Nat. Hazards Earth Syst. Sci., 18, 963–968, 2018
https://doi.org/10.5194/nhess-18-963-2018

Natural Hazards and Earth System Sciences
Open Access

Preface: Natural hazard event analysis for risk reduction and adaptation

Kai Schröter[1], **Daniela Molinari**[2], **Michael Kunz**[3,4], **and Heidi Kreibich**[1]

[1]Helmholtz Centre Potsdam, German Research Centre for Geosciences GFZ, Section 5.4 Hydrology, Telegrafenberg, 14473 Potsdam, Germany
[2]Department of Civil and Environmental Engineering, Politecnico di Milano, Piazza Leonardo da Vinci 32, 20133 Milan, Italy
[3]Institute of Meteorology and Climate Research, Karlsruhe Institute of Technology (KIT), 76344 Eggenstein-Leopoldshafen, Germany
[4]Center for Disaster Management and Risk Reduction Technology (CEDIM), Karlsruhe Institute of Technology (KIT), 76344 Eggenstein-Leopoldshafen, Germany

Correspondence: Kai Schröter (kai.schroeter@gfz-potsdam.de)

Published: 26 March 2018

1 Introduction

Despite significant efforts to reduce the risk from natural disasters, global disaster losses have been increasing in recent decades (IPCC, 2012; UNISDR, 2015). In the light of the projected rise of risk in many regions due to both the effects of climate change and augmented exposure in risk-prone areas (Mechler and Bouwer, 2014; Hallegatte, 2014; Elmer et al., 2012), an improved understanding of the fundamental causes of disasters and the identification of the main risk drivers are key to effective disaster risk reduction (IRDR, 2011). The third UN World Conference on Disaster Risk Reduction in March 2015 stated that disaster risk management should be based on an understanding of disaster risk in all its dimensions of vulnerability, capacity, exposure of persons and assets, hazard characteristics and the environment. Such knowledge can be used for risk assessment, prevention, mitigation, preparedness and response (UNISDR, 2015). In this context, event-centred research based on a multi-disciplinary approach is particularly suitable to learn from disasters about the complex interactions between the natural hazard, technical installations and infrastructures, and the societal institutions and capacities (Kunz et al., 2013; Kreibich and Thieken, 2009). This will help to improve the basis for integrated risk management and "building back better" (Merz et al., 2010). For the example of fluvial floods, Kreibich et al. (2017a) have compiled an international set of paired event studies which reveal the potential of societies to adapt and to reduce flood risk by learning from events. Further, regular evaluations of the implemented risk management strategy in the light of events, their management and consequences as well as all involved costs are essential for an efficient adaptation to changing risks (Kreibich et al., 2014).

The special issue "Natural hazard event analysis for risk reduction and adaptation" presents a series of contributions on advances in the field of event-centred research. It covers various aspects of methodological concepts including monitoring, analyses and structured documentation of natural hazard events as well as approaches for their rapid evaluation. Further, it contains analyses of actual events from a variety of natural hazards including heatwaves, wildfires, earthquakes and floods.

The special issue was organized as a result of the EGU 2015 NH9.2 Session "Forensic Disaster Analysis – Learning from Disasters" held in Vienna in April 2015 and also includes some outcomes of the 3-year research period of the Center for Disaster Management and Risk Reduction Technology (CEDIM; http://www.cedim.de) on near-real-time Forensic Disaster Analysis (FDA) from 2012 to 2015.

2 Event-centred research contributions

2.1 Methodological concepts, models and databases

Event-centred research aims to improve our understanding about complex interactions between multi-faceted processes in the natural environmental and socioeconomic systems.

Deriving general conclusions from the analyses of events is a challenge due to the uniqueness of each extreme event and requires a structured approach. With the objective to uncover the main drivers for increasing disaster risk, Keating et al. (2016) introduce a new methodology referred to as post-event review capability (PERC). It aims to provide accessible, consistent and generalizable insights and practical recommendations about disaster risk reduction, disaster risk management (DRM) and disaster resilience. The methodology is grounded on disaster resilience with three major components: (1) systems (*what* component), (2) institutions (*how* component) and (3) agents (*who* component), including interactions with one another. In that sense, it goes beyond an exclusive focus on DRM. All PERC reports follow a standardized procedure to ensure the holistic view by considering five elements: (1) physical context of the disaster event, including relation to other events; (2) socioeconomic disaster landscape, including trends in physical and social vulnerability; (3) exploration of the components of the DRM cycle, preparation, response and recovery phases, including success and failures; (4) key insights by identifying both drivers of the success across the DRM cycle and critical gaps; and (5) recommendations and opportunities for action in the future including building back better, so that future shocks have a lesser impact. By applying the PERC concept to seven severe flood events on different scales in different regions of the world, the authors succeeded in drawing generalizable conclusions across all events investigated. It is found that policy makers and practitioners in DRM face strikingly similar challenges across extremely varied contexts, indicating encouraging potential for mutual learning and effective adaptation.

Non-stationarity of natural and human systems, as for instance induced by climate and global change, may induce changes in the frequency of extreme events which in turn impact the probability of failures and the outcomes of risk assessments. Therefore, planning for adaptation needs to be agile in order to take up these possible changes. In view of increasing trends in natural hazards, Read and Vogel (2016) propose the application of hazard function analysis as an alternative methodology for describing the probabilistic behaviour of non-stationary natural hazards. Hazard function analysis, with applications in medicine, economics, engineering and many other disciplines, offers a well-established set of tools for conducting a time to event analysis and for understanding the distribution of failure times for a given process. However, the application of this methodology to natural hazard has not been investigated before. Hazard function analysis comprises three primary functions: (1) the hazard function, which represents the failure rate; (2) the survival function, which describes the exceedance probability for the random variable time; and (3) the cumulative hazard function, which accounts for the total number of failure events over time. Read and Vogel (2016) link the probabilistic properties of the random variable time to failure with the properties of the exceedance probability for a non-stationary natural hazard event. The two-parameter generalized Pareto distribution is used to introduce stationary and non-stationary models for natural hazard events for which the hazard function analysis relationships are derived. Assumptions on small and large trends in the data are used to exemplify the implications of non-stationarity on design. The results of their study demonstrate the usefulness of the cumulative hazard function as a metric for describing reliability over a certain planning horizon. Such information may support the communication of risks of failure associated with infrastructure design and adaptation planning.

Another important aspect of event analyses is the use of the gained knowledge for the development of operational tools. In this respect, Balbi et al. (2016) demonstrate that quantitative and semi-quantitative data can complement subjective and local knowledge and how this knowledge can be incorporated in an early warning system for urban flood risk. Balbi et al. (2016) present a spatially explicit Bayesian network model to assess the urban flood risk to people. Risk is assessed in terms of the likelihood of non-fatal physical injury, post-traumatic stress disorder and death. Model uncertainty is quantified by providing probability distributions for all of its outputs. The model application is demonstrated at the lower part of the Sihl Valley, Switzerland, where the city of Zurich is located. In this case study, the effect of improving an existing early warning system is assessed. Improvements of the warning system comprise an increased reliability and lead time as well as a larger number of people reached by the warning. The Bayesian network model results indicate that the potential benefits of an improved early warning in terms of avoided human impacts are particularly relevant in case of a major flood event.

Adaptation planning and risk mitigation strategies relay on reliable and consistent empirical data. The structured documentation of events is therefore an important pillar for learning from disasters (IRDR, 2015). Empirical data from natural hazards are also essential for model development and validation (e.g. Schröter et al., 2014). Menoni et al. (2016) and Vennari et al. (2016) present approaches for event documentation and event databases. Menoni et al. (2016) present a model to develop multipurpose complete event documentations to support a more integrated interpretation of flood events. The framework organizes available information after the event according to five "logical axes": (1) exposed sectors; (2) types of damage; (3) spatial scales of analysis; (4) temporal scales of analysis; and (5) hazard, exposure and vulnerability variables. This framework, together with the complementing IT tools (Molinari et al., 2014), supports multipurpose complete event analyses. The outcomes of this structured and formalized analysis may be utilized for the development of more effective risk mitigation strategies comprising the prioritization of interventions, damage accounting and compensation, risk assessment and disaster forensic investigation. The application of this model is exemplified by the November 2012 flood event in the Umbria region, Italy (Menoni et al., 2016). Vennari et al. (2016) discuss a novel database of flash flood events in the Campania Region (South Italy). Available database archive events only distinguishing between floods and landslides, with flash flood events included among the two categories depending on the subjectivity of the database editor. However, flash floods are the most frequent hydrogeological events in the area and more knowledge about them is required for the mitigation of their effects. Starting from available databases, all events in the region were carefully analysed comparing available information with the existing literature on flood events in Campania and the geographical features of affected catchments. This way, temporal and spatial information for 500 flash floods was filtered. In order to reconstruct flood scenarios, flash floods were then classified according to the main geological and geomorphological parameters of the affected catchment. This differentiation may be useful to understand the type of transported bed load (coarse vs. fine-grained) and to characterize the deposition area. Moreover, information about damage to people and the society (i.e. damage to buildings, lifelines and infrastructures) was collected. Such a database may be useful in different ways: first of all, it may help to locate the areas more susceptible to flash floods all over the region. Second, it may facilitate local authorities in charge of land management to select sites where monitoring and prevention and mitigation works need to be adopted.

Additionally, empirical data are required for the rapid assessments of hazard events to support disaster management and coping with extreme events (Kunz et al., 2013; Schröter et al., 2015). Volunteered geographical information has the potential to be a useful source of information (Goodchild, 2007; Paul et al., 2017). In this regard, Fohringer et al. (2015) investigate the usefulness of social media contents for rapid flood mapping (as a basis for rapid damage estimation). In particular, Twitter and Flickr are explored as potential sources of information, i.e. photos from which spatial flood patterns and inundation depths can be inferred. The paper introduces the "PostDistiller" tool which allows filtering information relevant for inundation mapping from the high amount of posts. The tool also provides a visual interface to analyse the filtered photos and to derive suitable data for mapping. To investigate the usefulness of photos posted via Twitter and Flickr, PostDistiller was used within the city of Dresden during the flood in June 2013. The outcomes of the application case are encouraging. In comparison with traditional data sources (i.e. satellite or water level gauges), social media can provide data more rapidly, particularly in urban areas where it is of great interest and alternative information sources do not perform very well. However, inundation depth estimates are still associated with uncertainty concerning the timing, location and magnitude. Another weakness is that social media information is not reliably available as it depends on the random behaviour of humans. Nevertheless, results obtained from the application case in Dresden support the initial hypothesis that social media contain additional and potentially even exclusive information that is useful for rapid inundation mapping, but also more generally for improving rapid flood assessments.

2.2 Event analyses

Novel methods, concepts and tools as listed above are an important basis for the analyses of and learning from natural hazard events for risk reduction and adaptation. The following contributions present findings from the analyses of actual events and shed light on the potential gain in knowledge and possibilities to use these insights for enhancing current approaches for risk management and adaptation planning.

In June 2013, wide parts of central Europe were hit by large-scale flooding with associated damage of the order of several billions of EUR. Thieken et al. (2016) explore what kind of impact data are available on which level, what kind of information can be retrieved from the data and how well data and information fulfil requirements proposed for disaster reporting on the European and international levels. Special attention is paid to the European Floods Directive that also requires reporting on human health, economic activities, cultural heritage and the environment. Information is gathered from governmental reports, communications on traffic disruptions and surveys of flood-affected residents and companies. The study reveals that flood-affected residents perceive psychological stress, reinstatement works and supply problems more seriously than financial losses such as damage to buildings or household contents. The most frequent damage type among affected companies was business interruption that was more widespread than damage to economic assets or infrastructure elements. This finding confirms that the current focus on direct losses is insufficient to estimate the adverse effects of flood events. A major restriction to holistically investigate events such as the 2013 flood is the lack of comprehensive, homogeneous, detailed and accessible data. Concerning the European Floods Directive (and others such as documentations proposed by IRDR), the authors conclude that procedures and standards for impact data collection in Germany are widely missing. The authors propose to build up an information system where all relevant cost categories including those for risk reduction and response should be included. Such a system also enables a linkage of flood event and impact indicators to get a measure for the improvement of flood risk management strategies on the long term.

Another motivation for in-depth analyses of hazard events is the improvement and testing of models to predict extremes. The Bosna River flood in May 2014 in Bosnia–Herzegovina was an extreme event with high impact on society and economy. Vidmar et al. (2016) provide comprehensive analyses of precipitation and discharge data using methods of extreme value statistics. Observed daily precipitation exceeded 100 mm locally and 4-day precipitation totals have been well above 150 mm. The results show exceptional return periods for daily and multi-day precipitation amounts above 100 years in large parts of the basin and even more than 500 years locally. The return periods for peak discharges and flood volumes also exceed 100-year flood levels in most parts of the catchment. The Bosna River basin (10 420 km^{-2}) is a complex hydrological system with varying response times due to differences in soil and underground characteristics. For instance, karstic underground leads to a delay in flood response, similar to storage effects observed for the reservoirs in the basin. Vidmar et al. (2016) show that for the May 2014 flood, prolonged precipitation led to the superimposition of runoff responses from different sub-catchments and, consequently, to extreme flood peaks. Furthermore, landslides and debris flow altered the morphology of river beds and, thus, streamflow response. These new insights into the hydrological behaviour of the catchment system under extreme conditions have been used to set up and validate a hydrological simulation model for the Bosna River basin. This model is used as a tool for reconstructing and analysing past floods, as well as forecasting floods and planning of flood risk mitigation measures.

In a similar vein, Price et al. (2016) examine prescribed burning as manmade events to test and improve models, assess pollution risk and derive guidance for mitigating wildfires. Prescribed burning is conducted to reduce the extent and potential damage of wildfires, but it produces its own smoke threat. Price et al. (2016) undertake a detailed study of smoke dispersal for one small and one large prescribed fire in New South Wales, Australia. The approach comprised the utilization of stationary and handheld pollution monitors, visual observations and rain radar data as well as a comparison of the observations with predictions from an atmospheric dispersion model. The small fire produced a smoke plume about 800 m high and 9 km long with partly high particle concentrations. The large fire produced a 2000 m high and 14 km long plume. Smoke from this fire collapsed to the ground during the night at different times in different locations, affecting a huge area including some towns. The atmospheric dispersion model accurately predicted the general behaviour of both plumes in the early phases of the fires, but was poor at predicting fine-scale variation in particulate concentrations. The model was not able to predict the night-time collapse of the plume from the large fire. Price et al. (2016) conclude that prescribed fires might have large impacts on communities, which challenges science to improve the accuracy in smoke dispersion modelling. More research is needed to better understand when and why such impacts might occur to provide better predictions of pollution risk.

Monitoring of events is a central component of event analyses. The use of multiple sensors and identification of meaningful proxies for earthquake predictions is the objective of Yildirim et al. (2016).They examine the correlation between ionospheric anomalies in the total electron content (TEC) and positional variations, on the occasion of the $M_w = 6.5$ earthquake, which occurred in the Aegean Sea on 24 May 2014. The objective of the analysis is to investigate the possibility of a seismic origin for ionospheric anomalies occurrence, in order to early forecast earthquakes. Both the TEC and positional variations were computed from the analysis of the Global Navigation Satellite System's (GNSS) signal; in detail, data of 15 stations were used, in a period spanning from 4 days before the earthquake and 7 days after. The analysis shows that when TEC values at precise points (i.e. at stations closer to the earthquake centre) are examined, at specific times before and after the earthquake, these values deviate and exceed the lower and upper limit TEC values. Such tendency is corroborated by TEC values obtained by the global ionosphere model of the Centre for Orbit Determination in Europe. Nonetheless, variations of approximately 10 and 3 cm were detected in the x, y and z directions, respectively, 3 days and 1 day before the earthquake, at the nearest station to the earthquake centre. Evidence strengthens the possibility of seismic origins for ionosphere anomalies.

Questionnaires and surveys are another useful approach to explore socioeconomic impacts of hazard events. In this regard, the study of Kreibich et al. (2017b) compares two household and company surveys in flood-affected areas undertaken after the major floods in August 2002 and June 2013 in Germany. The objective of this study was to gain more knowledge on how and when households and companies received flood warnings and how they responded in 2002 and 2013. After 2002, great efforts have been made to improve flood risk management including early warnings and emergency response. It is found that the share of companies that have an emergency plan in place has increased by a factor of 3 but is still low at 34 % of all surveyed companies. According to the study, the warnings during the 2013 flood reached significantly more people within longer lead times, presumably due to improvements in the warning systems, increased risk awareness and preparedness as well as the fact that the evolution of the flood event was clearly less dynamic than in 2002. However, the authors still found room for improvement of emergency communication and response as well as link to early warnings. For example, in 2013 only a third of the warnings contained information about recommended measures and emergency responses. It is assumed that an improvement of the warnings better supports and triggers private damage reduction efforts and, thus, reduces adverse effects from disasters.

Kunz-Plapp et al. (2016) analyse the subjective experience of heat stress by urban citizens, using the heatwave of July to August 2013 in Karlsruhe, Germany – marked with temperatures well above 30° during 3 weeks – as an example. A survey of 323 respondents forms the basis to improve the understanding of the determinants for subjective heat stress in daily life. The particular focus of this research is on learning about the individual and social factors as well as factors of the urban built environment that determine subjective heat stress in different contexts of daily life: in this context the extent to which urban citizens experience heat stress, how the heat affects their health and what measures are implemented to cope with it. Kunz-Plapp et al. (2016) present statistical analysis of the empirical data using descriptive univariate analysis, bivariate correlations and multiple regressions to understand what makes a difference in subjective heat stress and to identify the main determinants for subjective heat stress in general, at home and at work. Main findings are that subjective heat stress permeates everyday activities, with health impairments and the feeling of being helplessly exposed to the heat as main determinants. At home, the characteristics of the residential building, such as building type, floor level or outdoor recreational elements, and the built environment, for instance the distance to a public garden, play an additional role. Overall, individual subjective heat stress is context dependent and its determinants differ upon context regarding the relevance and type. Regarding long-term strategies to reduce heat stress for urban citizens, structural measures for heat protection of buildings, energy efficient refurbishment, and including green space in urban planning seem appropriate.

3 Concluding remarks

The contributions of the special issue "Natural hazard event analysis for risk reduction and adaptation" provide novel insights into the diverse aspects of analysing natural hazard events. This covers both the understanding of key drivers and coping capacities including preparedness, emergency response and disaster relief. Learning from hazard events is shown to be useful for the improvement and testing of models under extreme conditions. A prerequisite to gain additional insights and to increase knowledge is to closely monitor events on the various levels reflecting the complex interactions between the natural hazard, the technical installations and infrastructures as well as the societal institutions and capacities. Novel ways of making use of data streams as well as leveraging the potential of social media are interesting points of departure.

In addition to having a good understanding of the hazard event, which remains an important topic, methodological developments, embedding insights into operational tools and finding ways to support decisions on adaptation and risk mitigation are required. The contributions also demonstrate the complexities that arise from the multi-faceted aspects involved in comprehensive event analyses and the challenges to achieve a structured documentation of fragmentary, heterogeneous and incomplete data. Further, it is shown that policy makers and practitioners in disaster risk management face strikingly similar challenges across extremely varied contexts, indicating encouraging potential for mutual learning. Communication strategies are a key element to strengthen emergency response capabilities, including private precaution, for building capacities to better cope with future extreme events, including the risks of failure of mitigation measures.

By providing new insights and novel methodological approaches to tackle these complexities, this special issue contributes to advancements in the field of event-centred research.

References

Balbi, S., Villa, F., Mojtahed, V., Hegetschweiler, K. T., and Giupponi, C.: A spatial Bayesian network model to assess the benefits of early warning for urban flood risk to people, Nat. Hazards Earth Syst. Sci., 16, 1323–1337, https://doi.org/10.5194/nhess-16-1323-2016, 2016.

Elmer, F., Hoymann, J., Düthmann, D., Vorogushyn, S., and Kreibich, H.: Drivers of flood risk change in residential areas, Nat. Hazards Earth Syst. Sci., 12, 1641–1657, https://doi.org/10.5194/nhess-12-1641-2012, 2012.

Fohringer, J., Dransch, D., Kreibich, H., and Schröter, K.: Social media as an information source for rapid flood inundation mapping, Nat. Hazards Earth Syst. Sci., 15, 2725–2738, https://doi.org/10.5194/nhess-15-2725-2015, 2015.

Goodchild, M. F.: Citizens as sensors: the world of volunteered geography, GeoJournal, 69, 211–221, https://doi.org/10.1007/s10708-007-9111-y, 2007.

Hallegatte, S.: Natural disasters and climate change: An economic perspective, Springer, Cham, Heidelberg, New York, Dordrecht, London, 2014.

IPCC: Managing the risks of extreme events and disasters to advance climate change adaptation, New York, 2012.

IRDR – Integrated Research on Disaster Risk: Forensic investigations of Disasters: The FORIN project, Integrated Research on Disaster Risk, Beijing, 2011.

IRDR – Integrated Research on Disaster Risk: Guidelines on Measuring Losses from Disasters: Human and economic Impact Indicators, Integrated Research on Disaster Risk, DATA Publication No. 2, Beijing, China, 2015.

Keating, A., Venkateswaran, K., Szoenyi, M., MacClune, K., and Mechler, R.: From event analysis to global lessons: disaster forensics for building resilience, Nat. Hazards Earth Syst. Sci., 16, 1603–1616, https://doi.org/10.5194/nhess-16-1603-2016, 2016.

Kreibich, H. and Thieken, A. H.: Coping with floods in the city of Dresden, Germany, Nat. Hazards, 51, 423–436, 2009.

Kreibich, H., van den Bergh, J. C. J. M., Bouwer, L. M., Bubeck, P., Ciavola, P., Green, C., Hallegatte, S., Logar, I., Meyer, V., Schwarze, R., and Thieken, A. H.: Costing natural hazards, Nat. Clim. Change, 4, 303–306, 2014.

Kreibich, H., Di Baldassarre, G., Vorogushyn, S., Aerts, J. C. J. H., Apel, H., Aronica, G. T., Arnbjerg-Nielsen, K., Bouwer, L. M., Bubeck, P., Caloiero, T., Chinh, D. T., Cortès, M., Gain, A. K., Giampá, V., Kuhlicke, C., Kundzewicz, Z. W., Llasat, M. C., Mård, J., Matczak, P., Mazzoleni, M., Molinari, D., Dung, N. V., Petrucci, O., Schröter, K., Slager, K., Thieken, A. H., Ward, P. J., and Merz, B.: Adaptation to flood risk – results of international paired flood event studies: Adaptation to flood risk, Earth's Future, 5, 953–965, https://doi.org/10.1002/2017EF000606, 2017a.

Kreibich, H., Müller, M., Schröter, K., and Thieken, A. H.: New insights into flood warning reception and emergency response by affected parties, Nat. Hazards Earth Syst. Sci., 17, 2075–2092, https://doi.org/10.5194/nhess-17-2075-2017, 2017b.

Kunz, M., Mühr, B., Kunz-Plapp, T., Daniell, J. E., Khazai, B., Wenzel, F., Vannieuwenhuyse, M., Comes, T., Elmer, F., Schröter, K., Fohringer, J., Münzberg, T., Lucas, C., and Zschau, J.: Investigation of superstorm Sandy 2012 in a multidisciplinary approach, Nat. Hazards Earth Syst. Sci., 13, 2579–2598, https://doi.org/10.5194/nhess-13-2579-2013, 2013.

Kunz-Plapp, T., Hackenbruch, J., and Schipper, J. W.: Factors of subjective heat stress of urban citizens in contexts of everyday life, Nat. Hazards Earth Syst. Sci., 16, 977–994, https://doi.org/10.5194/nhess-16-977-2016, 2016.

Mechler, R. and Bouwer, L. M.: Understanding trends and projections of disaster losses and climate change: is vulnerability the missing link?, Climatic Change, 133, 23–35, https://doi.org/10.1007/s10584-014-1141-0, 2014.

Menoni, S., Molinari, D., Ballio, F., Minucci, G., Mejri, O., Atun, F., Berni, N., and Pandolfo, C.: Flood damage: a model for consistent, complete and multipurpose scenarios, Nat. Hazards Earth Syst. Sci., 16, 2783–2797, https://doi.org/10.5194/nhess-16-2783-2016, 2016.

Merz, B., Hall, J., Disse, M., and Schumann, A.: Fluvial flood risk management in a changing world, Nat. Hazards Earth Syst. Sci., 10, 509–527, https://doi.org/10.5194/nhess-10-509-2010, 2010.

Molinari, D., Mazuran, M., Arias, C., Minucci, G., Atun, F., and Ardagna, D.: Implementing tools to meet the Floods Directive requirements: a "procedure" to collect, store and manage damage data in the aftermath of flood events, in: Flood Recovery Innovation and Response IV, edited by: Proverbs, D. and Brebbia, C. A., WIT Press, Southampton, UK, 2014.

Paul, J. D., Buytaert, W., Allen, S., Ballesteros-Cánovas, J. A., Bhusal, J., Cieslik, K., Clark, J., Dugar, S., Hannah, D. M., Stoffel, M., Dewulf, A., Dhital, M. R., Liu, W., Nayaval, J. L., Neupane, B., Schiller, A., Smith, P. J., and Supper, R.: Citizen science for hydrological risk reduction and resilience building: Citizen science for hydrological risk reduction and resilience building, Wiley Interdisciplin. Rev.: Water, 5, e1262, https://doi.org/10.1002/wat2.1262, 2017.

Price, O. F., Horsey, B., and Jiang, N.: Local and regional smoke impacts from prescribed fires, Nat. Hazards Earth Syst. Sci., 16, 2247–2257, https://doi.org/10.5194/nhess-16-2247-2016, 2016.

Read, L. K. and Vogel, R. M.: Hazard function theory for nonstationary natural hazards, Nat. Hazards Earth Syst. Sci., 16, 915–925, https://doi.org/10.5194/nhess-16-915-2016, 2016.

Schröter, K., Kreibich, H., Vogel, K., Riggelsen, C., Scherbaum, F., and Merz, B.: How useful are complex flood damage models?, Water Resour. Res., 50, 3378–3395, 2014.

Schröter, K., Kunz, M., Elmer, F., Mühr, B., and Merz, B.: What made the June 2013 flood in Germany an exceptional event? A hydro-meteorological evaluation, Hydrol. Earth Syst. Sci., 19, 309–327, https://doi.org/10.5194/hess-19-309-2015, 2015.

Thieken, A. H., Bessel, T., Kienzler, S., Kreibich, H., Müller, M., Pisi, S., and Schröter, K.: The flood of June 2013 in Germany: how much do we know about its impacts?, Nat. Hazards Earth Syst. Sci., 16, 1519–1540, https://doi.org/10.5194/nhess-16-1519-2016, 2016.

UNISDR: Sendai Framework for Disaster Risk Reduction 2015–2013, UNISDR, Geneva, Switzerland, 2015.

Vennari, C., Parise, M., Santangelo, N., and Santo, A.: A database on flash flood events in Campania, southern Italy, with an evaluation of their spatial and temporal distribution, Nat. Hazards Earth Syst. Sci., 16, 2485–2500, https://doi.org/10.5194/nhess-16-2485-2016, 2016.

Vidmar, A., Globevnik, L., Koprivšek, M., Sečnik, M., Zabret, K., Đurović, B., Anzeljc, D., Kastelic, J., Kobold, M., Sušnik, M., Borojevič, D., Kupusović, T., Kupusović, E., Vihar, A., and Brilly, M.: The Bosna River floods in May 2014, Nat. Hazards Earth Syst. Sci., 16, 2235–2246, https://doi.org/10.5194/nhess-16-2235-2016, 2016.

Yildirim, O., Inyurt, S., and Mekik, C.: Review of variations in $M_W < 7$ earthquake motions on position and TEC ($M_W = 6.5$ Aegean Sea earthquake sample), Nat. Hazards Earth Syst. Sci., 16, 543–557, https://doi.org/10.5194/nhess-16-543-2016, 2016.