Journal of Hydrology 519 (2014) 863–870

Contents lists available at ScienceDirect

Journal of Hydrology

journal homepage: www.elsevier.com/locate/jhydrol

# Analysis of flash flood parameters and human impacts in the US from 2006 to 2012

Maruša Špitalar [a,b], Jonathan J. Gourley [c,*], Celine Lutoff [d,b], Pierre-Emmanuel Kirstetter [e,c], Mitja Brilly [a], Nicholas Carr [e]

[a] University of Ljubljana, Faculty of Civil and Geodetic Engineering, Ljubljana, Slovenia
[b] Cooperative Institute for Mesoscale Meteorological Studies, University of Oklahoma, Norman, OK, USA
[c] NOAA/National Severe Storms Laboratory, Norman, OK 73072, USA
[d] University Grenoble Alps, UMR PACTE, F-38100 Grenoble, France
[e] Advanced Radar Research Center, University of Oklahoma, Norman, OK 73072, USA

ARTICLE INFO

*Article history:*
Received 7 February 2014
Received in revised form 1 July 2014
Accepted 2 July 2014
Available online 30 July 2014
This manuscript was handled by Geoff Syme, Editor-in-Chief

*Keywords:*
Flash floods
Human impacts
Fatalities
Injuries
Statistical analysis

SUMMARY

Several different factors external to the natural hazard of flash flooding can contribute to the type and magnitude of their resulting damages. Human exposure, vulnerability, fatality and injury rates can be minimized by identifying and then mitigating the causative factors for human impacts. A database of flash flooding was used for statistical analysis of human impacts across the U.S. 21,549 flash flood events were analyzed during a 6-year period from October 2006 to 2012. Based on the information available in the database, physical parameters were introduced and then correlated to the reported human impacts. Probability density functions of the frequency of flash flood events and the PDF of occurrences weighted by the number of injuries and fatalities were used to describe the influence of each parameter.

The factors that emerged as the most influential on human impacts are short flood durations, small catchment sizes in rural areas, vehicles, and nocturnal events with low visibility. Analyzing and correlating a diverse range of parameters to human impacts give us important insights into what contributes to fatalities and injuries and further raises questions on how to manage them.

Published by Elsevier B.V.

## 1. Introduction

Flash floods cause extensive disruptions to a diverse range of living, working, societal, and spatial environments, which make them one of the deadliest natural hazards worldwide. Flood damages do not only depend on precipitation amounts but are also a consequence of geomorphological factors and human influences. High velocity runoff in small basins, short lead times, fast rising water, and transport of sediments make flash floods extremely dangerous to property, infrastructure, and human lives (Creutin et al., 2013). The framework of this paper is an integrated analysis of temporal and spatial flash flood parameters and human impacts (injuries, fatalities). The aim is to cross-correlate them to identify the sensitivity of each parameter in order to shed light on the interplay between societal factors and the natural hazard.

In the field of flash flooding, Gruntfest and Handmer (2001) emphasized interdisciplinary work by bringing social sciences into physical sciences. Creutin et al. (2013) did the same with a framework for collaboration between hydrologists and social scientists. An integrated approach incorporates numerous layers that are, despite different aspects, interrelated and necessary for effective decision making and solving complex problems. Considering that the field of flash flooding is a complex blend of different sciences, we evaluated diverse parameters in an interdisciplinary way. There have been some studies that helped us understand different angles of analysis of flash flood fatalities. Jonkman and Kelman (2005) focused on 13 flood events that happened in Europe and the US in order to improve understanding of the circumstances of flood deaths and contribute to prevention strategies. Other studies have also focused on defining and understanding circumstances surrounding flood fatalities for different environments such as Australia (Coates, 1999) and Puerto Rico (Staes et al., 1994).

French et al. (1983) explored fatalities from 1969 to 1981 and pointed out a higher percentage of vehicle-related fatalities while Sharif et al. (2012) focused on vehicle fatalities specifically in Texas. Additional information about the cause of the vehicle-related deaths is needed in order to reduce their impact. Are drivers simply unaware of the dangers of water moving over the

* Corresponding author. Address: National Weather Center, 120 David L. Boren Blvd, Norman, OK 73072-7303, USA. Tel.: +1 405 325 6472.

*E-mail address:* jj.gourley@noaa.gov (J.J. Gourley).

http://dx.doi.org/10.1016/j.jhydrol.2014.07.004
0022-1694/Published by Elsevier B.V.

roadway? Do they have a false sense of security in their vehicle? Or perhaps they simply donot see the impending danger? Some of these social connotations were addressed by Ruin et al. (2008) who utilized qualitative research tools to explore information regarding flood victims on one hand and hydrometeorological circumstances on the other.

Creutin et al. (2009) has shown the influence of the watershed on society. Catchment response time is related to the size of the catchment, its geomorphological characteristics, and the natural hazard itself, thus it varies in space and time. Small catchments tend to be particularly vulnerable to human impacts because there are few structural defenses against flooding and individual exposure is enhanced (Drobot and Parker, 2007). Ruin et al. (2008) also showed through analysis of a major flooding event in the south of France in September 2002 that half of the flash flood fatalities occurred in catchments around 10 $km^2$ in area. Given the link between enhanced societal impacts and catchment response time, further consideration of additional factors is required in order to prevent fatalities, which may have been avoided due to mitigating actions and evacuations immediately following the onset of the storm (Montz and Gruntfest, 2002).

The dynamics of small-sized catchments is complex as it includes geomorphological characteristics, degree of channelization, urbanization, and initial soil states and river conditions. The importance of catchment dynamics was analyzed by Costa (1987). The sample contained 12 of the largest flash floods in the conterminous United States, where in small basins (0.39–370 $km^2$) the ratio of maximum rainfall-to-runoff was examined. He also evaluated factors such as the channel hydraulic radius, depth, velocity, energy, channel side slopes, shear stress, and unit stream power, among others. Results showed that shear stresses and unit stream powers produced by floods in small basins are higher by several hundred times than floods in large rivers. This was the case even with the small basins that had lower unit discharges. This indicates that floods are not controlled by absolute discharges alone. This is just one aspect of small watersheds and it is important to point out the differentiation from larger basins when examining human impacts. Connecting and defining human impacts with size of the watershed is important for forecast improvements and flash flood damage reduction and mitigation.

In this study, the distributions of human impacts from flash flooding (fatalities and injuries) vs. events with no human impacts are evaluated as a function of basin size, population density, seasonality, time of day, and flood duration. This paper uses an interdisciplinary, socio-hydrological approach of analyzing hazardous events, in our case flash floods, and contributes towards better understanding of human vulnerability in this context. Due to the brevity of the six-year time period used in the study, it is not intended to provide a robust, climatological analysis of flash-flooding impacts as was done in Ashley and Ashley (2008). However, this time period corresponds to precise locations and times of reported flooding in the database and includes a very large sample of 21,549 events. Thus, the results reach well beyond case-based analyses to more statistically significant findings. The paper is organized as follows. The next section discusses the details of the data analysis framework. Then, we analyze several influencing factors on the human impacts, followed by a summary of results and conclusions.

## 2. Data analysis framework

In this study we used a recently assembled database of flash flooding described in Gourley et al. (2013), available at http://blog.nssl.noaa.gov/flash/database/, to carry out our analysis of crucial factors involved in human impact and non-human impact flash-flood events. One component of the database includes *Storm Data* reports collected by the National Weather Service. These reports include extensive information about the event type, year, month, state, county, region, time zone, beginning date and time, end date and time, property damages, fatalities (direct, indirect), injuries (direct, indirect), flood cause, location (latitude and longitude), and event narratives. All of the indirect and direct fatality reports were grouped together, as well as for the injury reports. The time scale of collected data in the compiled database goes from October 2006 until 2012 and involves 21,549 flash flood events. There were 224 total reports of injuries and 326 fatalities in the database. *Storm Data* reports cover a much longer timeframe than that, but the recent six years have the reports stored as georeferenced polygons, whereas they were previously reported by political boundaries (i.e., by county). Population density, event duration, time of day, location, and basin size were all co-analyzed with human impacts for each event. Considering that 20,999 or 97.4% of flash flood events had no human impacts, it was important to include this group into the analysis for comparative purposes.

## 3. Results

### 3.1. Annual and interannual variability of flash flood events

Using descriptive statistics to characterize the dependency of impacts on the considered physical parameters provides an interdisciplinary approach to analyzing the societal factors of flash floods. It exposes various aspects of the problem and provides a more holistic understanding of flash flood impacts, a necessary first step before implementing mitigating practices and procedures. Fig. 1 shows the impacts across years for the high-resolution *Storm Data* reports from October 2006 through the end of 2012. Only three months of reports are included in 2006, which explains the low numbers for that year. The numbers of impacts are computed in terms of number of events per year with injuries, fatalities, and then those that yielded no human impacts, referred to hereafter as NHI events. Annual variations from October 2006 to 2012 reveal that injury and fatality events are correlated and there are two peaks in 2007 and 2010. NHI events have less interannual variability, but there was a noted lull in events in 2012, which coincided with a significant warm season drought that affected the southern Great Plains of the U.S.

Fig. 2 shows the monthly anomalies computed from the annual median values of injury, fatality and NHI events. Positive anomalies

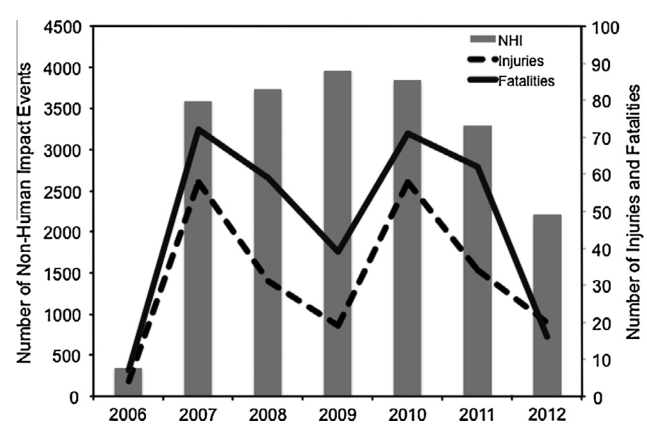


**Fig. 1.** Annual flash flooding events that resulted in no human impacts (NHI), injuries, and fatalities for the 6-year *Storm Data* database used in the study. Note that 2006 only contains events from October through December. The NHI events (gray columns) are plotted against the primary ordinate while the injuries and fatalities are on the secondary ordinate.