Brief communication: Loss of life due to Hurricane Harvey

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Abstract. An analysis was made of the loss of life caused by Hurricane Harvey. Information was collected for 70 fatalities that occurred due to the event and were recovered within the first two weeks after landfall. Most fatalities occurred due to drowning (81%), particularly in and around vehicles. Males (70%) and people over 50 years old (56%) were overrepresented in the dataset. More than half of the fatalities occurred in the greater Houston area (n=37), where heavy rainfall and dam releases caused unprecedented urban flooding. The majority of fatalities in Harris County were recovered outside the designated 100- and 500-year flood hazard areas.

1. Introduction and background

Loss of life is one of the most critical consequences of floods. Previous analyses of flood fatalities have focussed on certain regions (Coates, 1999; Zahran et al, 2008; Ashley and Ashley, 2008) and the causes and circumstances of fatalities based on aggregated data for multiple smaller events (Jonkman and Kelman, 2005). Documentation of flood events with significant life loss is scarce and limited to a few cases, such as the flooding of New Orleans due to Hurricane Katrina (2005) (Jonkman et al., 2009) or more general data for large-scale events such as cyclones in Bangladesh (1991) (Chowdhury et al., 1993). However, detailed analysis of mortality during past flood events is important for the development and improvement of consequence and risk models, and to inform policies and public communication to reduce losses during future flood events.

On August 25, 2017, Hurricane Harvey made landfall near Rockport, Texas as a Category 4 storm with maximum sustained winds of approximately 200 km/hour. Harvey caused severe damages in coastal Texas due to its extreme winds and storm surge, but will go down in history for record-setting rainfall and flood-related damages in southeast Texas. Rainfall totals during the six-day period between August 25 and 31, 2017 were amongst the highest ever recorded in U.S. history. Across large portions of southeast Texas, rainfall exceeded 1000 mm. The highest recorded rainfall total was 1539 mm (60.58 inches) in Nederland, Texas near Port Arthur (Blake and Zelinsky, 2018).

The City of Houston and surrounding areas experienced unprecedented urban flooding. Many of Houston's creeks and bayous exceeded their channel capacities, reaching water levels never before recorded, and widespread pluvial flooding was reported

in communities across the greater Houston area on the morning of August 27. While the floodwaters in most areas receded within 24-48 hours after the heaviest rainfall, in a smaller number of areas (e.g. downstream of Addicks and Barker reservoirs), water levels remained elevated for a period of days to weeks. It is estimated that more than 80,000 homes were affected by flooding of at least 46 cm (18 inches) (FEMA, 2017). In parts of Houston, the 3-day rainfall during Harvey has been estimated

5   to have exceeded a 9,000-year event (Oldenborgh et al., 2017).

During the period between August 25 and 31, rising waters necessitated major rescue operations. In total, more than 120,000 people were rescued by professional and volunteer rescuers (FEMA, 2017). No large-scale mandatory evacuation was ordered by the mayor of Houston before or during Harvey, as the risks of evacuating millions of people were considered too high. Instead, people were advised to shelter at home and to prepare themselves. However during the course of the event several

10   local evacuations were ordered for areas with specific risks and circumstances, e.g. in Fort Bend County near the Brazos River. As part of a larger rapid fact-finding effort in the wake of Hurricane Harvey (Sebastian et al., 2017), a dataset of flood fatalities was compiled. The objective of this paper is to analyse the causes and circumstances of the fatalities in southeast Texas due to Hurricane Harvey.

2. Data and methods

15   In order to analyse the Harvey-related fatalities, a database of reported flood fatalities was compiled (Godfroy et al., 2017). Information about the personal characteristics (age, gender) and the location, time of recovery and circumstances of death were included.

The database is limited to fatalities that were recovered within the first two weeks after landfall (August 25-September 8, 2017). Following the definitions adopted by the National Weather Service (2016) a distinction is made between direct fatalities,

20   i.e., those directly attributed to the hydrometeorological event, and indirect fatalities, i.e., those that occur in the vicinity of a hydrometeorological event, or after it has ended, but are not directly caused by impact or debris from the event.

The dataset was compiled using both official government sources and media reports. In the days after Hurricane Harvey, information about casualties appeared mostly on local news websites. Official reporting on casualties and the level of detail

25   varied greatly between counties. Harris County, where most of the casualties occurred, is the only county at the time of writing that has published an official and public list of casualties (IFS, 2017).

3. Results

Based on our analysis, at least 70 deaths can be attributed to Hurricane Harvey. The fatalities occurred across 14 counties with a large spatial scatter throughout southeast Texas. Approximately half of the casualties (37 out of 70) were located in Harris

30   County. This is the most densely populated county in the affected area and it was severely affected by flooding . Six fatalities

occurred in Orange County around the City of Beaumont and in Galveston County south of Houston. The recovery locations of the fatalities are shown for the state of Texas (fig. 1) and for Harris County which covers a large part of the Houston area (fig. 2). For Harris County the 100- and 500-year floodplains have been added using the FEMA National Flood Hazard layer available through the Texas Natural Resources Information System (TNRIS) (TNRIS, 2017). Of the 37 casualties in Harris

5 County, 18 were located inside the designated 500-year floodplain, of which 8 in the 100-year floodplain. Also at the state level most fatalities (37 – so 53%) occurred outside the 500 year floodplain. 33 fatalities (47%) occurred within the 500 year floodplain, of which 14 in the 100 year floodplain. Four casualties occurred in hospitals which are not located in the designated floodplains. The majority of all fatalities (80%) occurred within the first seven days after landfall.

Figure 3 shows an overview the causes and circumstances of death. Most fatalities were caused by drowning (57 out of 70;
10 81%) so directly due to the event. Many of the casualties were discovered after floodwaters had receded and some were even recovered in the second week after landfall of Harvey.

A significant proportion of the fatalities drowned as a result of driving a vehicle into floodwaters or getting swept away by the current while getting out of a car (confirmed for 21 of 57 drowning fatalities). A tragic example is a case were six individuals of one family, including four children, drowned when their van was swept off a flooded road by the current and ended up in
15 high water in east Houston. A small number of deaths (8 of 57 drowning casualties) were found inside buildings after the flood water receded. Six people drowned when their boat capsized, while they were trying to rescue residents in need from their flooded houses. It is unknown whether these people wore life jackets. 28% of the drowning fatalities (16 out of 57) were recovered in the open and no further information on the exact circumstances was available.

The other fatalities (19%) were due to indirect causes. Electrocution and lack of medical treatment each caused four fatalities.
20 The category "lack of medical treatment"

 includes fatalities that occurred when (very) ill people were not able to gain access to proper treatment in time (i.e. dialysis or treatment of asthma and heart conditions). A smaller number of fatalities occurred due to other causes such as physical traumas (i.e. car accidents, falling trees) (n=3) or infection due to contact with contaminated flood water (n=1)

Of the fatalities, 70% were male and 30% were female. This distribution is in line with findings for previous floods in which
25 it has been suggested that males are more likely to be involved risky activities, such as driving during flooding and high water rescues (Jonkman and Kelman, 2005).

The age distribution was also analyzed: 9% of the fatalities were younger than 18, whereas 56% of fatalities were older than 50 years and 29% older than 65, suggesting an increased vulnerability of people above 50 years old.

30 **4. Discussion**

The previous analyses are based on data gathered from a combination of official public sources and media sources. When only information from the official source for Harris County was utilized (N=37), findings with respect to the importance of drowning (92%), and the over-representation of males (73%) were still obtained.

The present analysis is based on a dataset that includes 70 fatalities due to Harvey. Smith et al. (2017) reported 84 fatalities for the event. A difference could be due to the selection criteria. Local media have reported at least ten other casualties. These were not included in the present database when the relationship with Hurricane Harvey could not be confirmed by authorities or when no additional details on the death or incident were released.

5   Of the 37 casualties in Harris County, only 22% occurred within the designated 100-year floodplain – used as the primary delineation of flood risk in the United States – and 49% within the 500-year floodplain. This is in line with previous research which finds that in the greater Houston region, the 100-year floodplains have served as a poor predictor the location of damaging flooding (Highfield, Norman, and Brody, 2013; Brody et al., 2015; Blessing, Sebastian, and Brody, 2017). While the flooding from Hurricane Harvey should be expected beyond the 100-year and even 500-year floodplains, our finding also

10   suggests that high hazard areas outside of the floodplain, such as low water crossings, have not been adequately delineated or communicated to the public. . As future work it is recommended to recreate and map the flood conditions during Harvey based on modelling and field observations to better understand the flood conditions at the time and location of fatalities.

Previous studies have concluded that the majority of fatalities during Atlantic tropical cyclone events occur due to flooding, particularly due to storm surge (Rappaport, 2014). During Harvey, most fatalities were associated inland flooding in the greater

15   Houston area, primarily driven by Harvey's extreme rainfall. Storm surge of about 2 to 3 meters mainly affected local coastal areas in south Texas and two fatalities were reported in this area.

Findings for Harvey can be compared to other events that affected the same region. During Hurricane Ike (2008) only 11% of the 74 fatalities were due to drowning (Zane et al., 2011). Others were due to injuries and illnesses, partly also related to the mass-evacuation. In terms of rainfall-driven flooding there are more similarities to Tropical Storm Allison (2001). Tropical

20   Storm Allison dropped more than 762 mm (30 inches) of rainfall over the eastern portion of Harris County June 5-9, 2001. The event led to 41 fatalities, of which 23 occurred in Texas (Stewart, 2001). Twenty-seven deaths were attributed to drowning from freshwater flooding during T.S. Allison.

It is estimated that more than 100,000 people were directly affected by floodwaters from Harvey. The overall mortality is thus smaller than 0.1% which is an order lower than typical mortality values reported for storm surge flooding which are around

25   1%, such as for New Orleans (Jonkman et al., 2009). However, the flooding of Houston is expected to be less deadly than those in New Orleans during Katrina for a number of reasons: flood depths and flow velocities in most areas were lower, waters receded more quickly, and people were better warned for flooding beforehand. Still, during Harvey the great majority of fatalities occurred due to drowning, especially in and around vehicles, but relatively few fatalities (11% of the total) were found in buildings.

30   The findings also provide a basis for policy recommendations. Following previous studies (Kolen, 2013; Jonkman and Kelman, 2005; Drobot et al., 2007), it is clear that driving on flooded roads is extremely dangerous and several risks are associated with rescue clean up and recovery (e.g. electrocution, CO poisoning). Results of this study and findings from previous floods in the Houston area can be used to identify 'high-risk' areas for drowning, such as low-water crossings. During future events, preventive closure of these areas could be considered. Life loss is influenced by individuals' behaviour and the warning and

evacuation strategy by the government (Chowdhury et al. 1993; French et al., 1983; Parker et al., 2009). The events during Harvey can also be utilized to evaluate and improve the performance of the evacuation strategy and emergency management for the region, also addressing the need for timely evacuation from specific high risk areas.

The present study focussed on mostly direct fatalities during and shortly after the event. Analysis and recording of longer term health impacts is recommended. Finally, standardized data collection for future events is recommended to provide a wider data basis and better information for prevention and public communication to avoid future flood fatalities.

5. Data availability

The database that was used is publicly accessible at the data repository of the Dutch 4TU.federation (Godfroy et al., 2017).

6. Acknowledgements

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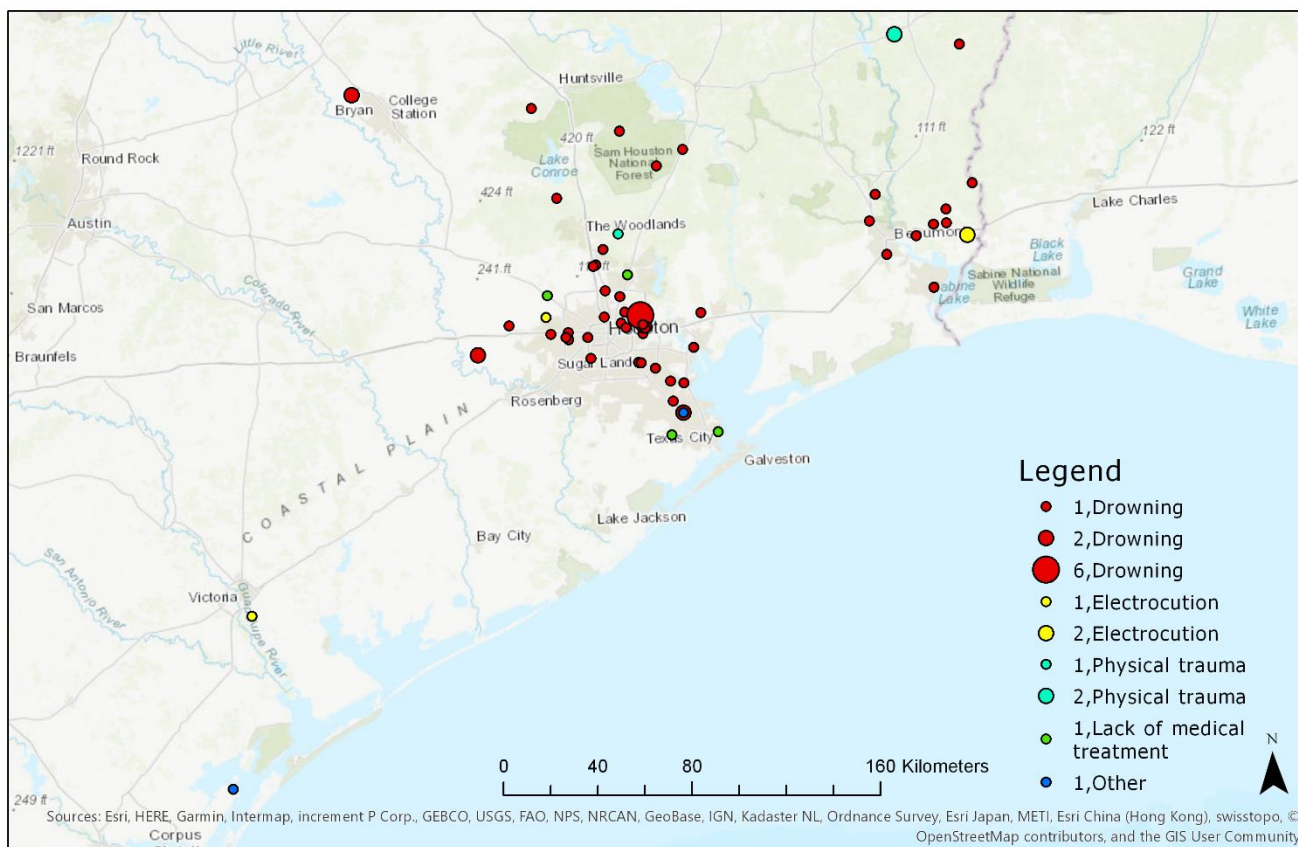
Figure 1: Location and cause of fatalities due to Hurricane Harvey in Texas as of September 8, 2017.
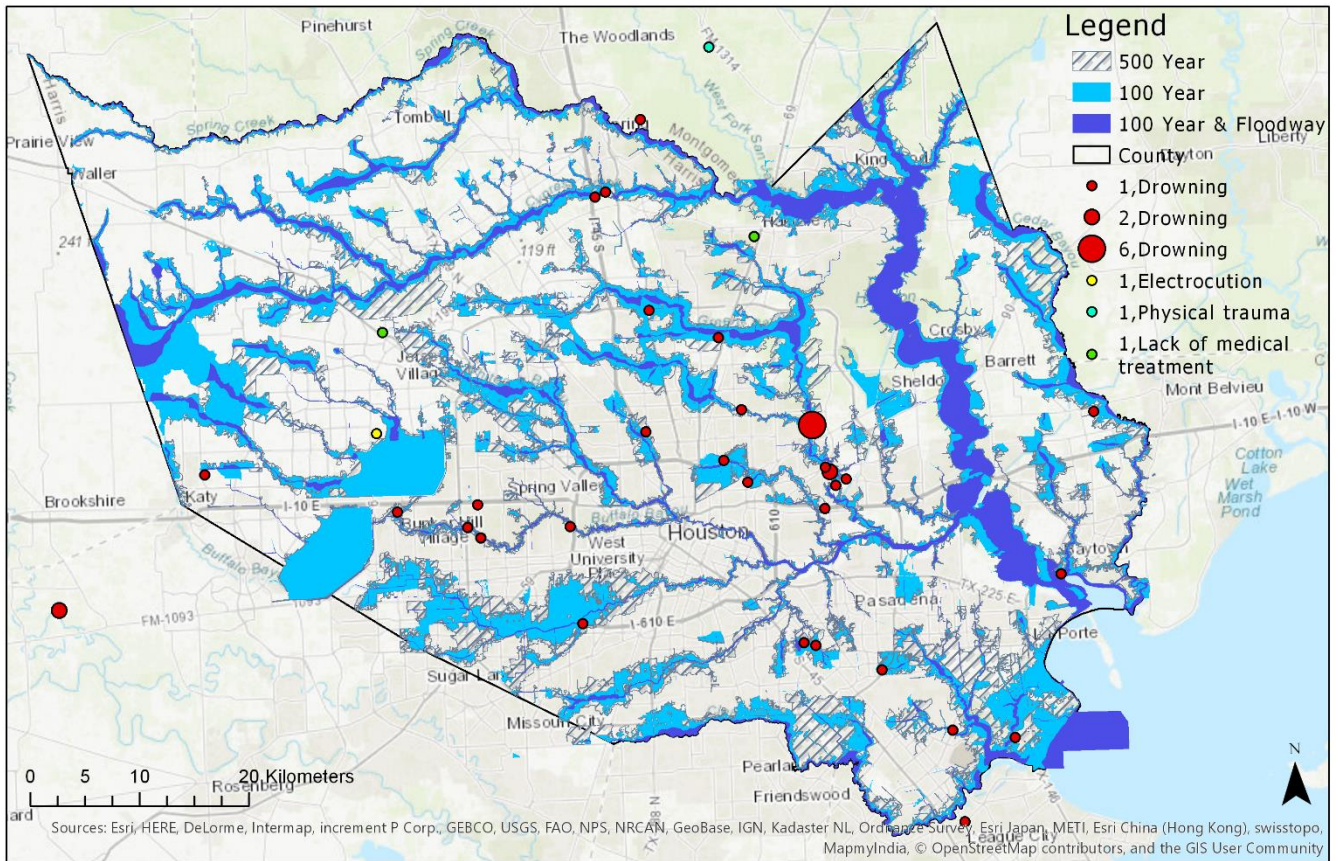
Figure 2. Location and cause of fatalities due to Hurricane Harvey in the Houston metropolitan area (Harris County) as of September 8, 2017. For the people who died in the hospital (4), the location of the hospital is shown.

Cause of death

- Drowning
- Physical trauma
- Lack of medical treatment
- Electrocution
- Other

81%
3%
6%
6%
4%

Drowning - subcategories

- In a vehicle
- Swept away while exiting vehicle
- From a boat
- As a pedestrian
- Inside a building
- Found outside - details unknown

8%
9%
9%
11%
23%
21%
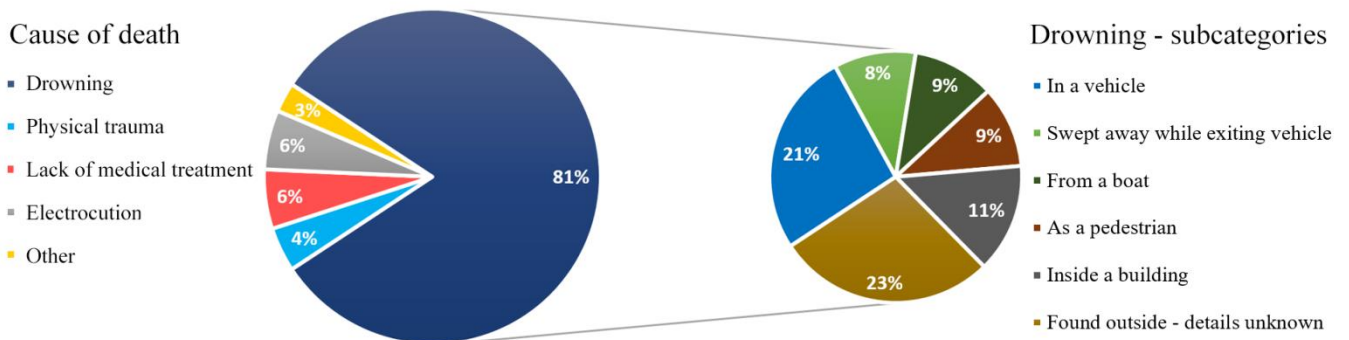
Figure 3**. Causes of death for Hurricane Harvey (n=70).**