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Vehicle-related flood fatalities in Australia, 2001–2017

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Abstract

This study analyses the circumstances of vehicle-related flood fatalities between 2001 and 2017, in Australia. The research identified 96 deaths from 74 incidents during this period. The aim of this analysis is to understand the demographic, spatial and temporal patterns, and the situational conditions in which those ($n = 96$) deaths have occurred. This is important for informing efficient and strategic risk reduction strategies to reduce vehicle related deaths and injuries in floodwater. Data were accessed from the Australian National Coronial Information System (NCIS), which includes witness and police statements, forensic documents, and detailed coronial findings. Analysis was conducted in two phases. In phase one, data were coded and categorised according to a range of factors previously identified as significant in vehicle-related flood fatalities internationally. In phase two, a detailed analysis was conducted on 11 selected incidents for which there were complete sets of records. This detailed analysis provides insight into the multifaceted nature of fatal vehicle-related flood fatality incidents. The overall results reveal that, for drivers, middle-aged and elderly males are over-represented in the fatality statistics. As passengers, young women and children are vulnerable. The study also identified deep floodwater with high flow contributes more to vehicle immersion, and the presence of alcohol and drugs, leading to impaired responses, reduces the chance of survival for the vehicle occupants.

KEYWORDS

driver, drowning, fatalities, flood, natural hazard, passenger, vehicles

1 | INTRODUCTION

Vehicle-related incidents account for a significant proportion of flood fatalities globally (Ashley & Ashley, 2008; Diakakis & Deligiannakis, 2015; FitzGerald, Du, Jamal, Clark, & Hou, 2010; Jonkman & Kelman, 2005; Jonkman & Vrijling, 2008; Kellar & Schmidlin, 2012; Peden, Franklin, & Leggat, 2016; Terti, Ruin, Anquetin, & Gourley, 2015; Yale, Cole, Garrison, Runyan, & Ruback, 2003). In the United States, Ashley and Ashley (2008) reported 63% of all flood deaths were vehicle-related. Similarly, in relation to flash flood deaths specifically, Špitalar et al. (2014) and Terti et al. (2015) both identified that 68% of fatalities were vehicle-related. Jonkman and Vrijling (2008) identified that vehicle-related deaths were lower in Europe than the United States during the period 1989–2002, with only 27% of flood deaths associated with a vehicle in Europe compared to 63% in the United

States. In Greece, fatalities that occurred inside a vehicle, increased from 30% to 58% during the period 1960–2010 (Diakakis & Deligiannakis, 2016). In Portugal, fatality rates were generally lower (14%), but also increased in the last three decades with 25% of total flood fatalities between 2001 and 2010 being vehicle-related (Pereira, Diakakis, Deligiannakis, & Zêzere, 2017). In Australia, FitzGerald et al. (2010) reported that between 1997 and 2008, 49% of flood fatalities were vehicle-related, similarly Haynes et al. (2017) identified 49% between 1900 and 2015. Recent research in Australia (Haynes et al., 2017; Peden, Franklin, Leggat, & Aitken, 2017) has documented and quantified vehicle-related flood fatalities; however, these studies have done so in the context of an investigation of all flood fatalities over an extended time frame, and gaps remain in our understanding of vehicle-related flood deaths specifically.

The focus of this study is recent vehicle-related deaths in Australia that occurred between 2001 and 2017. Our research explores the circumstances surrounding these fatalities using coronial findings to better understand the situational, demographic, and environmental conditions under which these deaths occurred. The study explores the age and gender patterns of the vehicle occupants, specifically: how many people were inside the vehicle when one or more fatalities occurred; the distribution of deaths – the driver or the passenger(s); gender and age of the drivers and passengers; and, circumstances of survivors – number of survivors, approximate age and in vehicle role of survivors, what influenced the survivability of those who are able to escape the vehicle – compared to those who were unable to. This research also provides a record of the spatial and temporal patterns and the environmental circumstances surrounding these fatal events and makes an important contribution to the growing international body of knowledge of how and why vehicle-related flood fatalities occur.

2 | METHODS

2.1 | Data

The Australian National Coronial Information System (NCIS) was accessed to gather information on all vehicle-related flood fatalities that occurred between 2001 and 2017. A few recent fatality cases that were not yet available within NCIS were identified from archived newspaper reports. Additional information was also accessed from archived newspaper reports and relevant websites such as the Australian Bureau of Statistics and the Australian Bureau of Meteorology (BoM). To search for specific incidents in Australian newspapers, the Factiva database was used, alongside a number of online news portals, for example, ABC News, the Northern Star, the West Australian. Google maps was utilised to investigate the spatial context of each fatality.

All fatalities included in this study were carefully selected from the NCIS database as those directly attributed to flood events and the use of motor vehicles. The variables of interest were based on a previous review of international literature (Ahmed, Haynes, & Taylor, 2018), and were selected to mirror the important risk factors that were identified, for example, gender, age, role in vehicle, influence of drugs and alcohol, and so forth. The initial search for relevant fatality case identification was time consuming as the classification of flood fatalities and lists of casualties were not consistently described in the database coding structure. Coronial findings were not available for all cases, especially recent cases which were not yet closed, or were noted as not having had the inquest yet. Despite these shortcomings, the NCIS database allowed the researchers the retrieval of witness and police statements, forensic documents (e.g., autopsy reports), and detailed contained in coronial findings for the majority of the fatalities.

2.2 | Analysis

The data search identified a total of 96 deaths that occurred between 2001 and 2017 due to flood-related vehicle incidents; 79 from the NCIS database and 17 from archived newspapers. The details of the 96 fatalities were recorded in Microsoft Excel, and contained a set of selected variables describing the circumstances of the incident adapted from Haynes et al., 2017 (Table 1). The formation of the Excel data file allowed the development of a systematic record of data, based on evidence fragmented across several reports, and provided standardisation of the information for analysis. The complete analysis of the 96 fatalities was conducted in two phases, detailed below.

2.2.1 | Phase 1

In this stage, 22 incidental variables were selected based on the vulnerability factors of fatalities, which were directly associated with motor vehicles and caused due to flood events. The variables were grouped into four major categories – demographic, spatial, temporal, and situational. Next the variables under these major categories were classified into subcategories (Table 1) and each subcategory was coded using numerical coding schema to turn the qualitative data into quantitative data for

TABLE 1 Variable categories and sub categories included in coding fatality and incident data

Major category	Variables	Subcategories
Demographic	• Driver/passenger(s) age	• Age groups: 0–9 (small children), 10–19 (child), 20–29 (youth), 30–39 (young adult), 40–49 (adult), 50–59 (middle aged), 60–69 (middle aged), 70–79 (elderly), 80+ (old)
	• Driver/passenger(s) gender	• Gender: male, female
Spatial	• State	• State: QLD, NSW, ACT, WA, NT, VIC, TAS
	• Location/suburb	• Suburb: postcode used for graphical heat map
	• Location type	• Location type: a low-water crossing, bridge, or causeway, a ford or weir, a normal stretch of road
Temporal	• Year	• Year: 2001–2017
	• Month	• Month: January–December
	• Day of the week	• Day: Monday–Sunday
	• Season	• Season: summer, autumn, winter, spring
	• Time of day	• Time of day: morning (07:00 a.m. to 11:00 a.m.), around noon (11:00 a.m. to 03:00 p.m.), afternoon (03:00 p.m. to 5:00 p.m.), evening/night (7:00 p.m. to 4:00 a.m.) and twilight (4:00 a.m. to 7:00 a.m. – dawn and 5:00 p.m. to 7:00 p.m. – dusk)
	• Lighting conditions	• Lighting conditions: daylight (good light), dawn/dusk (fading/golden glow), dark (poor lighting)
Situational	• Number of fatalities per incident	• Number
	• Number of occupants in the vehicle	• Number
	• Number of occupants who survived	• Number
	• Presence of alcohol/drugs	• Presence of alcohol/drugs: yes, no
	• Work-related duties	• Engaged in work-related duties/on duty: yes, no
	• Causes of death	• Causes of death: drowning, injury with drowning, others (e.g., heart attack)
	• Weather conditions	• Weather condition: no rain, raining but not heavy, heavy rain, others (e.g., storm/wind, overcast)
	• Water flow	• Water flow: no flow/still, moderate flow, fast flow
	• Proximity to driver's home	• Proximity to home: less than 10 km, 10–20 km, 20–50 km, more than 50 km
	• Type of vehicle	• Type of vehicle: cars, sport utility vehicles (SUVs), utility vehicles (utes), motorbikes, trucks, vans, tractors, other
	• Journey characteristics	• Journey details and reasons for entering floodwater: travelling en route to/from home/work/other destinations, evacuating, working, attempting to rescue/retrieve property, etc.

Note: Where functional information was missing, the fatalities were labelled as unknown in that subcategory.

analysis. The research team completed the full coding task crosschecking the entire register. After coding, simple mathematical operations were used to quantify percentages of subcategories of each variable in Phase 1 to provide a broad overview. Descriptive approaches were used to summarise the findings. To investigate the representation of a limited set of variables in the observed fatality data, that is, age, gender, vehicle occupant role – driver/passenger, simple (2×2) chi-square analyses were conducted.

2.2.2 | Phase 2

In this phase, 11 incidents from across Australia with full report findings were selected for further qualitative

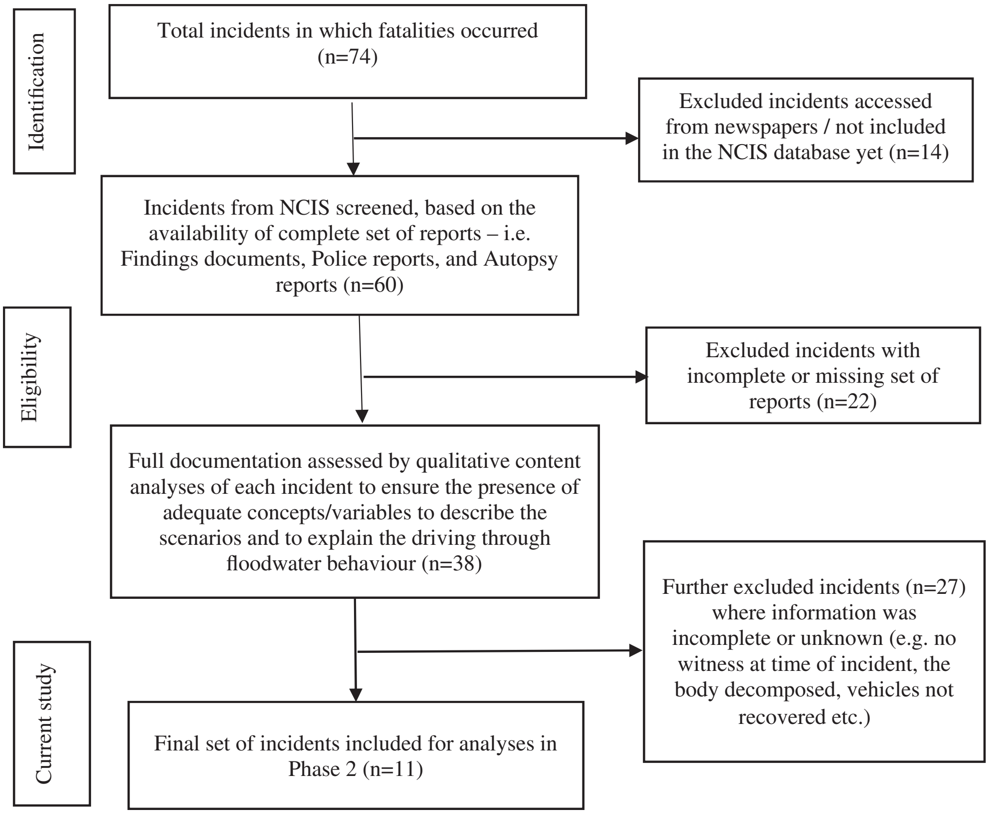

FIGURE 1 Selection of incidents for further analysis in Phase 2

analysis. The steps involved in selecting the 11 incidents are summarised in Figure 1.

The inclusion criteria for incident selection were: first, the availability of a full set of reports in the NCIS database which was, indisputably, important to explain the incident scenario adequately; secondly, presence of those factors in each incident that previous literature had demonstrated as important in understanding decision-making and the behaviour of driving into floodwater (Ahmed et al., 2018). To assess the availability of information, basic qualitative content analyses (Weber, 1990) was undertaken. Exclusion criteria were: incidents accessed from newspaper, which were not open in NCIS database; incidents for which all reports-findings, police and autopsy report were not available in the NCIS database; and incidents for which information identified as important for understanding the scenario was incomplete or unknown, such as, lack of a witness statement, lack of evidence for causes of death, missing vehicle information where vehicles were not recovered.

Systematic narrative syntheses of the selected incidents were then undertaken from the evidence: how environmental and physical cues were understood to have influenced the driver's decision-making; the errors or mistakes made; what form of rescue attempt was made to save the victims and recover the deceased; the presence and possible impact of warnings and risk indicators that were present; and the role of passengers, or others, who were present at the scene. This analysis also explored the vehicle status and floodwater characteristics during the incidents, the actions taken by the deceased prior to death, their reported level of awareness or knowledge of the flooding and possible dangers, and the reported capacity of the victim to act.

3 | RESULTS AND DISCUSSION

The final database contained the details of 96 individual vehicle-related flood fatalities in Australia that occurred between 2001 and 2017. These deaths took place during 74 flood-related vehicle incidents, with a mean of 1.3 fatalities per incident.

The following sections report on the Phase 1 analysis, and include the demographics of the fatalities, the spatial and temporal patterns of the fatalities and incidents, and the situational factors surrounding the fatal vehicle incidents. In order to ensure incidents or cases are not identifiable, the x axis begins at 5 in the bar graphs (Figure 2, 3, 5, 6, 8 & 9) and in the pie charts categories with <5% have been combined (Figure 4, 10, 11, 12, 13). The Phase

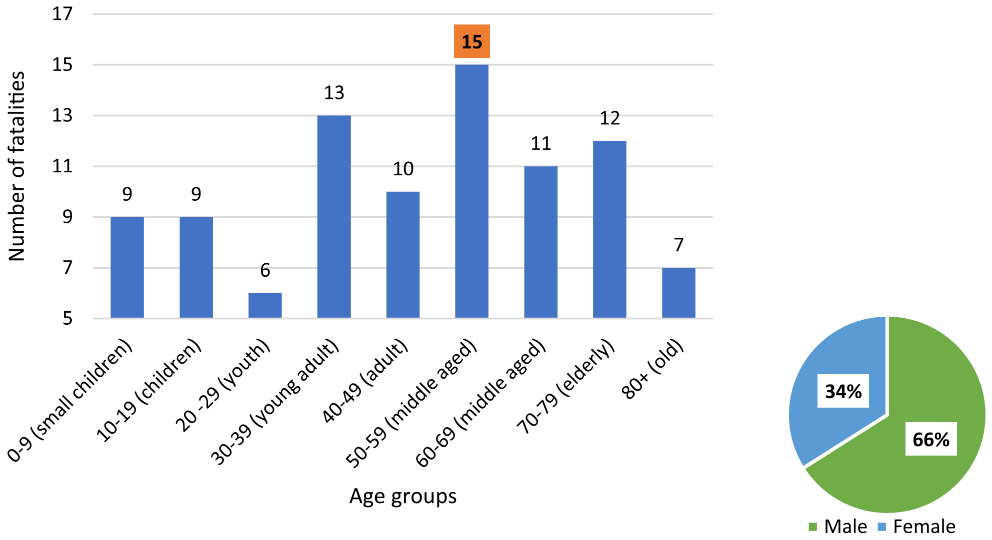

FIGURE 2 Breakdown of vehicle-related fatalities by age and gender

2 analysis follows, with a more detailed breakdown of the 11 selected incidents.

3.1 | Phase 1

3.1.1 | Demographic factors

The ages and genders of the fatalities were categorised, and are shown in Figure 2.

Data in Figure 2 indicate that, overall, a slightly greater number of fatality cases were noted for those aged 50–59 years ($n = 15$) and 30–39 years ($n = 13$), and fewer for those aged 20–29 year ($n = 6$) and over 80 ($n = 7$). However, due to the relatively small numbers involved, overall differences across age groups are not statistically significant. This finding is different to the pattern seen in longer time series of flood-related fatalities due to all causes in Australia. Haynes et al. (2017) explored flood fatalities due to all causes from 1900 to 2015 and in these data, youth and young adults are overrepresented.

Males accounted for a higher number of deaths overall (66%; $n = 63$) than females (34%; $n = 33$). This notably higher proportion of male to female deaths is in accord with male overrepresentation in vehicle-related flood death statistics reported in the broader literature (Diakakis & Deligiannakis, 2013; Drobot, Benight, & Gruntfest, 2007; Haynes et al., 2017; Jonkman & Kelman, 2005; Kellar & Schmidlin, 2012; Maples & Tiefenbacher, 2009; Sharif, Jackson, Hossain, Bin-Shafique, & Zane, 2010).

When gender data are examined across age groups, the number of male deaths is notably higher in most age groups; the exceptions being small children (0–-9 years), youth (20–29 years), and adults (40–49 years). Gender differences are generally more apparent in those aged over 30, where the number of male deaths recorded for those aged 50–59 and 70–79 was much higher than the number of female deaths. The relationship between age and gender was tested using chi-square tests; however, this relationship was found not to be statistically significant ($\chi^2 = .801$, df $= 1$, $p = .371$).

With regard to the victims' in-vehicle roles (Figure 3 and Figure 4), 60% of the total fatalities were drivers ($n = 58$), 31% were passengers ($n = 30$) and 8% were unknown. Of the 58 drivers, 72% were male ($n = 42$), 28% female ($n = 16$) and of the 30 passengers, 57% were male ($n = 17$), 43% female ($n = 13$). The proportion of female to male fatalities is higher for passengers than drivers, that is, 43% of passenger fatalities were female compared to 28% of driver fatalities. The distribution of fatalities by in-vehicle roles across age is shown in Figure 3, and the distribution of fatalities by in-vehicles role and gender is shown in Figure 4.

The age distribution of the driver fatalities shows that the majority 88% ($n = 49$) are aged over 30 years. As might be expected for passengers, the number of child fatalities ($n = 14$, 46%) is higher than adult fatalities. These distributions were compared using chi-square tests and differences were highly statistically significant ($\chi^2 = 16.53$, df $= 1$, $p < .001$).

The results of demographic trends (driver and passenger dimensions) identified in this research have implications for the development of intervention strategies targeting those at risk. It is imperative that more is done to communicate the risks of entering floodwater in a vehicle from a passenger's point of view, particularly for children and young female adults. This could involve messaging, or approaches, that persuade

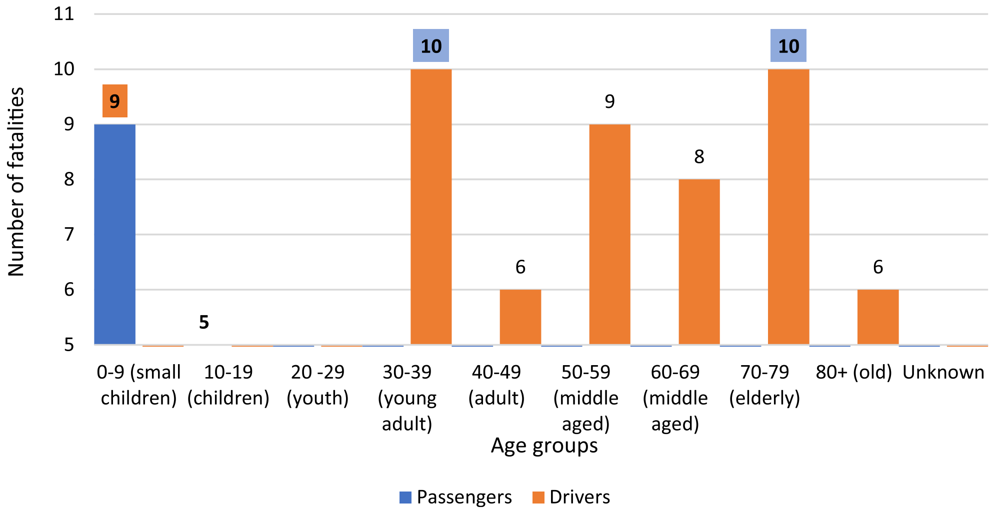

FIGURE 3 Breakdown of vehicle related fatalities by in-vehicles roles and their age

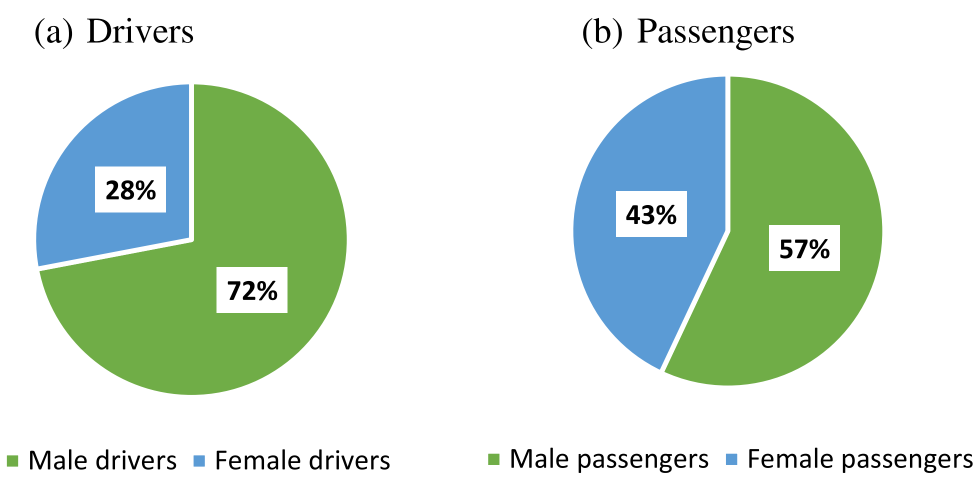

FIGURE 4 Breakdown of vehicle related fatalities by in-vehicles roles and their gender

drivers to put the responsibility for their passengers ahead of their journey and also assist passengers to understand their risks and provide approaches to enable them to express their concerns to the vehicle driver.

It is also important to note the prevalence of males in these fatality statistics. Although this is not a surprising finding, the relatively greater numbers of older males perhaps go against the stereotype of young, reckless drivers making risky impulsive decisions. This finding also suggests that driving experience and complacency may play a greater role in these incidents and that possibly there is a higher degree of cognitive engagement in these decisions. This has implications for risk messaging and education, where questioning assumptions, based on experience or ability, may be helpful.

3.1.2 | Spatial and temporal patterns

The annual number of fatalities during the period 2001 to 2017 is shown in Figure 5. The annual death toll is highest in 2011 with 17 fatalities (attributable to a widespread severe flooding event in Queensland in January 2011). The mean death toll across the study time period is 5.65 fatalities per year. Data show a moderate rising trend from 2001 to 2011. Since 2006, the annual number of fatalities has continued above the mean almost every year, except 2012 and 2014. No vehicle-related fatalities were recorded in 2014. In recent years, since 2015, the number of fatalities annually appears to have increased again in comparison with the early 2000s.

Fatalities with respect to the month of occurrence are summarised in Figure 6, and fatalities by Australian State/Territory are shown in Table 2.

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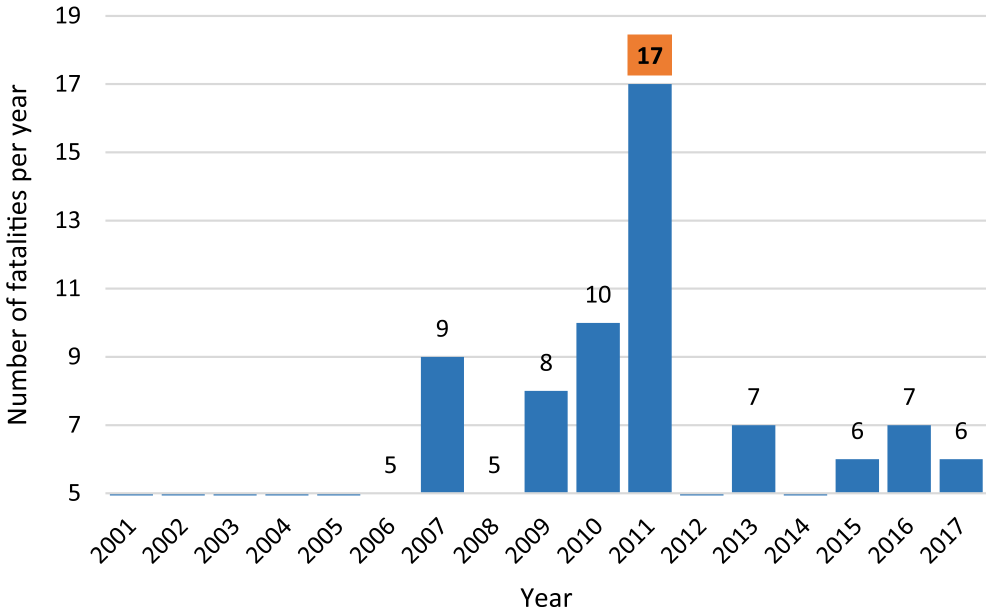

FIGURE 5 Annual number of vehicle-related flood fatalities from 2001 to 2017

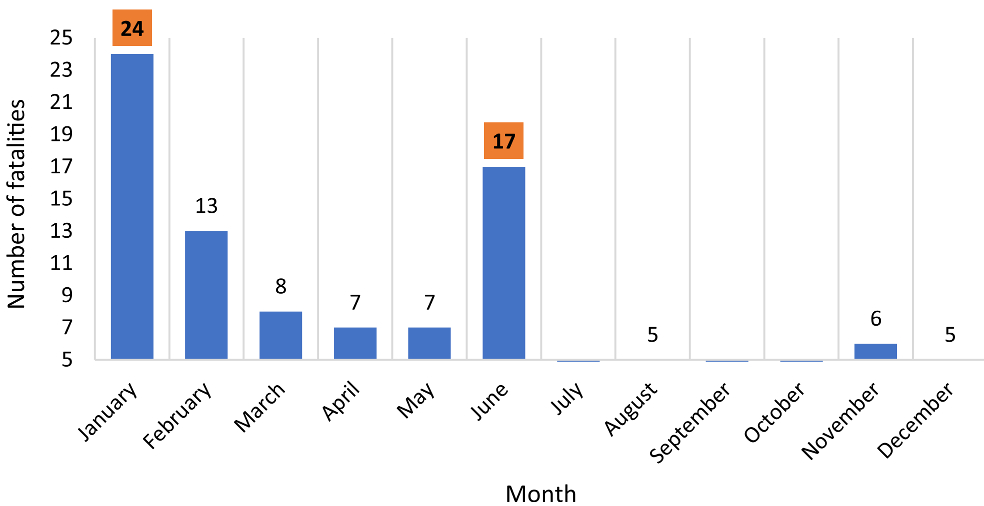

FIGURE 6 Monthly distribution of vehicle-related flood fatalities during the period 2001–2017

A higher number of fatalities occurred during the Australian summer months of January ($n = 24$; 25%) and February ($n = 13$; 14%), and the winter month of June ($n = 17$; 18%).

By states, Queensland (QLD) and New South Wales (NSW) accounted for 84% of the overall number of fatalities ($n = 81$). Other states accounted for 16% of all fatalities ($n = 15$). Of note in Table 2, is the proportionally higher number of fatalities in QLD (54%), despite its relatively low population compared to other states (only 22% of the Australian population). Whereas 28% of the population live in VIC, but only 6% of the vehicle-related flood fatalities occurred in that State. Significant meteorological differences exist between these two states, and help to explain these findings, that is, QLD has a more tropical climate with monsoonal and cyclonic impacts (CSIRO & Bureau of Meteorology (BoM), 2015). However, both states have been subject to multiple major flooding events during the period of our study. The costliest summer for floods in Australian history was 2010–2011, with extensive flooding in the state of QLD, with flood impacts also occurring in NSW and VIC. This event resulted in 36 deaths (24 vehicle related), impacted over 2.5 million people and resulted in A\$6.7 and A\$7.4 billion (2015 dollars) in tangible and intangible costs, respectively. Other major flood events that led to multiple fatalities over the period studied include the June 2007 Hunter Region and Central Coast storms in NSW with 10 fatalities (8 vehicle

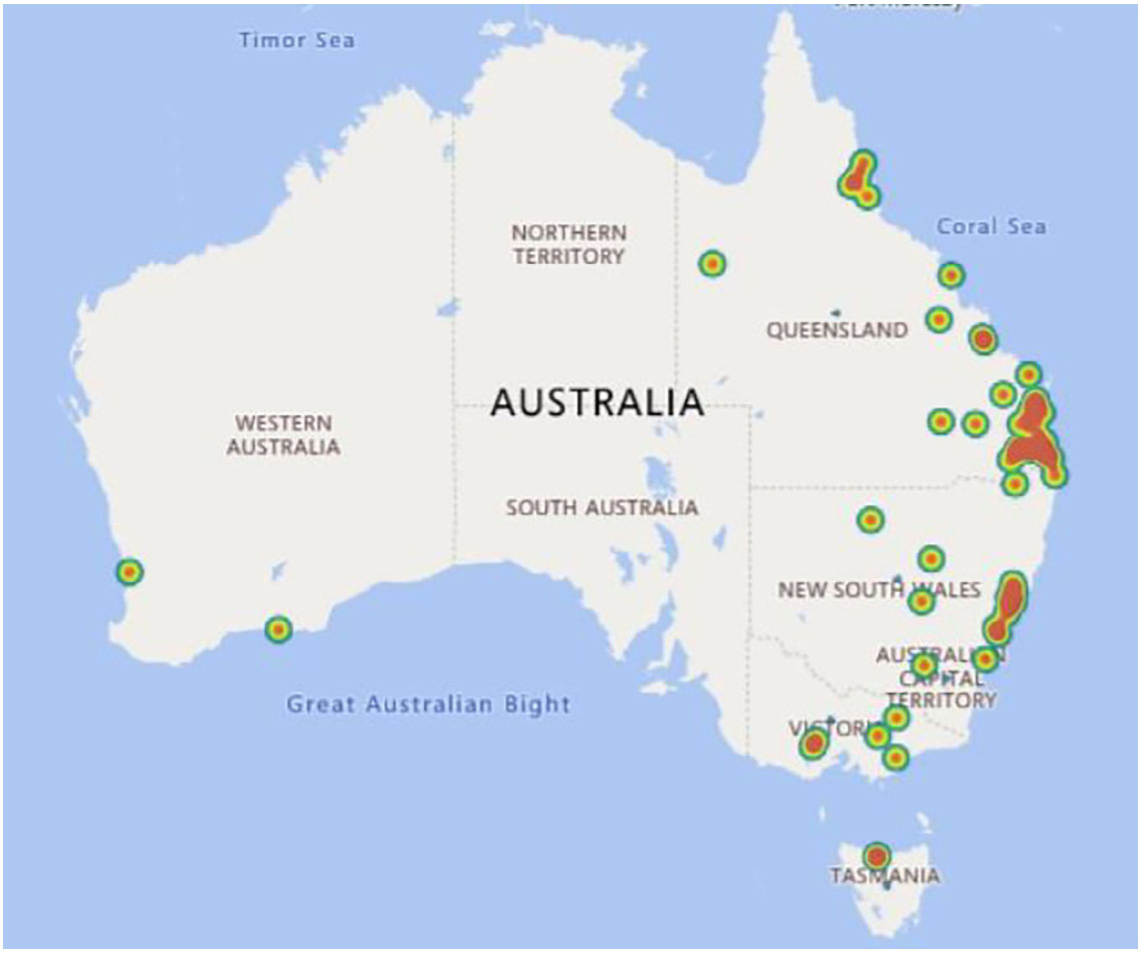

FIGURE 7 Geographical heat map of vehicle-related fatalities in Australia (2001–2017)

related), 6,000 homeless and A$1.35 billion in insurance losses (Callaghan & Helman, 2008). The 2017 flooding across southern QLD and northern NSW led to several fatalities (at least six vehicle related) and 20,000 evacuated (Haynes, Tofa, Avci, van Leeuwen, & Coates, 2018). Unlike other hazards such as bushfires, flood fatalities do not cluster around large events, instead, fatalities are distributed more evenly with small numbers occurring more frequently through time (Haynes et al., 2017).

The geographical heat map (Figure 7) shows that the majority of fatalities have occurred along the east coast of QLD and NSW. The coastal strip from mid-NSW (Wollongong) to mid-QLD (Marlborough) has been identified previously as the most hazardous zone in Australia with regard to flood fatalities generally (Coates, 1999).

A comparison between the year and month of fatalities in QLD and NSW are shown in Figures 8 and 9.

Peaks in vehicle-related flood fatality numbers can be seen in QLD and NSW and in the months of January and June, respectively. These mostly relate to two large flooding events. QLD experienced the highest annual number of deaths ($n = 12$) in 2011, with most fatalities overall occurring in the month of January. Between late November 2010 and mid-January 2011 widespread flooding occurred across QLD (BoM, 2012). During the second week of January, 2011 the most severe flooding of the season (including river and flash flooding) occurred in the State capital city of Brisbane and southeast QLD. A total of 30 flood-related fatalities occurred in QLD during this event, with 12 being vehicle-related and reported in this study. The second highest number of annual fatalities occurred in NSW in June 2007 ($n = 9$). June 2007 was notable for four major 'east coast low' weather events which brought heavy rain and severe winds to the region. Substantial flooding occurred in the Hunter Valley and in coastal areas between Sydney and Newcastle during the second week of the month (BoM, 2007). These spatial and temporal patterns of fatalities by annual and monthly distribution have implications in terms of developing, maintaining, and prioritising engagement in risk messaging and interventions in relation to time (season)

FIGURE 8 Number of vehicle-related flood fatalities from 2001 to 2017 in QLD and NSW

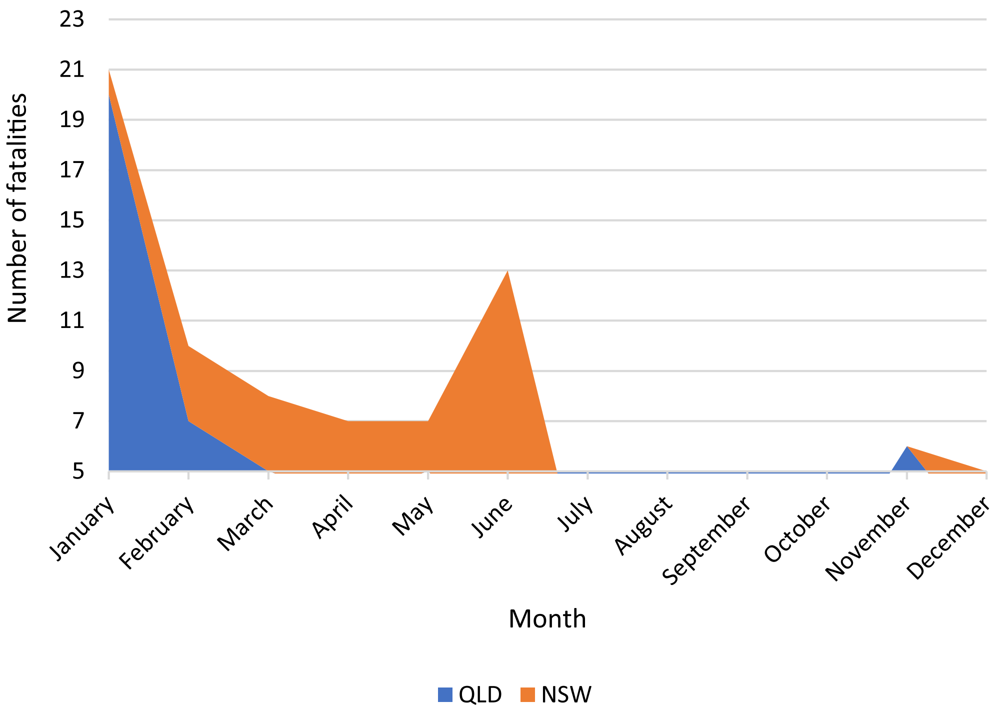

FIGURE 9 Monthly distribution of vehicle-related flood fatalities during the period 2001–2017 in QLD and NSW

and location (state). It can also assist in terms of more seasonally focused forecasting, monitoring, and reporting of flood hazards on roads.

Further analysis was undertaken to investigate a range of additional temporal and spatial factors associated with vehicle-related flood fatalities. For this section,

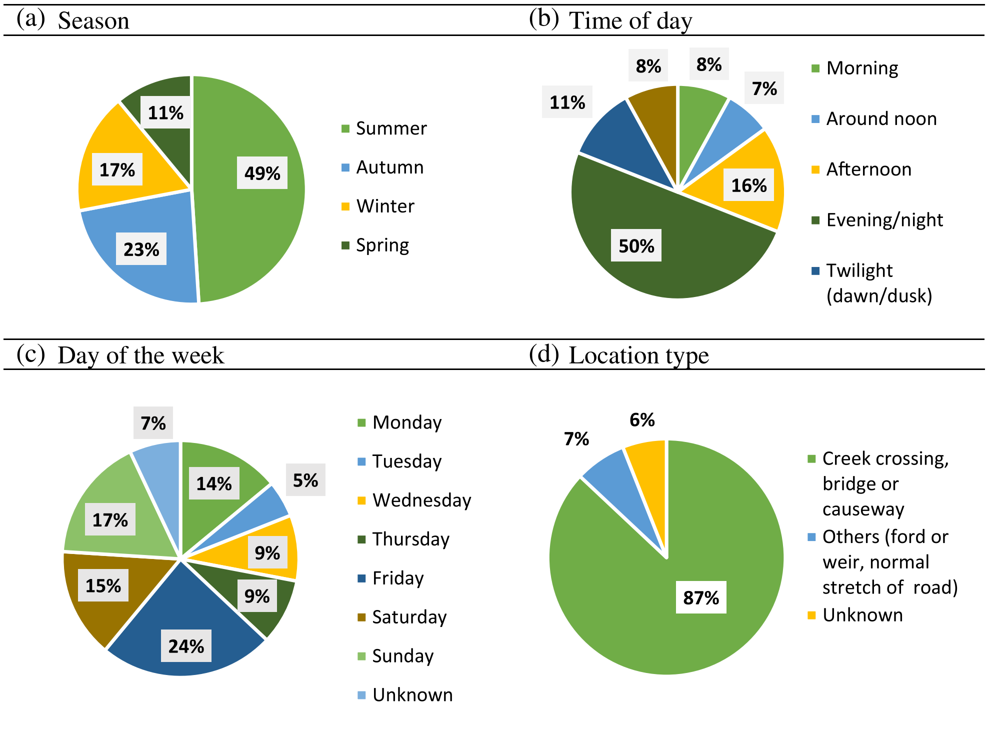

FIGURE 10 Breakdown of incidents ($n = 74$) by: (a) season, (b) time of day, (c) day of the week, and (d) location type

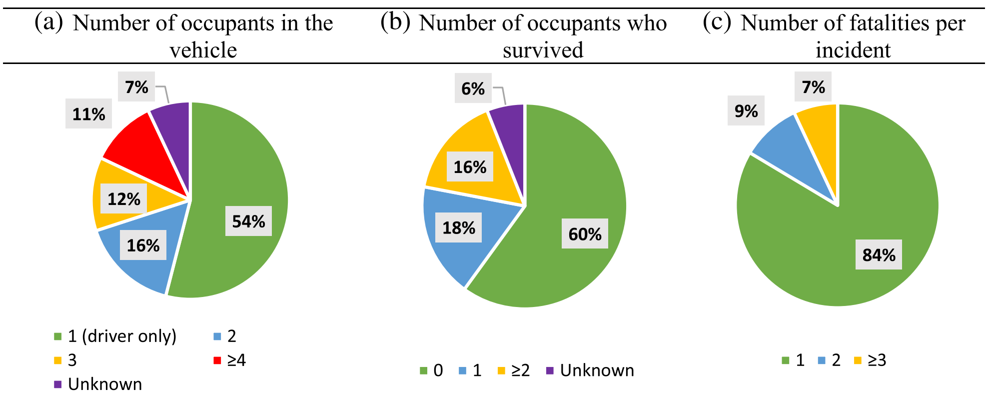

FIGURE 11 Distribution of the incidents ($n = 74$) with respect to (a) number of occupants in the vehicle, (b) number of occupants who survived, and (c) number of fatalities per incident. *Note: In order to ensure that small case numbers cannot be identified, categories with <5% have been combined

data were calculated by incident. As there were, on average 1.3 fatalities per incident, reporting by incident more accurately reflects some of the temporal and situational factors, for example, location type and vehicle type, and avoids overrepresentation in the overall presentation of the data. This approach also provides potentially more useful road safety information regarding 'higher risk' locations, times of day, and so forth. Figure 10 provides a breakdown by season, time of day, day of the week, and location type for the 74 fatal incidents.

As can be seen from Figure 10, more fatal incidents occur in summer (49%, $n = 36$) and in the evening/at night (50%, $n = 37$). In our study, we categorised time of incidents into four main groups to explore the influence of light at the time of the incident (Table 1). This categorisation is adopted from Peden et al. (2016). However, in our study, and similarly to the work of Haynes et al. (2017), we added an additional category – twilight (4:00 a.m. to 7:00 a.m. – dawn and 5:00 p.m. to 7:00 p.m. – dusk) determined on an incident by incident basis and

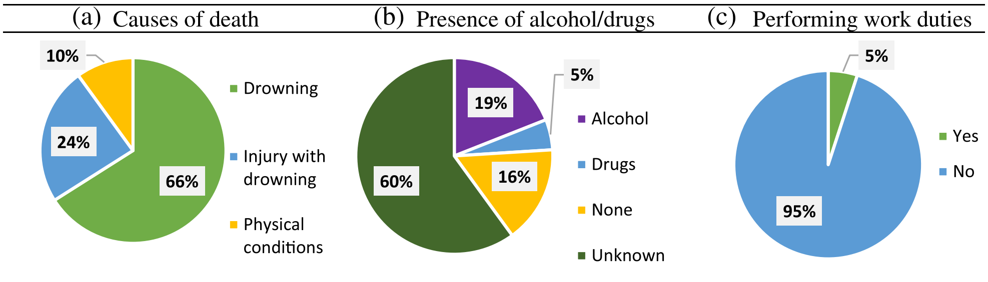

FIGURE 12 Distribution of the fatalities ($n = 96$) with respect to (a) causes of death, (b) presence of alcohol/drugs, and (c) whether the deceased was performing work duties at the time of the incident

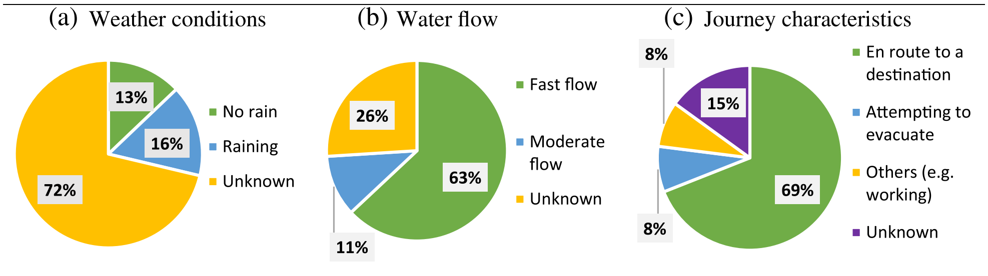

FIGURE 13 Distribution of the incidents ($n = 74$) with respect to (a) weather conditions, (b) water flow, and (c) journey characteristics at the time of entering floodwater

dependent on the season and time/time adjustment in the relevant States. The addition of a twilight category helps to minimise potential confusion about general lighting conditions at the time of the incident, for example: in summer, 6:00 p.m. is still daylight, whereas in winter it is dark/night, and in QLD there is no daylight-saving time adjustment. This more detailed understanding of the lighting conditions at the time of the incident is an important distinction to make, given that much current effort to reduce fatalities centres around risk communication. However, if more fatalities occur when visibility is compromised, then it may indicate that other efforts are necessary, such as improved lighting or other structural changes to reduce risks at known hot spots. The implications of this additional category are that some fatalities that may have been coded as afternoon in the Peden et al. (2016) study would now be categorised as twilight within this study.

The results of our analysis identified that the largest proportion of fatalities occurred in the evening and night when it was dark (50%, $n = 37$) which support a recent review study of previous research concerning vehicle-related fatalities in Australia, Greece, and the United States which showed that most fatalities occurred at night (Ahmed et al., 2018). Eleven percent of incidents occurred in twilight (semi-darkness or half-light) when light levels were reduced, and 31% ($n = 23$) of incidents occurred in daylight when natural lighting was good. When daylight incidents are considered, the majority occurred in the afternoon 16% ($n = 12$), 8% in the morning ($n = 6$), and 7% occurred around noon ($n = 5$). Regarding the day of the week, incidents occurred mostly just before the weekend (Friday, 24%; $n = 17$) and in many cases at night, and noticeably at weekends (Sunday, 17%; $n = 13$ and Saturday, 15%; $n = 11$). On working days, large numbers of incidents occurred on Mondays (14%; $n = 10$).

In terms of the types of locations where fatal incidents occurred, the majority of incidents occurred when victims were attempting to cross creeks, bridges or causeways (87%; $n = 64$) and the crossings were flooded due to rising water levels. Much smaller proportions occurred at a ford or weir, or on a normal stretch of (flooded) road.

TABLE 2 Vehicle-related flood fatalities (2001–2017) and population distribution by State and Territory

	Vehicle-related flood fatalities		Population (Dec 2017)	
States	**(*n*)**	**(%)**	**(*n*) '000**	**(%)**
Queensland (QLD)	52	54.2	4,965.0	21.6
New South Wales (NSW)	29	30.2	7,915.1	34.4
Victoria (VIC)	6	6.3	6,385.8	27.7
Total of other states	9	9.3	3772.1	16.4

The findings around the temporal aspects of vehicle-related flood fatalities have implications for emergency services and emergency broadcasters regarding the timing of communication campaigns and broadcast messaging. Although emergency services are likely to be familiar with overall weather patterns to optimise the timing of their campaigns, the ability to better target the timing of public safety messages on radio or social media can be informed by these findings.

3.1.3 | Situational factors

Detailed analysis was undertaken to identify the main situational factors associated with vehicle-related flood fatalities. These include: the presence of alcohol, whether engaged in work duties/on duty, the flow of the water, the weather conditions, proximity to driver's home, and the reasons for entering into floodwater. In addition, other factual information about the incidents, such as the type of vehicle involved, the number of fatalities per event, the number of occupants present in the vehicle, the number of occupants who escaped from the vehicle, and the causes of death has also been extracted and collated. A number of additional situational variables were considered for this analysis, such as water depth, signage, width of floodwater at crossing, vehicle status at the time of incidents, peer or group or social influence; however, details in coronial findings were insufficient, or too inconsistent, to incorporate these variables for the majority of incidents.

Data relating to situational factors are shown in Figure 11 and Table 3 for the 74 fatal incidents. Additional situational data relevant to the 96 individual fatalities is shown in Figure 12.

The number of occupants in the vehicle at the time of the incident ranged from 1 to 7 (Figure 11a), the number of survivors ranged from 0 to 5 (Figure 11b). In total, at least 131 individuals were involved in the 74 incidents, 43 of whom survived (33%). For five incidents (7% of incidents overall accounting for 8 fatalities), information relating to the number of occupants in the vehicle and number of occupants who survived was not reported in fatality/case records. In 54% of incidents (n = 40) the driver was the sole occupant of the vehicle and was, therefore, also the sole fatality in the incident (Figure 11a). In over a third of the incidents there was one or more passengers in the vehicle (39%; n = 29) at the time of the incident, in 7% of incidents this figure was unknown (Figure 11a). In 60% of incidents (n = 44), no individual was recovered alive (Figure 11b); this statistic comprised 40 single occupant incidents/sole driver fatalities, and four multiple fatality incidents.

A total of 62 incidents (84%) were single fatality incidents, and in the majority of these (n = 40; 64% of single fatality incidents) drivers were alone in the vehicle when they drove into floodwaters (Figure 11c). Twelve passengers died in single fatality incidents, where the driver managed to escape (Table 3).

According to post mortem reports, drowning was identified as the primary medical cause of death in 66% of the recorded fatalities, 24% occurred due to injury while drowning, for example, injury to head, chest, neck etc. In 10% of fatalities death occurred due to other physical conditions triggered by trauma before or after drowning (such as coronary atherosclerosis, hypertensive heart disease, emphysema, anoxia) (Figure 12a).

The presence of alcohol and drugs was identified as an important factor in vehicle-related flood fatalities (Figure 12b). For the 38 fatality cases in which drug and alcohol levels were tested/able to be tested, 55% of the fatalities (n = 21) were identified to have alcohol in their urine or blood from autopsy reports. In most fatality cases in which the presence of alcohol was unknown (n = 58), an alcohol level was not identified due to decomposition of the body (when the recovery of the deceased had been delayed) or not verified by police after incidents where the driver survived but was responsible for a passenger death.

There were 21 fatalities in which alcohol was recorded. These fatalities occurred in 16 incidents, and comprised nine drivers; eight sole driver/single fatality incidents and one multiple fatality incident, and nine passengers in five incidents. This result is supported by a recent study in Australia where alcohol was identified as present in just over a fifth (21%) of all flood-related nonaquatic transport incidents (Peden et al., 2017) and in a study in Sweden where one third of drivers (32%) tested positive for alcohol

TABLE 3 Distribution of fatalities (n = 96) by incident (n = 74) and in-vehicle role (driver/passenger)

Number of fatalities per incident	Number of incidents		Number of driver fatalities		Number of passenger fatalities		Number of unknown (driver/passenger) fatalities	
	N	%	N	%	N	%	N	%
1	62	84	49	51	12	12	<5	<5
≥2	12	16	9[a]	9	18	19	<5	<5
Total	74	100	58	60	30	31	8	9

[a]This includes motorcyclists who were categorised as 'drivers' in the analysis.

in vehicle-related flood incidents (Stjernbrandt, Öström, Eriksson, & Björnstig, 2008). In addition, there were five fatalities, in which drugs were present.

Although it is not a significant proportion, it is worth noting that 5% of fatalities (n = 5) occurred to individuals who were performing work-related duties (on duty, for example, emergency services, truck drivers) at the time of the fatal incident (Figure 12c).

Weather, water flow conditions, and journey characteristics at the time of entering floodwater are noted in Figure 13.

In this study, although the flooding events were primarily precipitation based (none was due to river or dam break) in investigating weather conditions (Figure 13a) at the time of the incident, information was not available in coronial findings for a large proportion of incidents (71% of incidents). However, heavy rainfall was reported during 12% of incidents (n = 9). There was no rain at the time of nine incidents (13%), but heavy rainfall was reported by witnesses just prior to these incidents. Regarding the water itself, fast flowing or rapidly increased floodwater over crossings, bridges or causeways were the environmental characteristics present in almost two thirds of incidents (63%; n = 46), and moderate water flow was reported in nine incidents (11%) (Figure 13b). Fast-moving, unpredictably rapidly rising floodwater was mentioned in many incidents, which lifted or floated vehicles within very short times. More than two thirds of vehicles (68%, n = 51) were being driven en route to a destination; with the majority of these journeys en route to home (n = 22, 43%), 8% (n = 6) were attempting to evacuate, and 8% were others such as working/on duty when the vehicle entered the floodwater (Figure 13c). The proximity of the incident from the driver's home was calculated for all incidents where home address information of the driver was noted. These data are presented in Table 4.

It was identified that out of 74 incidents, just under half (43%; n = 33) occurred within 20 km of home. Less than a quarter of incidents occurred more than 20 km from home. The findings suggest that a combination of familiarity and/or opportunity is an important feature of the fatality data. Although it is likely that drivers are more familiar with locations closer to their homes, and may feel more confident to judge local risks (and possibly be more prone to making errors) it is also likely that, statistically, they would be driving in these locations more frequently, and hence have more opportunity to be in these areas.

Vehicle stability in floodwater research in Australia (Smith, Modra, Tucker, & Cox, 2017) found that the vehicle stability threshold in terms of floodwater flow and depth could vary due to vehicle size and operation mode.

TABLE 4 Distribution of incidents (n = 74) with respect to proximity to driver's home

Proximity to driver's home	*N*	%
Less than 10 km	21	28
10–20 km	11	15
More than 20 km	15	20
Address unknown (passenger fatality incidents where driver survived)	15	20
Address unknown (driver fatality incidents but address unavailable)	11	15
Total	76[a]	100

[a]This total includes motorcyclists who were categorised as 'drivers' in the analysis, therefore there are 76 drivers in 74 incidents.

TABLE 5 Distribution of incidents (n=74) with respect to vehicle type

Vehicle type	*N*	%
Car, e.g., sedan, hatchback	21	28
Sports utility vehicle (SUV), e.g., range rover, land cruiser	19	26
Utility vehicle ('ute'), e.g., dual cab, pick-up truck	15	20
Others (Motorbike, Truck, Station wagon, Van, Tractor, Gator)[a]	12	16
Unknown	7	9

[a]Vehicles combined here to ensure low incident numbers are not identifiable.

Thus, characteristics of the motor vehicle were regarded as important features reported by police to capture in our analysis. However, the study faced difficulties in classifying vehicles as their characteristics were reported in various ways; for example: by size, that is, small, medium, large; by manufacturer, that is, Toyota, Holden, Land Rover; by type, that is, SUV, ute (utility vehicle), van, truck; and by wheel operation, that is, 2WD, 4WD, all-wheel drive. Table 5 summarises vehicle type, as this category of description was used most frequently in official records.

As can be seen from Table 5, just under a quarter of incidents (28%) occurred in sedan cars, 26% in sports utility vehicles (SUVs) and 20% in utility vehicles (utes). At least 29% of all vehicles trapped in floodwater were officially reported as four-wheel drive vehicles (4WD). This finding represents a well-established trend noted in Australia (Haynes et al., 2017; Peden et al., 2017) in which 4WD vehicles account for an increasing number of vehicle-related flood fatality incidents. In total, some 229 flood fatalities in Australia were associated with vehicles between 1960 and 2015 where 64% of vehicle-related flood fatalities were associated with sedans and 19% with 4WDs (Haynes et al., 2017). Since 1960, the prevalence of transport related fatalities associated with sedans has decreased (76 death before 1960 and 147 since 1960), whilst fatalities involving 4WDs has increased (only 2 deaths prior to 1960, 51 death since 1960) (Haynes et al., 2017). Recent flood fatality analysis on nonaquatic transport incidents in Australia (Peden et al., 2017) reported, victims were commonly in cars (39%), utilities (31%), and 4WDs (23%).

Findings relating to situational factors provide rich data to inform communication and education campaigns and other mitigation measures. For example, knowing that fatalities are more likely to occur in driver-only situations and knowing higher risk location and journey characteristics mean that these conditions can be used in advertising and other media. These aspects are also less likely to be salient to drivers or be the ones highlighted in typical road safety campaigns. For instance, drivers may have good awareness of water characteristics and be good at associating deep or fast flowing water with danger, but they might believe that passengers are more likely to encourage risky driving and not think that just 'normal' journeys (rather than urgent one) are likely to result in risk taking in this context.

3.2 | Phase 2

3.2.1 | Analyses of selected incidents

The 11 incidents with complete sets of reports/data selected for more detailed description (refer Figure 1) were analysed in relation to the following:

- Description: who, when, where, and how the incidents occurred.
- Circumstances: water, weather, lighting conditions, location details, vehicle status.
- Reasons identified for accident and death: main findings after the investigation.
- Punishment: what kind of punishment was imposed by law for risky driving.
- Warnings and risks indicators: warnings, barricades, depth markers, guard rails, signage, and so forth.
- Recommendations: suggestions by councils, law enforcers, road transport authority and court.

As can been seen from the listing above, focussing on a smaller number of detailed incidents enabled the identification of a number of additional features not reported on in the Phase 1 analysis, such as reasons for the incident, the outcome/punishment of drivers who survived, and the status and role of warnings and risk indicators at the scene.

The listing below, picks out some distinct elements contained within the official documentation for each of the incidents to highlight key points that were reported to have influenced driver behaviour, or contributed to the fatal incident:

- Incident 1: underestimating the risks, overconfidence in the vehicle and personal ability, past-experience of successful crossings.
- Incident 2: the effect of alcohol and drug consumption responsible for slower reaction times.
- Incident 3: ignoring risk warnings and indicators such as water-depth indicators and signs in the environment (heavy rain). This represents a typical situation for most vehicle-related flood cases.
- Incident 4: ignoring road closure signs, familiarity with location and crossings.
- Incident 5: fatigue due to overtime work, inappropriate flood depth marker.
- Incident 6: failure of emergency service worker to identify water hazards.
- Incident 7: where legal measures were taken and punishment imposed for risky driving.
- Incident 8: absence of road signage and warnings.
- Incident 9: disobeying the directions of emergency services by the drivers.
- Incident 10: when no adequate alternative route available to change journey plan.
- Incident 11: resource constraints for rescue operations by emergency services.

3.3 | Findings from incident analyses

The analysis of coronial findings and witness reports of selected incidents indicated the lowest water depth was 20 cm and the deepest was more than 2 m at the time when incidents occurred. Incidents that occurred at night all had reported absence of adequate street lighting. Visibility was also interrupted by moderate to heavy rain and in some incidents due to branches or broken parts of long trees on roads. The fast-moving rapidly rising floodwater often surprised and misguided the drivers to negotiate floodwaters which resulted in the fatal incidents. In most incidents the vehicle(s) stalled midway through the floodwater, floated, and were washed away, with the vehicle becoming submerged leaving occupants a short time to escape. In some cases, electric auto windows did not open when the engine cut out, and made it difficult to escape.

The effect of alcohol and drugs was also reported to impede survivability in some incidents, being attributed to an incapacity to act or immediately respond just prior to death in various ways, such as judging the water depth and velocity, causing slower reaction times to take decisions to avoid the water course or to enter the water, to escape from vehicle, and/or to help others to escape.

The major reasons identified for accidents and deaths found through investigation of coronial findings were: underestimating the risks, overconfidence in the vehicle and driver's own-ability, past successful crossing experience, familiarity with place and crossings, alcohol and drug intoxication, ignoring warnings and indicators, fatigue, inappropriate flood depth markers, lack of warnings and inadequate risk indicators (no road closure signs), lack of knowledge of assessing water hazards on the road, and incapacity to move or swim that led directly to the fatal incident.

Analysis regarding warnings and signage, found that drivers in fatal incidents were not likely to see or follow warnings, signage and indicators. This in part supports claims that the public's general knowledge and awareness of flood threats on roads is inadequate (Ashley & Ashley, 2008). However, this is as much about ensuring the adequacy of signage and warnings as educating drivers and passengers. In particular, as a number of incidents occurred when visibility was poor, work needs to prioritise communications or structural changes that will have an impact day or night and in heavy rain. Identifying potential high-risk locations is important in order to prioritise and implement time- and place-specific flood operations procedures, such as putting up flood signage, where relevant, either temporarily or permanently. Checking the effectiveness of existing risk indicators and evaluating their efficacy with road users regularly is highly recommended. Inappropriate depth gauges or badly positioned water level markers and false readings of actual depth were identified as a major contributing factor in one incident in this study. In another incident, the submergence of one-meter warning signs and the absence of 2-m flood warning signs confused the driver who then decided to enter floodwater. Installation of sensor systems linked to a flashing light system which indicates 'Road closed when flashing' was recommended by court in that particular incident.

Vehicle drivers died in six of the 11 incidents and therefore, punishments (usually meted out to the driver/controller of the vehicle) could not be applied in those cases. None of the selected incidents reported legal action taken for disobeying road closure signage and barriers.

Analysis of incidents found that a number of rescue attempts were too late, or failed, and recovery processes of the deceased were delayed in a few incidents. These findings highlight the situational complexity of some incidents and also the resource constraints of emergency service agencies, particularly during emergency periods, that is, during or immediately after flooding rains. Further training of emergency personnel, particularly agencies who traditionally do not focus on flood hazards (e.g., fire, police, paramedics), in identifying water hazards would be helpful when facing dangerous operational and rescue activities was recommended in one incident in this study. Fatigue management, safe driving operations and structuring working schedules differently during times of difficult driving conditions (working hours, rosters) could reduce fatalities associated with work duties, and was recommended in another incident in the present study.

3.4 | Strengths and limitations of the study

As noted, although our study has a number of strengths, there are also limitations, such as those related to missing or incomplete data. Although the study included a systematic interrogation of the best source of fatality data and official records of fatalities in Australia, we also identified 14 recent incidents (2016 and 2017) from archived newspapers that were not found in the NCIS database. It is possible, therefore, that additional fatal vehicle-related flood incidents occurred during this time that have been missed in our current analysis. Also, although closed cases from NCIS were included in this study (in which the investigation is completed and reasons for death determined) there were still some incidents with incomplete sets of reports (i.e., missing findings documents, police reports). There was also minimal information available about drivers involved in fatal incidents where they survived (with data mostly relating to the deceased persons). This meant that in these cases some data, such as driver's proximity to home and driver's alcohol level at the time of the incident were unknown/unreported, making interpretation of some incidents less accurate than others, especially regarding drivers' decision-making, risk taking, and other factors that may have been relevant to the incident. This limitation is an important point for practitioners involved in flood fatality research. More detailed flood fatality reporting systems are necessary in order to ensure that all relevant information is collected.

To compensate for missing data, and the use of a restricted set of variables in the Phase 1 analysis, a brief synthesis of 11 incidents was provided for which more complete data were available, making it possible to provide a more comprehensive understanding of the features of recent vehicle-related flood fatality incidents. No technical assessments of water flow (such as cubic meters per second) and no records of national climate data for weather conditions were included in this study. The assessment of water and weather conditions were derived from the assessments of the responding officials, witnesses, or noted by the survivors. Although flood flow records and weather conditions are available for some of the fatality cases, these were not necessarily accurate for the location where the fatality occurred – which may have been anywhere in the catchment, and not necessarily in a location near a flood gauge or for where the weather data were most accurate. It was therefore considered best to rely on the observations of the responding officials and witnesses, although it is acknowledged that these may be subjective. In spite of these limitations, the findings from both phases of analysis provided directions for future research to explore the influence of a number of variables on drivers' decisions to drive into floodwater, and also highlighted the need for greater community engagement in flood risk education, and communication campaigns.

4 | CONCLUSIONS

This research contributes to our knowledge of the demographic, spatial, contextual, and temporal patterns of vehicle-related flood hazards by investigating 74 recent vehicle-related flood incidents in Australia. The study explored age and gender patterns from the viewpoint of both driver and passenger dynamics.

Middle aged and older males were identified as a high-risk group as drivers, whereas young women and children are a vulnerable group as passengers. Most incidents occurred in the east coast of Queensland, in summer (January), on a Friday, in dark (poor lighting) conditions during the evening/night, and in heavy rain. Most of the fatalities occurred whilst on a creek crossing, bridge or causeway. They mostly occurred close to home, where drivers might have been expected to be familiar with the locations and the nature of the roads. The use of alcohol and drugs was identified in official records as a major contributing factor to death in incidents where it was recorded. Water flow/velocity influenced most accidents even when the lowest water level was reported as only 20 cm. Vehicles were mostly 4WDs and ranged across all vehicle sizes. Detailed analysis of a subset of 11 fatal incidents suggested that often vehicles stalled midway through crossing floodwater, only to be swept away and submerged.

Considering the results of the study, educational strategies should be tailored according to the needs of specific groups such as by age and gender (middle-aged and elderly males, young women), high- risk groups (children, emergency workers), in-vehicle role (passengers). Educational campaigns must involve local councils, schools, emergency service agencies, and police as well as vehicle manufactures, and insurance companies to ensure participation and collaboration amongst all, and reinforcing messages about the potential dangers of entering floodwater in vehicles. More should also be done to communicate the risks of entering floodwater in a vehicle from the passenger's point of view, both to support advocacy of passengers (including children) as well as to encourage drivers to view risks from the perspectives of others in the vehicle.

The results also demonstrate a need for improved flood depth indicators and warning signage, with installation of visual cues (flash lighting and automated barricades) in high-risk locations and the enhancement of legal obligations (such as increasing fines and demerit points or licence disqualifications) if intoxicated while driving.

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CONFLICT OF INTEREST

The authors have declared that no competing interests exist.

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ENDNOTE

[1]Queensland Floods Commission of Inquiry, March 2012. http://www.floodcommission.qld.gov.au/

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

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