	229.05 (23.82-2202.06)	

Note: Population information is calculated from June 2003 to June 2012 and is sourced from the Australian Bureau of Statistics (ABS). Data on Aboriginal or Torres Strait Islander population, Country of Birth and Remoteness Classification of incident location is calculated as three year averages from Australian Census years from 2001, 2006 and 2011. *There were 15 flood-related drowning deaths across the 10 years where Aboriginal or Torres Strait Islander descent was unknown. **There were 22 flood-related drowning deaths across the 10 years where country of birth was not known. ^ ^^ Population estimates drawn from different ABS data cubes

Table 2: Flood related drowning deaths average per annum and percentage, annual population and crude rate of drowning per annum by sex, age group, people of Aboriginal or Torres Strait Islander descent, state or territory of drowning death, country of birth and remoteness classification of incident location, relative risk (RR) and 95% confidence interval (CI), Chi Squared (p value), Australia, 2002/03 to 2011/12 (n=129).

People of Aboriginal or Torres Strait Islander descent were 5.25 times more likely to drown in floods than non-Indigenous flood victims (χ^2 =37.3; p<0.001). (Table 2). The state of New South Wales recorded the highest number of river flood related drowning deaths (n=29) however those who drowned in the Northern Territory and Queensland were 13.16 (p<0.001; CI: 1.57-110.47) times and 3.96 (p<0.001; CI: 1.00-15.60) times more likely to drown in flooded rivers compared to non-flooded rivers. (Table 2)

People born in Australia, were 2.60 (χ^2 =10.5; p=0.001) times more likely to drown during river flooding, compared to those born outside of Australia. (Table 2) The majority of victims were not visitors to the drowning location (81.4%). Visitor status of the victim was not found to increase drowning risk. There were no flood related drowning deaths among international tourists to Australia during the study period. (Table 1) There was an increased risk for those who drown in remote areas, with people in remote areas being 79.59 (p<0.001; CI: 6.91-917.33) times and those in very remote areas being 229.05 (p<0.001; CI: 23.82-2202.06) times more likely to drown during times of river flooding than those who drown in major cities. (Table 2)

River flood related drowning deaths most commonly occurred in the summer months (December to February) (55.8%) (χ^2= 20.4; p<0.001). Almost half of all flood related drowning deaths occurred in the afternoon (40.3%), with a further fifth (20.9%) occurring in the evening, however time of day was not found to be statistically significant. (Table 1) Alcohol (i.e. a BAC ≥0.05%) was known to be present in a fifth (20.2%) of river flood related drowning deaths, however the involvement of alcohol was not found to be statistically significant (Table 1). Males accounted for 76.9% of cases where alcohol was known to be present.

Non-aquatic transport incidents were the leading activity immediately prior to drowning, accounting for over half (55.0%) of all flood related drowning deaths (χ^2= 110.0; p<0.001), followed by being swept away by floodwaters 17.1% (χ^2= 73.3; p<0.001). The third leading activity prior to drowning was a fall into water (11.6%), however a fall was found to be significantly less likely to occur during times of flood when compared to drowning deaths in rivers not in flood (χ^2= 16.5; p<0.001). (Table 1) Males outnumbered females in all categories of activity immediately prior to drowning with the exception of the category of Swept Away (54.5% female), however sex was not found to be statistically significant by activity prior to drowning.

River flood related deaths as a result of non-aquatic transport incidents were more likely in winter (χ^2= 35.8; p<0.001) and more likely to occur on a Friday when compared to drowning as a result of other activities. For flood related drowning deaths in rivers, Monday was the most common day (24.0%) (χ^2= 9.1; p=0.002); however these were less likely to be related to non-aquatic transport incidents when compared to Friday (26.8% of all flood related non-aquatic transport incidents).The largest proportion of flood-related non-aquatic transport drowning deaths occurred in afternoon (38.0%), however time of day was not found to be statistically significant. Alcohol was known to be present in just over a fifth (21.1%) of all flood related non-aquatic transport incidents, however alcohol was not found to be statistically significant.

Causal factors

There were three main activities prior to drowning in floods, those who fell into water, those who were swept away and those who drowned as a result of non-aquatic transport incidents. Deaths as a result of these activities represented 83.7% of all river flood related drowning deaths.

Falls into water

There were 15 drowning deaths as a result of falls into water, 60.0% of which were adults, 73.3% were alone, 27.3% were children and alcohol was known to be involved in 26.7% (100.0% of which were adults). Common scenarios were children who either fell into floodwaters from the creek/river bank (33.3%) or whilst wading in the water (50.0%). Interestingly, two children were alone when they drowned, whilst another two were with company, however supervision had lapsed. For adults, common scenarios were being alone (72.7%) and falling from the creek/river bank (36.4%), two cases of which involved alcohol (Figure 2).

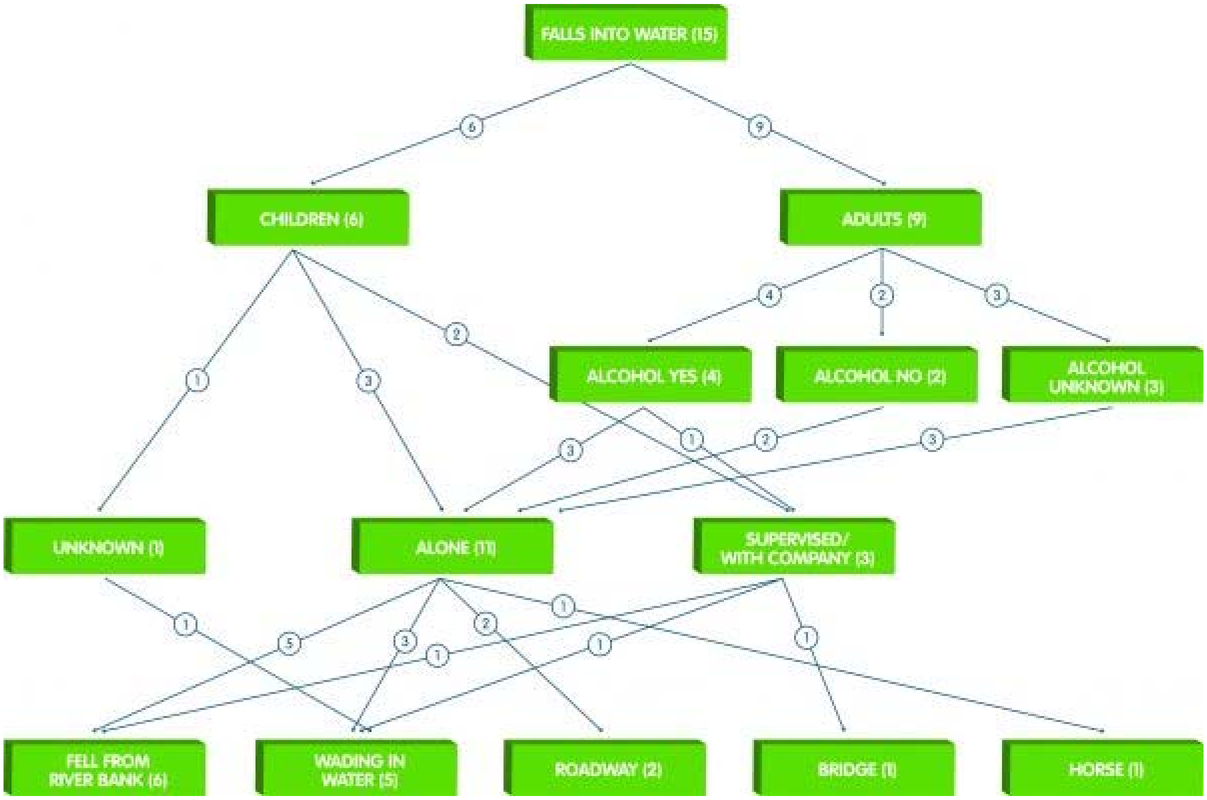

Fig. 2: Flood related drowning deaths as a result of falls into water (n=15).

Swept away

Being swept away by floodwaters accounted for 22 drowning deaths between 2002/03 and 2011/12, of which 18 deaths (81.8%) were from one incident (the 2010/11 Queensland floods). In 72.7% of cases the person was unexpectedly swamped by water, commonly in their home (87.5%) and in all cases (100.0%) there was no prior warning of the inundation. For those who intentionally entered floodwaters (27.3%), all (100.0%) entered on foot, with 66.7% of these being swept away by floodwaters whilst crossing a flooded bridge, all of which occurred during periods of slow-onset flooding (100.0%) whilst the victims were trying to get home (100.0%) (Figure 3).

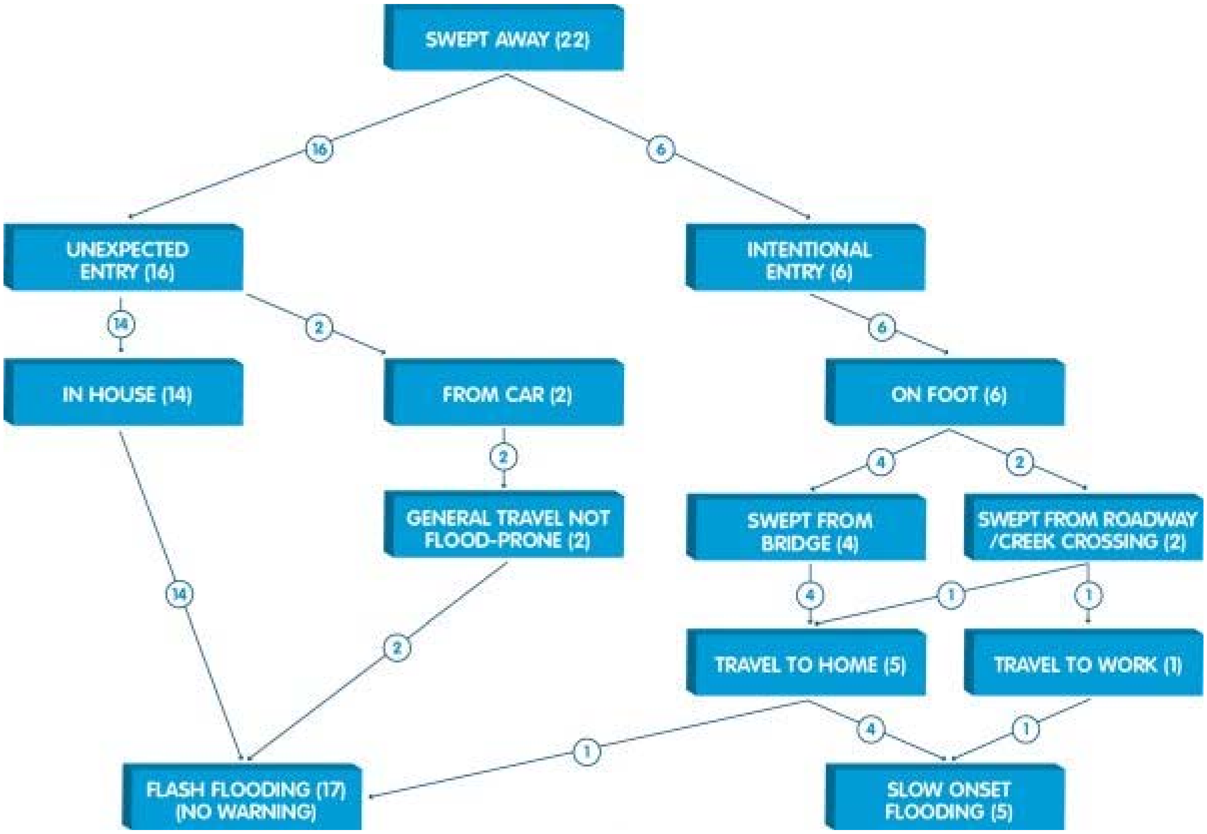

Fig. 3: Flood related drowning deaths as a result of being swept away (n=22).

Non-aquatic transport incidents

There were 71 drowning deaths due to non-aquatic transport incidents, the most common activity being undertaken prior to drowning in river floods. In almost two thirds (60.0%) of cases those who drowned were the drivers and were alone in the car when they drove into floodwaters. Drivers were most commonly in 4WD vehicles and attempting to reach their home or a friend's home (60.0%). (Figure 4)

Almost two thirds (60.6%) occurred on roads that were known to be open at the time of the incident. Drivers were alone in the vehicle in 58.3% of road open cases, the remaining 41.7% of drivers drove through floodwaters with passengers in the vehicle. Almost a third (30.2%) of non-aquatic transport victims on open roads were intending to travel to their own home or a friend's home, most commonly in cars (38.5%), utilities (30.8%) and 4WDs (23.1%). Just over a fifth (25.6%) of those who drowned on open roads were intending to travel to work/appointments. All victims driving heavy vehicles or machinery were undertaking paid employment at the time of their drowning. All incidents (100.0%) involving motorbikes/ATVs occurred when the victim was riding for recreation (Figure 4).

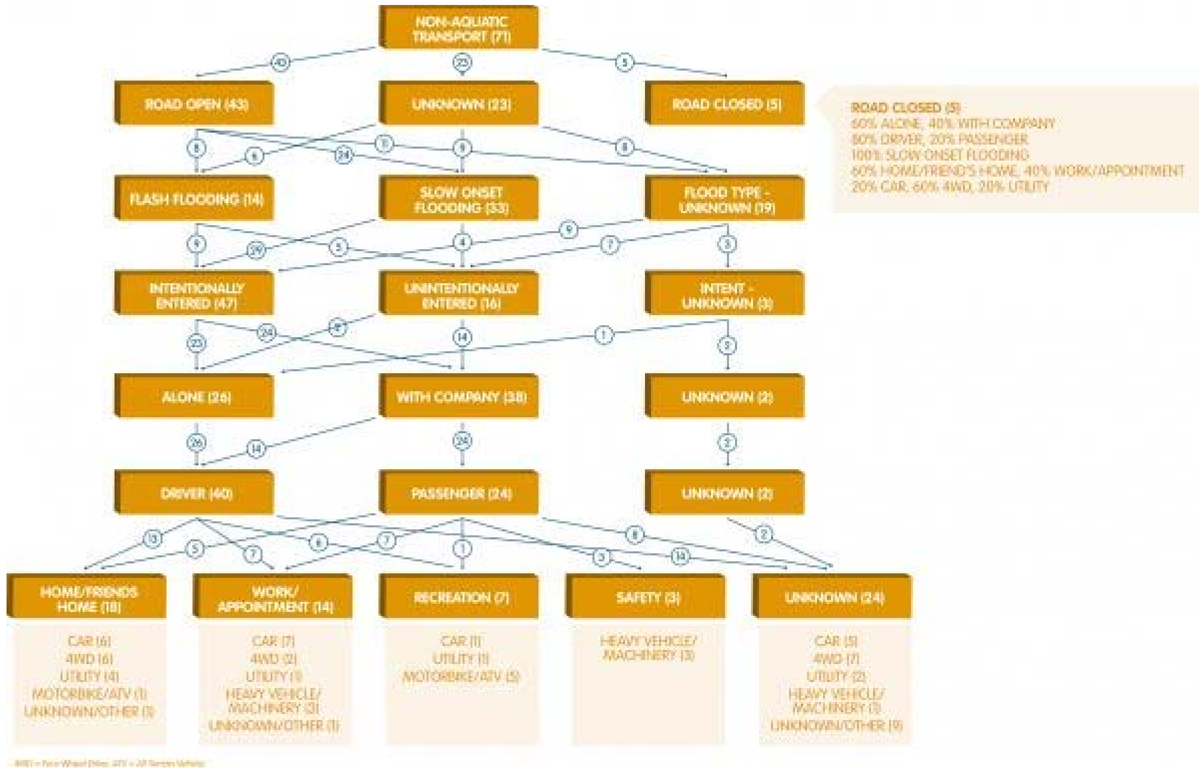

Fig. 4: Flood related drowning deaths as a result of non-aquatic transport incidents (n=71).

Discussion

River flood related unintentional fatal drownings are a regular occurrence in many countries around the world [5,1,36]. This study, the first to analyse Australian river flooding deaths using coronial data, found those at an increased risk include: males, children and those residing in states prone to tropical rainfall patterns (Northern Territory and Queensland); and those involved in non-aquatic transport incidents or those swept away. Risk factor identification has been shown to be an important tool for developing successful prevention strategies [11,37,3836].

Understanding causal pathways to inform prevention

This study uses causal pathway analysis to understand common scenarios leading to drowning and depicts these as flow charts. Similar work has been undertaken to understand causal pathways leading to drowning of young children in home swimming pools [39] and among divers [40].

While not the first to use flow charts to depict flood related drowning deaths, this study expands on Fitzgerald's [41] work using a flow chart to depict circumstances of flood victims before death. Our study differs in that it uses coronial data (rather than newspaper reports or historical accounts) to examine causal factors for the three leading activities prior to drowning. Fitzgerald's study found almost half (43.8%) of flood fatalities in Australia between 1997-2008 were vehicle related, with crossing a waterway the leading contributor, a finding that is mirrored in this study. Our research reported similar proportions of watercraft related flood drowning (4.4% in Fitzgerald, 4.1% in this study), but a higher proportion of victims being trapped and subsequently swept away by floodwaters (17.1%) with most being trapped in their home (63.6%). Fitzgerald reported zero flood fatalities of this type, with our study reflecting the 2011 mass casualty event in the State of Queensland [42].

Causal factor analysis provides important information about the chain of events leading to river flood related drowning to inform prevention. The development and implementation of prevention strategies must also consider work beyond epidemiological studies, such as behavioural psychology, to determine motivations underpinning behaviour, such as the decision to drive through floodwaters [43].

Challenges around definitions of flooding

A key challenge when conducting analysis of river flood related drowning deaths is the lack of a consistent definition. This has previously been identified as a limitation in the published literature around defining and isolating river drowning statistics [18]. This study has classified river floods as slow onset or flash flooding; and while attempts have been made to define different types of flooding in the past [5,44], a lack of consistency in terminology and classifications has made the comparison of different studies difficult. This limits the ability to examine how risk differs between types of floods across a range of studies. A consistent set of definitions allows flood type and flood characteristics to be routinely collected at the time of death investigation (primarily by police). This information may then allow for opportunities to predict the severity [5] of flood events to develop and implement evidence based strategies for prevention.

Consistent terms that are then communicated to, and well understood by, those at increased risk, may increase the effectiveness of prevention strategies. Clearly communicated prevention strategies may increase recall and impact on behaviour [45,46] and therefore the likelihood that such activities will be effective in their aim of reducing flood related drowning.

Falls into water

A fall into water, although statistically more common when rivers are not in flood, was the third leading category of activity prior to drowning in river floods. Causal factor analysis raises questions regarding the protective nature of supervision, with a third of all children drowning due to falls into flooded rivers whilst with company. In order to be effective, supervision must be focused, continuous and proximate [47]. Drowning prevention strategies aimed at parents and carers of young children must highlight the key elements of effective supervision, including around floodwaters. Floodwater risks to children must be communicated prior to the traditional risk taking teenage years with the average age of child victims being 8.2 years.

Almost half (44.4%) of all adults who fell into flooded rivers were known to have consumed alcohol prior to drowning. With the contributory role of alcohol having been identified in river drowning deaths in Australia [48], this study highlights the need to ensure flooding is considered in any strategies developed to address alcohol related river drowning deaths.

Swept away

While being swept away was a significant cause of death, 21 people (17.1% of all river flood related drowning deaths) in this study drowned in a single flood event in the state of Queensland in 2011 [12]. Victims from this event accounted for 81.8% of all deaths as a result of being swept away. Events such as these are worthy of further examination with extreme weather predicted to increase the likelihood of such events in the future [38]. It is therefore vital that prevention efforts focus on those most at risk during such events.

Half (50.0%) of those who drowned as a result of being swept away were aged 55 years and over, identifying the vulnerability of older people. Almost all (90.9%) of those aged 55 years and over who were swept away by floodwaters, were swept from their house when it was inundated as a result of flash flooding. The 2011 Queensland floods occurred during the day, when older victims, more likely to be retired from the workforce, were home. This event highlights the impact of age related reductions in mobility and chronic conditions on drowning risk during floods [49]. To reduce the risk, including for older people, the implementation and evaluation of prevention strategies such as predictive modelling, early evacuation, the relocation of flood prone communities and improved urban planning to avoid building on floodplains should be considered [12,50,51].

Non-aquatic transport related fatal drownings

Similar to previous studies on drowning deaths in flooded rivers, non-aquatic transport incidents were the most common activities being undertaken prior to drowning [41,52,53,6]. Males are consistently at an increased risk, postulated to be due to greater confidence to drive into floodwaters [54]. For prevention targeting males with effective education and awareness raising messages will be critical. As over half of all females who drowned as a result of non-aquatic transport incidents were passengers in the vehicle education strategies highlighting risk to life for both driver and passengers may be more effective [43].

While trucks and motorcycles accounted for a small proportion of vehicles driven through floodwaters (13.8%) in this study, rates per 100,000 registrations per annum [35] were 4.33 and 3.67 times that of cars (0.13 / 100,000 and 0.11 / 100,000 respectively). This is partially explained by Coles (2008) research where occupants of bigger vehicles are more likely to try to travel across floodwaters [55]. Although registration data is only a proxy for exposure, this highlights the need for education and prevention efforts to be targeted at drivers of such vehicles. Future research should focus on exposure studies [18] to identify those at an increased risk of drowning due to river floods.

Preventing drowning in floodwaters is a challenge and ultimately the most effective strategy is to prevent drivers from crossing flooded roads. In this study only 7% of all deaths were from people traveling on closed roads, as such timely road closures may save lives. Road closures which are automatically based on real time flood water data and are physical in nature (e.g. barriers) [11] are likely to be effective. Providing information about alternative routes and information prior to reaching the flood water to allow for a change of route may also help. Enforcement of closed roads is also important as this helps to reinforce the signage as a means of providing information and may enhance effectiveness.

Prevention may also encompass better urban design, including building infrastructure and bridges to enable safe travel across flood-prone locations. Further research is required to determine effectiveness, and implications for disobeying road closure signage and barriers must be considered. Further work is required to explore other prevention strategies such as enforcing the culpability of those who deliberately drive through floodwaters and put others at risk and the use of regulations to hold driver's liable for costs incurred during their rescue from floodwaters.

Prevention

This study has identified a number of risk factors where prevention strategies should be targeted. These include targeting males, those who drive through flooded rivers (particularly truck drivers and motorcycle riders) and those residing in the northern areas of Australia prone to tropical rainfall.

Unlike drowning deaths at coastal locations that commonly involve international tourists [56], all victims who drowned in river floods were Australian residents, the majority of which (83.3%) drowned within 100kms of their residential postcode. It could be postulated that these people were in areas where they are more likely to have "local knowledge" about normal conditions [57], or in the case of non-aquatic transport incidents, on roads they had driven on many times in the past. This mirrors research conducted by Hamilton et al into the key beliefs underpinning people's decisions to drive through floodwaters, which found that people regularly ignore road closed and flood warning signs if they had previous experience of driving on roads that regularly flooded [58,11]. Further qualitative studies that focus on people who reside in flood-prone areas and who have driven through floodwaters may assist in the development of effective prevention strategies for this group that account for the majority of river flood-related drowning victims.

Those who drowned in the Northern Territory and Queensland were at a significantly increased risk for river flood-related drowning, which is related to their tropical climate and wet season. Prevention strategies must consider rainfall patterns and climate differences in order to be better tailored, and therefore relevant, for those at an increased risk. This is evidenced by permanent signage, used in parts of northern Queensland, which shows open and closed roads 50 to 100kms ahead to allow motorists to make decisions about which route to take. This signage is particularly important during the wet season, however the effectiveness of this method has yet to be evaluated.

There is limited evidence regarding the effectiveness of prevention strategies for those who drive through floodwaters. Key prevention strategies currently utilised are low order strategies [59,60], such as signage (road closed and depth markers) and barriers. This study also shows signage appears to be ineffective, with 63.6% of non-aquatic transport incidents in remote and very remote areas known to have occurred on roads that were open at the time of the drowning incident. Signage and detour routes are reactive strategies and hard to enact if authorities do not know if there is water on the road in such isolated locations [61]. Further work is needed to explore how to make signage more effective.

In Australia, the use of the "If it's flooded, forget it" slogan, to discourage people from deliberately entering floodwaters, be it in a car, on foot or for swimming, has been recommended [12]. However this campaign has yet to be evaluated. The motivational factors behind people's decisions to drive through floodwaters must be considered when developing prevention strategies.

There are many challenges associated with effective prevention of river flood drowning deaths. One such challenge is these deaths are reasonably rare in any given location as they are geographically dispersed across the country. Slow onset flooding moves long distances and can affect river systems hundreds and thousands of kilometres from where rainfall occurred, potentially leading those in flood-prone locations to underestimate risk to self and others [62]. Gathering evidence that particular stratagems are effective is an ongoing challenge.

Limitations

There may be limitations associated with this study. Firstly, not all flood related drowning deaths may have been identified. Relying on ICD codes has been found to under report drowning deaths as a result of flooding [18] and boating accidents [63]. Just over one fifth (20.3%) of cases in this study recorded an unknown for the involvement of flooding. Where the case remained open (i.e. under investigation within the coronial system) there is limited information available on the circumstances of the drowning. A case that is open will also not be coded to ICD 10 coding. With 6.9% of drowning cases open within the coronial system, this paper may under report the number of drowning deaths as a result of flooding in Australia during this period.

As this study uses data for cases where a coroner must investigate, there is a period of time where there is limited information about the case. Until the case is officially closed by the coroner (i.e. no longer under investigation and a cause of death has been determined) there is minimal data available about the circumstances surrounding the drowning death. The period under analysis has been chosen to minimise incomplete data, however 6.9% of river drowning cases remain open (i.e. under investigation) within the coronial system.

Calculations for crude fatal drowning rates by population of remoteness classifications uses an average from three years 2001, 2006 and 2011 (Population census years in Australia) for population and drowning data from 2002/03 to 2011/12. This may produce rates that are not as accurate as if population data was available for each year of drowning data. These rates were calculated using the yes variable only and therefore some of the unknown cases may be flood related and this may underestimate the rate.

Alcohol involvement was unknown in 27.9% of river flood related drowning deaths. This study may therefore underestimate the involvement of alcohol in incidents of fatal drowning during river flooding. The difficulty with retrieving bodies during times of flood may also artificially inflate BAC readings due to rapid decomposition in water [64].

The chi squared analysis in Table 1 was calculated using the yes and no variables for flooding only. The authors are therefore making the assumption that the unknowns would be evenly distributed between the known categories. Relative risk was calculated on only the yes variable for flooding and as such may be impacted by the unknown cases.

The relative risk calculations based on remoteness of drowning location use census population data by remoteness classification for a victim's residential location. It is possible that a victim may have drowned in one remoteness classification but resides (and is therefore counted in population data) in a different remoteness classification. This may therefore have an impact on the accuracy of the relative risk calculations.

Conclusion

Although periods of drought and flood may well be inevitable in many countries, including Australia, fatal drowning does not have to be a by-product of such weather events. Prevention strategies are vital to reducing the needless loss of life during flood disasters. This study identifies key risk factors that must be considered when developing prevention strategies such as communicating the risk of floodwaters to children prior to the teenage years, highlighting the dangers of driving through floodwaters, the need to target people in rural and remote areas with prevention messages, drivers of trucks and motorcycles and those in tropical areas prone to periods of seasonal increased rainfall.

By implementing and evaluating a range of prevention strategies based on evidence, it is hoped that the number of drowning deaths occurring in Australia due to flooding, can be minimised, and ultimately prevented.

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Competing Interests

The authors have declared that no competing interests exist.

Data Availability Statement

With respect to the minimum dataset underlying this research, this data is available on request however as the data is via a third party (coronial data), ethical approval and permission from the data custodians, the Australian National Coronial Information System (NCIS) is required before the authors are able to provide their dataset to the person inquiring. There are strict ethical restrictions around use of this data and it can therefore not be sent to a public repository. Once ethical approval and permission from the NCIS as data custodians has been achieved, researchers can contact ncis@ncis.org.au to gain access to the data.

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