Panta Rhei benchmark dataset: socio-hydrological data of paired events of floods and droughts (version 2)
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1. Licence

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Changelog:

- Revision of the data description
- Addition of DOIs (or URLs) for references in the file "2023-001_Kreibich-et-al_key_data_table"

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3. Data Description

As the negative impacts of hydrological extremes increase in large parts of the world, better understanding of the drivers of changes of risk and impacts is essential for effective flood and drought risk management and climate adaptation. However, there is a lack of comprehensive, empirical data about the processes and feedbacks in complex human-water systems leading to flood and drought impacts. To fill this gap, we present an IAHS Panta Rhei benchmark dataset containing socio-hydrological data of paired events, i.e. two floods or two droughts that occurred in the same area (Kreibich et al. 2017, 2019). The contained 45 paired events occurred in 42 different study areas (in three study areas we have data on two paired events), which cover different socioeconomic and hydroclimatic contexts across all continents. The dataset is unique in covering floods and droughts, in the number of cases assessed and the amount of socio-hydrological data contained.

References to the data sources are provided in **2023-001_Kreibich-et-al_Key_data_table.xlsx** where possible.

3.1.Sampling method

Based on templates (see 6. Attachment of this document), detailed, review-style reports (PairedEventReports.pdf) describing the events and key processes between the events in the case study areas were collected. The reports contain data that characterise impacts, hazard, exposure, vulnerability and management of the paired events in the case study areas.

The campaign to collect the review-style reports on paired events started at the EGU General Assembly in April 2019 in Vienna and was continued with talks promoting the paired event collection at various conferences. Communication with the IAHS Panta Rhei community and other flood and drought experts identified through snowballing techniques was important. Thus, data on paired events were provided by professionals with excellent local knowledge of the events and risk management practices.

3.2.Data processing

From the detailed review-style reports (PairedEventReports.pdf), key data characterising management shortcomings, hazard, exposure, vulnerability and impacts of the paired events in the case study areas was extracted and organised in the key data table (Key_data_table.xlsx). Definitions of impacts, hazard, exposure, vulnerability and management shortcomings indicators and examples of description or measurement of variables for their assessment are provided in Table 1. For transparency reasons, and to give data users the opportunity to judge the quality of the data themselves, data source information (citations, references) is also compiled in the key data table. According to the authors personal assessment, sources of the information and data as given in the reports were categorised in descending quality as follows: scientific study (peer reviewed paper and PhD thesis), report (by governments, administrations, NGOs, research organisations, projects), own analysis by authors, based on database (e.g. official statistics, monitoring data such as weather, discharge data, etc.), newspaper article, and expert judgement.

Table 1 Definitions of indicators and examples of how to describe or measure variables to assess these indicators of flood and drought impacts, hazard, exposure, vulnerability and management shortcomings.

Indicator	Definitions	Example description or measurement for floods	Example description or measurement for droughts
Impacts			
Number of fatalities (only floods)	Number of fatalities due to the direct impact of a hazard.	Number of fatalities, e.g. reported in newspapers	*Not relevant*
Direct economic impacts	Direct economic impacts are due to the direct physical effect of a hazard on economic assets[14]	Flood damage to buildings expressed in Euros, e.g. recorded by insurance companies	Drought damage to crops expressed in Euros, e.g. quantified by compensation programmes
Indirect impacts	Indirect impacts occur inside or outside the hazard area, often with a time lag. They are commonly induced by direct impacts[14]	Disturbance of supply chains, e.g. described in economic reports	Loss of livelihoods, job loss in agriculture, e.g. described in governmental reports
Intangible impacts	Intangible impacts refer to damage to people, goods and services that are not easily measurable in monetary terms because they are not traded on a market (these can be direct or indirect impacts)[14]	Damage to cultural heritage, e.g. described by authorities	Damage to ecosystems, e.g. described by authorities

Drivers of impact			
Hazard			
Severity of flood/drought	Severity of the event in terms of hydro-meteorological processes, i.e. hazard	Maximum discharge measured at gauging station	Standardized Precipitation Evapotranspiration Index (SPEI), estimated based on the water balance
Duration of drought (only droughts)	Number of months in drought conditions[54]	*Not relevant*	Drought starts in the month when Standardized Precipitation Index falls below −1 and it ends when SPI returns to positive values
Precipitation / weather severity (only floods)	Heavy precipitation or severe weather that triggered the flood	Precipitation measured at weather stations	*Not relevant*
Antecedent conditions (only pluvial and riverine floods)	Conditions at the onset of an event that may exacerbate or mitigate the event[55]	Antecedent precipitation index, which is the weighted sum of past daily precipitation amounts, used as a proxy for soil moisture or: as an indicator for catchment wetness	*Not relevant*
Tidal level (only coastal floods)	Tidal water level at the time of coastal flood occurrence	Tidal water level measured at tide gauges	*Not relevant*
Storm surge (only coastal floods)	Rise in sea or estuary water level caused by the passage of a low pressure centre[55]	Sea water level measured at tide gauges	*Not relevant*
Exposure			
People/area/assets exposed	Number of people, size of area (e.g. settlement area, agricultural area) or number/value of assets located in affected areas[9]	Number of buildings in inundated area, e.g. estimated from satellite imagery	Number of inhabitants in drought affected area, e.g. from population statistics
Exposure hotspots	Areas of particularly high exposure affected during an event	Large scale industrial facility affected by flood	Hydraulic energy production affected by drought
Vulnerability			
Lack of awareness and precaution	Lack of understanding of the risk (e.g. sources, hazards, potential consequences, etc.) and implementation of suitable precautionary measures. Depends e.g. on experience, risk communication campaigns, incentives to implement precautionary measures	Ineffective risk communication, lack of guidelines and incentives for private precaution	Lack of drought experience
Lack of preparedness	Lack of knowledge and capacities developed by communities and individuals to effectively anticipate and respond to an event, e.g. via private emergency measures	Late early warning, insufficient resources like pumps, shutters, sandbags	Lack of water shortage response plans
Insufficient official emergency/crisis management	Organisational emergency or crisis management before or during an event was insufficient to optimally mitigate impacts	Lack of emergency plans, non-effective governance	Ineffective water demand management
Insufficient coping capacity	Coping capacity, which is the ability of communities using available skills and resources, to manage an event was	Low or lacking public flood compensation to individuals and businesses	Insufficient governmental aid or compensation

	insufficient due to a lack of funding (insurance, risk transfer), resources or skills		
Management shortcomings that influence the drivers of impact			
Problems with water management infrastructure	Water management infrastructures such as levees, reservoirs, sewage systems, etc. failed or did not work optimally during an event due to deficits in maintenance, sub-optimal design, etc.	Number of levee breaches	Lack of water in reservoirs, insufficient storage capacity
Non-structural risk management shortcomings	Non-structural risk management measures, e.g. spatial planning that avoids increase of exposure in hazard-prone areas and private property level risk mitigation measures were not optimally implemented	Lack of hazard and risk maps	Ineffective water use restrictions

On basis of this key data (in Key_data_table.xlsx), indicators-of-change that represent the differences between the first event used as baseline, and the second event were developed (Indicators_of_change.csv). The indicators-of-change are categorised as large decreases/increases (-2/2), small decreases/increases (-1/1) and no change (0). Additionally, five summary indicators-of-change for management shortcomings, hazard, exposure, vulnerability and impacts were derived by qualitatively comparing and integrating the values of the respective associated indicators-of-change (see Indicators_of_change.csv).

To minimise subjectivity and uncertainty in assigning values for the indicators-of-change, a quality assurance protocol was implemented. The quality assurance was driven by a core group (authors of this data publication: HK, AvL, KS, PW, GdB) and was undertaken in the following steps: (a) on the basis of the detailed report a core group member suggested values for all indicators-of-change for a paired event; (b) a second member of the core group reviewed these suggestions. In case of doubt, both core group members rechecked the paired event report, and provided a joint suggestion; (c) all suggestions for the indicators-of-change for all paired events were discussed in the core group to improve consistency across paired events; (d) the suggested values of the indicators-of-change were reviewed by the paired event report authors; (e) finally, the complete table of indicators-of-change was reviewed by all authors to ensure consistency across paired events. Representative examples of qualitative and quantitative indicator values from flood and drought paired events corresponding to the five classes of the indicators-of-change are provided in Table 2.

Table 2 Representative examples of quantitative and qualitative variables from flood and drought paired events corresponding to the five classes of the indicators-of-change, i.e. large decreases/increases (-2/2), small decreases/increases (-1/1) and no change (0). Examples are taken from the key data table (Key_data_table.xlsx) (ID = paired event ID).

Impacts					
Impact indicators for floods					
Indicators of change		**Number of fatalities**	**Direct economic impacts**	**Indirect impacts**	**Intangible impacts**
Large decrease (-2)	1st flood	Dead and missing: 4407 (ERD, 2008) (ID 20)	1,158 million USD (ERD, 2008) in 2007 values. Re-estimated as 1,329 million USD in the year 2009 and converted to 930 million EUR (ID 20)	Indirect damage of the flood event is estimated at USD 1,287 million for 2007 (Bappenas, 2007) (ID 4)	NA*

	2nd flood	Dead and missing: 190 (UNDP, 2010) (ID 20)	269.28 million USD (Xinhua, 2009) (converted to 188 million EUR) (ID 20)	Indirect damage of the flood event is estimated at USD 130 million for 2013 (Lurah Galur et al., 2013; Lurah Karet Tengsin et al., 2013; Lurah Petamburan et al., 2013) (ID 4)	NA
Small decrease (-1)	1st flood	9 fatalities (ID 15)	4 billion Euro (ID 15)	Some cascading effects due to damage to the gas network (ID 12)	Mercè festival events cancelled; damage to the Romanesque church of Sant Pere (ID 12)
	2nd flood	5 fatalities (ID 15)	2.32 billion Euro (ID 15)	no relevant indirect impacts (ID 12)	Damage to the Filmoteca (film library) and the Maritime Museum (ID 12)
No change (0)	1st flood	2 (indirect) fatalities in Saint-Anne-des-Monts, Quebec (IBC, 2019a; Peritz, Perreaux, & Stone, 2017) (ID 41)	[Total monetary damage unknown] CAD $223 million in insured damages (in 2017 value) (IBC, 2017). This is equivalent to CAD $230.06 million in 2019 value when adjusted for inflation (using Bank of Canada Inflation Calculator) (ID 41)	Common problems post-flooding include mould, contamination, debris. Other possible indirect economic impacts due to road closures; supply, use, and disposal of sandbags; costs associated with dispatching Canadian Armed Forces and supplies. However, specific numbers or problems have not been reported as of April, 2020 (ID 41)	Water-borne diseases at informal residential areas along flooded canals in rainy seasons (HCM People's Committee, 2019; Huynh et al, 2020; Nguyen et al, 2017) (ID 28)
	2nd flood	1 (indirect) fatality in Pontiac, Quebec (CBC, 2019a) (ID 41)	[Total monetary damage unknown] Insured losses reported to be CAD $208 million (in 2019 value) (IBC, 2019a). The estimate for financial assistance paid for 2019 flooding by Quebec is CAD $25.9 million as of June 2019 (Montreal Gazette, 2019) (ID 41)	Common problems post-flooding include mould, contamination, debris. Other possible indirect economic impacts due to road closures (Silcoff, 2019); supply, use, and disposal of sandbags; costs associated with dispatching Canadian Armed Forces and supplies. However, specific numbers or problems	Water-borne diseases (Huynh et al, 2020; Nguyen et al, 2017) (ID 28)

				have not been reported as of April, 2020 (ID 41)	
Small increase (+1)	1st flood	0 fatalities (DRBC, 2006) (ID 42)	3.5 billion USD (at national level) (INDECI, 1998; CAF, 2000) (ID 13)	Comparatively small indirect loss due to the suspension of the tourist activities in the late holiday season in September, roads and railroads were temporarily interrupted (ID 40)	The Ontario portion of the Ottawa River was designated as a Canadian Heritage River in July 2016 to acknowledge its recreational and cultural value to Indigenous Peoples and its history as a transportation route (Government of Canada, 2016). The Ottawa River runs through the Algonquin Indigenous territories in Ontario that comprises ten Indigenous communities in Ontario (Water Canada, 2017). Flooding events along the river disrupt their traditional lifestyles and recreational activities (ID 41)
	2nd flood	4 fatalities (Suro et al., 2009) (ID 42=	3-9 billion USD (at national level) (Venkateswaran et al., 2017; INDECI, 2017) (ID 13)	High indirect loss due to the early suspension of the tourist activities at the peak of the holiday season in August, roads and railroads were temporarily interrupted (ID 40)	Similar disruptions as during the previous event due to flooding at the Ontario portion of the Ottawa River, a Canadian Heritage River (Government of Canada, 2016; Water Canada, 2017); Other long-term impacts comprise psychological impacts due to flooding fatigue caused by repeated flood events in similar regions or trauma due to emergency relocation and loss of belongings (Payne 2019, CBC, 2019b) (ID 41)
Large increase (+2)	1st flood	NA	SEK 60 million (GP, 2010) (ID 45)	NA	In post cyclone period, there was a rise in mental health related problems (Kabir et al., 2016). Sidr caused severe damage to the Sundarbans, which is a World heritage site (ERD, 2008). However, the regeneration capacity of Sundarbans was high (Kumar Bhowmik and Cabral, 2013) (ID 20)
	2nd flood	NA	SEK 600 million in total; of this SEK 440	NA	A large number of people were displaced or

			million paid by insurance (SOU 2017:42) (ID 45)		migrated. In several areas, people could not return for 3-4 years due to continued tidal flooding. A large number of people changed their livelihoods to daily labor or fishing to cope (Kumar Paul, 2013; Abdullah et al., 2016). This change in livelihood had extreme impacts on their culture, standard of living and social status (ID 20)
Impact indicators for droughts					
			Direct economic impacts	**Indirect impacts**	**Intangible impacts**
Large decrease (-2)	1st drought		17,134 billion Euro (EEA, 2019a) (ID 9)	NA	NA
	2nd drought		2,172 billion Euro (EEA, 2019a) (ID 9)	NA	NA
Small decrease (-1)	1st drought		12% decrease in energy GDP regional contribution to the national energy GDP; 4% decrease in agriculture GDP regional contribution to the national agriculture GDP (computed as the difference between 1999 and 1998 GDP values from Banco Central de Chile, 2020) (ID 6)	Explosion of spruce and fir bark beetle (Geiger 1951) (ID 8)	Famine (Fegert, 2017), fish death (Deutscher Wetterdienst in der US-Zone 1947) (ID 8)
	2nd drought		13% increase in energy GDP regional contribution to the national energy GDP; 12% decrease in agriculture GDP regional contribution to the national agriculture GDP (computed as the difference between 2014 and 2013 GDP values from Banco Central de Chile, 2020) (ID 6)	Similar indirect impacts as in 1947 event, but easier to cope with. (ID 8)	Fish death (less than 1947) (ID 8)
No change (0)	1st drought		USD 50 million (EM-DAT (2019) (ID 10)	alga proliferation, 5% drop in electrical voltage, drought tax (ID 7)	Fish mortality and tree mortality (young plants) (ID 7)
	2nd drought		USD 70 million due to agricultural losses (Choudhary et al. 2015) (ID 10)	bar beetle epidemic, increase in climate multi-risk insurance (ID 7)	Significant and unusual tree mortality (Département de la santé des forêts, 2019) (ID 7)

Small increase (+1)	1st drought		10 to 12 billion US Dollars (recalculated as at 2010) (ID 25)	Conflicts between different sectors of water uses (hydraulic, tourism, irrigation, drinking water) (Ricart and Pavon, 2014) (ID 34)	Damage to the environment, soil erosion (Gibbs, 1984; Heathcote, 1988) (ID 35)
	2nd drought		15 billion US Dollars (ID 25)	Political conflicts between the party that was in the Government of Spain, the opposition and the Government of Catalonia, mainly because of the proposed transfer of water from Segre River to Internal Basins of Catalonia. Conflicts between hydroelectric, Water Catalan Agency, AGBAR for the overexploitation of water wells. (Llasat et al, 2009), newspaper La Vanguardia (2021) (ID 34)	Depression, exhaustion, drop in tourism, damaged aquatic and terrestrial ecosystems (Sherval et al., 2014, Bond et al. 2008; LeBlanc et al. 2012) (ID 35)
Large increase (+2)	1st drought		The estimated agricultural damage for 2003 is around 520,000 euros, the total agricultural damage is about 3% of the total crop value in the area. (ID 38)	Limited indirect impact (ID 44)	NA
	2nd drought		The estimated agricultural damage for 2018 is about 4 times as high as in 2003: 2,200,000 euros, which is about 11% of the total crop value in the area (ID 38)	About 35,000 job losses in agriculture, estimated 50,000 people pushed below poverty line due to job losses and food price inflation, drop in tourism (Ziervogel 2019; City of Cape Town 2019; WWF 2018) (ID 44)	NA
Drivers of impact					
Hazard indicators for floods					
		Antecedent conditions	**Precipitation/weather severity**	**Severity of flood**	

Large decrease (-2)	1st flood	Before the rains from Ivan arrived, the Delaware River at Montague and Trenton, New Jersey was flowing at 298 percent and 265 percent of normal, respectively, for the first half of September (DRBC, 2004, 2006) (ID 42)	Average precipitation in the southern part of basin was 595 mm; average precipitation in the northern part of basin was 410 mm (Wu 2006) (ID 3)	Total runoff of the southern part of basin was 5,995 billion m³; total runoff of the northern part of basin was 1,539 billion m³ (Wu 2006) (ID 3)
	2nd flood	Normal to dry streamflow condition (Suro et al., 2009) (ID 42)	Areal mean rainfall in the north branch of Daqinghe river was 125 mm; areal mean rainfall in the south branch of Daqinghe river was 123 mm (Wu 2006) (ID 3)	Total volume into Baiyandian from north and south branch was 1,536 billion m³ (Wu 2006) (ID 3)
Small decrease (-1)	1st flood	Above-normal (150-200% of average) fall precipitation and saturated soils. High winter snowpack (90-130% of normal) with high snow water equivalent. Low winter temperatures and significant frost penetration (Manitoba Infrastructure, 2013; Blais et al. 2016) (ID 31)	327mm/6 days (Bappenas, 2007), 50 year RP (Bappenas, 2010) (ID 4)	Maximum recorded peak flow in Piura river ever (3367 m3 s-1) (ENFEN, 2017) (ID 13)
	2nd flood	Normal antecedent fall and winter conditions. Late spring melt and wet soils (Szeto et al. 2015; Ahmari et al. 2016) (ID 31)	250-300mm/15 days (Pertiwi, 2013), 30 year RP (Budiyono et al., 2016) (ID 4)	Peak flow of 2754.5 m3 s-1 (ID 13) (ENFEN, 2017)
No change (0)	1st flood	No rainfall in the last previous 3 days. Numerous inlets clogged by leaves (CLABSA, 1995) (ID 12)	Areal average April-May precipitation over the basin for period 1981-2010 was recorded to be 150 mm. In 2017, it was 257 mm (174% of average) (ORRPB, 2018). (ID 41)	4.16m surge (Adnan et al. 2019) plus low tide (ERD, 2008) (ID 20)
	2nd flood	No rainfall in the last previous 5 days. Some inlets clogged by leaves (BCASA, 2018) (ID 12)	April-May accumulated precipitation between 240-300 mm (preliminary data, Agriculture and Agri-Food Canada, n.d.) (ID 41)	4.10 m surge (Adnan et al. 2019) plus high tide (UNDP, 2010) (ID 20)
Small increase (+1)	1st flood	Late winter conditions and snowpack were considered average for the basin for May-April. Heavy localized rainfall events happening at the same time as snowmelt led to high soil saturation and river flows in early April. However, the primary driver of flooding was rainfall runoff (McNeil, 2019; ORRPB, 2018). (ID 41)	62.5 mm (Areal average of 3-day precipitation maxima for German part of the Upper Danube catchment) (Schröter et al., 2015) (ID 15)	7,700 m³/s peak discharge at gauge Achleiten (~HQ50) (HND 2021); 1,081 cm water level at gauge Passau; 10,250 m³/s peak discharge at Korneuburg/Vienna (Blöschl et al., 2013) (ID 15)
	2nd flood	Snow-cover did not reduce much till late April due to prolonged winter conditions. Snowpack/snow water	75.7 mm (Areal average of 3-day precipitation maxima for German part of the Upper	10,100 m³/s peak discharge at gauge Achleiten

		equivalent in 2019 was considered to be 150-188% of average at peak amount. This led to increased freshet in late April. 2019 rainfall was above-average for the basin but less than that of 2017 and was more distributed over the basin. Hence, primary driver of flooding was a combination of above-average rainfall and snowmelt (McNeil, 2019 ; ORRPB, 2019).(ID 41)	Danube catchment) (Schröter et al., 2015) (ID 15)	(~HQ150) (HND 2021); 1,289 cm water level at gauge Passau, i.e. highest water level in Passau since 1,501 flood; 11,055 m³/s peak discharge at Korneuburg/Vienna (Blöschl et al., 2013) (ID 15)	
Large increase (+2)	1st flood	NA	Max precipitation: 175.26 mm, 50-to-100-year recurrence interval for a 24-hour storm (Brooks, 2005) (ID 42)	< 25 years return period of precipitation for 6-hour duration (Sörensen & Mobini, 2017) (ID 45)	
	2nd flood	NA	Max Precipitation: 339.34 mm in 24 hours at Walton New York (Suro et al., 2009) (ID 42)	> 130 years return period of precipitation for 6-hour duration (Sörensen & Mobini, 2017) (ID 45)	
Hazard indicators for droughts					
			Duration of drought	**Severity of drought**	
Large decrease (-2)	1st drought		SPI6: 23 months, SPI12: 59 months (Cavus 2019; Cavus and Aksoy, 2019, 2020) (ID 26)	Average values for Maule region: SPI12 = -2.63; SPEI12 = -2.01 (ID 6)	
	2nd drought		SPI6: 9 months, SPI12: 13 months (Cavus 2019; Cavus and Aksoy, 2019, 2020) (ID 26)	Average values for Maule region: SPI12 = -0.95; SPEI12 = -1.06 (ID 6)	
Small decrease (-1)	1st drought		Hydrological drought duration: 3.4 years (ID 22)	The core of the 2003 drought event (12°W-30°E; 35°N–55°N) recorded an extreme value of August SPEI3 = - 1.62 (Schär et al., 2004) (ID 9)	
	2nd drought		Hydrological drought duration: 2.1 years (ID 22)	The core of the 2015 drought event (0°E- 45°E; 40°N–60°N) recorded an extreme value of August SPEI3 = -1.18 (Ionita et al., 2017) (ID 9)	
No change (0)	1st drought		May to September 2003, based on SPEI3 drought index (EDC, 2003a) (ID 9)	SPEI extremely dry (SPEI <-2) (ID 21)	

	2nd drought		Late May to September 2015 based on the SPEI3 drought index (Ionita et al., 2017) (ID 9)	SPEI extremely dry (SPEI <-2) (ID 21)
Small increase (+1)	1st drought		24 months (NDMC 2020c ; NC DMAC 2020b) (ID 33)	Average inflow into reservoir system 57% lower than the long-term average (Araújo 1986) (ID 37)
	2nd drought		27 months (NDMC 2020c ; NC DMAC 2020b) (ID 33)	Average inflow into reservoir system 77% lower than the long term average (Nobre et al. 2016) (ID 37)
Large increase (+2)	1st drought		2 years annual rainfall below threshold (Jacobs et al. 2007) (ID 44)	At peak intensity, over 30% of area affected by exceptional drought (D4) (NDMC 2020b; NC DMAC 2020b) (ID 33)
	2nd drought		4 years annual rainfall below threshold (Otto et al. 2018, Wolski 2018) (ID 44)	At peak intensity, over 60% of area affected by exceptional drought (D4) (NDMC 2020b; NC DMAC 2020b) (ID 33)
Exposure indicators for floods				
		People/area/assets exposed	**Exposure hotspots**	
Large decrease (-2)	1st flood	More than 175,000 people exposed in South Carolina; at least 800,000 homes and businesses lost power access in South Carolina (Stewart, 2017) (ID 19)	NA	
	2nd flood	About 40,000 people exposed in South Carolina; about 250,000 homes and businesses lost power access in South Carolina (Stewart, 2017) (ID 19)	NA	
Small decrease (-1)	1st flood	8000 people and 4800 buildings exposed (Vologda regional government 2005) (ID 17)	50 flooded locations in the city (SCFC, 2011) (ID 28)	
	2nd flood	7400 people and 2900 buildings exposed (Vologda regional government (2016) (ID 17)	31 flooded locations in the city, including the landing zone of Tan Son Nhat Airport (SCFC, 2016) (ID 28)	
No change (0)	1st flood	Specifics around overall exposure of assets not well known (Westdal et al. 2015), but approximately similar between events. 3 million acres of cultivated farmland were exposed (MIT, 2013) (ID 31)	Flooding impacted primarily residential and city areas, including regions in Ontario (Dundas, Hamilton, Ottawa, Cumberland) and Quebec (Pontiac,	

			Gatineau, Montreal island, Rigaud Saint-Jean sur Richelieu, Secteur Île Bizard, Île Mercier, Maniwaki, Mansfield-et-Pontrefact Shawinigan, Laval) (ORRPB, 2018; Floodlist, 2017) (ID 41)
	2nd flood	Specifics around overall exposure of assets not well known (Westdal et al. 2015), but approximately similar between events. About 2.5-3.5 million acres of cultivated farmland were exposed (AAFC, 2014) (ID 31)	Flooding impacted primarily residential and city areas, including regions in Ontario (Ottawa, Constance Bay, Fitzroy Harbour, Cumberland) and Quebec (Gatineau, Pontiac, Montreal, Sainte-Marthe-sur-le-Lac, Pointe-Calumet, Laurentians and the Chaudière Appalaches region) (Statistics Canada, 2019) (ID 41)
Small increase (+1)	1st flood	60,000 people exposed in Austria (EM-DAT, 2019) (ID 15)	Oldest part of the city, city center and cultural heritage (medieval walls and churches) exposed (ID 12)
	2nd flood	80,000 people exposed in Bavaria (likely not all of them in the Danube basin); 16697 residential houses in Bavaria and Baden-Württemberg exposed (likely not all of them in the Danube basin) (Thieken et al., 2016a) (ID 15)	Oldest part of the city, city center, with great commercial and touristic activity and cultural heritage (medieval walls, churches, new Filmoteca (film museum and library)) exposed (ID 12)
Large increase (+2)	1st flood	>350 buildings exposed, estimated on basis of flood claims to LF Skåne and (insurance company) and VA SYD (water utility company) (Sörensen & Mobini, 2017) (ID 45)	28 cities exposed, 2257 industrial, mining and railway enterprises in cities of Bao Ding, Xing Tai, Han Dan Shi Jia Zhuang and 116.4 km railway affected (Xiao et al. 1998) (ID 3)
	2nd flood	>4700 buildings exposed, estimated on basis of flood claims to LF Skåne and (insurance company) and VA SYD (water utility company) (Sörensen & Mobini, 2017) (ID 45)	91 cities exposed, 94,000 township enterprises, 15 national roads, 76 provincial roads and 396 bridges affected (Xiao et al. 1998) (ID 3)
		Exposure indicators for droughts	
		People/area/assets exposed	**Exposure hotspots**
Large decrease (-2)	1st drought	NA	NA
	2nd drought	NA	NA

Small decrease (-1)	1st drought	Farmers across the UK exposed to soil moisture drought. No hosepipe bans so limited exposure to hydrological drought (Marsh, 2014; EA, 2017); Some local water supply difficulties in North West Scotland (Marsh, 2004) (ID 23)	In 1976 the drinking water supply was an exposure hotspot to drought especially in rural and industrial area because of insufficient drinking water network to satisfy the water demand (Mission interministérielle de l’eau 1977; Agence de l’Eau Rhin-Meuse 1977) (ID 7)		
	2nd drought	Farmers in Eastern and Southern England exposed to soil moisture drought. Localised impact of hydro drought in the South and East of the UK (Marsh et al, 2014; EA, 2017) (ID 23)	Agricultural land (Chambre d’agriculture) and few rural villages exposed (decline of industry) (ID 7)		
No change (0)	1st drought	Sown area: 1,488.2 thousand Ha; persons employed in agriculture: 205,275 (ID 21)	Drought hotspot at the Central Valley (urban and hydropower users) (ID 36)		
	2nd drought	Sown area: 1,463.5 thousand Ha; persons employed in agriculture: 209,160 (ID 21)	Drought hotspot at the Central Valley (urban and hydropower users) (ID 36)		
Small increase (+1)	1st drought	Large part of central Europe, ~3,700,000 km² (ID 9)	Cape Town domestic and industrial water users (Steenkamp, 2005) (ID 44)		
	2nd drought	Whole Europe (Ionita et al., 2017), ~5,400,000 km² (ID 9)	Cape Town domestic and industrial water users & Western Cape Agricultural Users (Muller, 2018; WWF 2018) (ID 44)		
Large increase (+2)	1st drought	1,035,377 of inhabitants in the Adana province were exposed together with more from the Seyhan River basin (DPT, 2008) (ID 26)	NA		
	2nd drought	2,165,595 of inhabitants in the Adana province were exposed together with more from the Seyhan River basin (ID 26)	NA		
Vulnerability indicators for floods					
		Lack of awareness and precaution	**Lack of preparedness**	**Insufficient official emergency/crisis management**	**Insufficient coping capacity**
Large decrease (-2)	1st flood	Flood risk awareness of the population as well as authorities was limited and only few precautionary measures were undertaken before the event (ID 13)	The SENAMHI river flow forecasts and flood alerts did not yet exist for the 1998 event. Although weather forecasts existed, it can be assumed that these were much less precise than for the 2017 event (ID 13)	Official emergency management activities were limited (ID 13)	The capacity to manage localized flooding was significantly reduced in the early 1990s subsequent to the privatisation of the water industry in the UK (Pitt, 2007); household flood insurance was in place (during both flood events) (ID 11)

	2nd flood	NGOs such as 'Practical Action' have implemented disaster risk reduction activities such as evacuation exercises and awareness campaigns (French and Mechler; 2017); In 2011, the national Centre for the Estimation, Prevention, and Reduction of Disaster Risk (CENEPRED) was founded, which strongly improved risk awareness also among authorities (ID 13)	Around 2000, the national hydrometeorological service started issuing medium-range weather forecasts that allowed preparations months before the 2017 event. The national flood early warning system issued daily weather and river flow forecasts (SENAMHI, 2020) (ID 13)	The National Institute of Civil Defence (INDECI), and the national Centre for the Estimation, Prevention, and Reduction of Disaster Risk (CENEPRED), both founded in 2011, undertook and supported effective emergency management (ID 13)	Exposed communities formed networks and were able to effectively hold authorities to account. This means they were able to define their needs well and mobilise political support (e.g. the Pang Valley Flood Forum https://www.floodalleviation.uk/). This gave communities access to new funding for flood risk management, which requires evidence of effective local partnerships (ID 11)
Small decrease (-1)	1st flood	Last severe floods in 1974 and 1976. Prior to these floods, the 1954 Hurricane Hazel's flash-flooding resulted in 81 fatalities, which prompted Ontario to develop more stringent rules on infrastructure development on areas close to water (Perreaux, 2018) (ID 41)	Germany: penetration rate of early warning and actionable knowledge are low (Kreibich and Merz, 2007, DKKV, 2015, Kreibich et al. 2017) (ID 15)	In both, Germany and Austria, flood early warning was rather late and imprecise, coordination between the responsible authorities was limited (Thieken et al., 2016b, DKKV, 2015) (ID 15)	Economic compensations by state insurance "Consorcio de Compensación de Seguros" (CCS) helped to recover within several weeks (ID 12)
	2nd flood	Increased awareness since 2017 with more information available at various government and NGO websites on flood management and recovery (City of Ottawa, n.d.; Ottawa Riverkeeper, 2019; Pfeffer, 2019; Ontario Ministry of Natural Resource and Forestry, 2019; ORRPB, 2019) (ID 41)	Penetration rate of early warning and actionable knowledge had increased significantly after 2002 event (Kreibich and Merz, 2007, DKKV, 2015, Kreibich et al. 2017) (ID 15)	In Germany and Austria: improved information and coordination capacities between the responsible authorities at federal, state and community levels (Thieken et al., 2016b, DKKV, 2015) (ID 15)	Economic compensations by state insurance "Consorcio de Compensación de Seguros" (CCS) helped to recover within some days; the metro was fully operational again within a few hours (ID 12)
No change (0)	1st flood	Private precautionary measures implemented, such as storage of important items on higher level ground or upper floors of buildings, prepared door frames for shutters or dikes (Budiyono, 2018) (ID 4)	Happened Saturday evening, after rainfall all day (Sörensen & Mobini (2017); No official warnings or risk communication to the general public (ID 45)	Emergency management was supported by the military, as there were not enough emergency personnel available (MIT, 2013) (ID 31)	Main coping instruments include disaster recovery assistance (municipal, provincial, and federal when applicable) and private insurance (IBC, 2019b) (ID 41)
	2nd flood	Similar level of private precautionary measures implemented (Budiyono, 2018) (ID 4)	Happened early Sunday morning (4.30–7.30) when few people were in office, many people were sleeping (Sörensen & Mobini 2017); no official warnings or risk communication to the	Emergency management was supported by the military, as there were not enough emergency personnel available (Westdal et al. 2015) (ID 31)	Main coping instruments include disaster recovery assistance (municipal, provincial, and federal when applicable) and private insurance (McNeil, 2019) (ID 41)

			general public (Bentzel 2019) (ID 45)		
Small increase (+1)	1st flood	High awareness and precaution - the Province recognized early in the fall of 2010 that there would be major flooding throughout Manitoba in the spring of 2011. Issued first spring flood outlook with high flood risk warning January 2011 (MIT, 2013). High knowledge and good operations of staff acknowledged as critical to successful management (MIT, 2013) (ID 31)	Manitoba Emergency Measures Organization began planning months ahead of flood event, including opening MB Emergency Coordination Centre (remained open for 103 days), purchasing 2 sandbag machines, etc. (MIT, 2013) (ID 31)	Responses to emergency calls were manageable (ID 45)	In 2011, Manitoba applied for Federal Disaster Financial Assistance Arrangements ($780 M) to help with recovery (Kavanagh and Annable, 2017), and also launched a $175 M compensation and mitigation program (Westdal et al. 2013) (ID 31)
	2nd flood	Less awareness and precaution because spring melt was complete and the flood did not resemble typical floods for the region (Healy, 2014). In 2014, the spring flood outlook predicted only minor to moderate risk (Ahmari et al. 2016) (ID 31)	In 2014, the Province had much less time to prepare for the flash flooding that occurred rather unexpected as it was a non-typical event for the basin (Healy, 2014) (ID 31)	Collaboration between different departments was good during the 2014 event, however a central coordinator would have been good since the roles and responsibilities were unclear. The warning was late and the staff were not mentally prepared for such an extreme event (Lindher, 2015) (ID 45)	In 2014, Manitoba applied for Federal Disaster Financial Assistance Arrangements ($180 M) to help with recovery (Kavanagh and Annable, 2017) (ID 31)
Large increase (+2)	1st flood	NA	NA	NA	NA
	2nd flood	NA	NA	NA	NA
Vulnerability indicators for droughts					
		Lack of awareness and precaution	**Lack of preparedness**	**Insufficient official emergency/crisis management**	**Insufficient coping capacity**
Large decrease (-2)	1st drought	Low drought awareness, no precaution (ID 8)	No warning systems, no seasonal forecast available for people and farmers (Hydrometeorological Center 1973, 1976) (ID 25)	No special public management organisation for droughts, no emergency plans available, volume of water redirected to Don irrigation system 2,5 km³ per year (ID 25)	No drought insurance available, the food trade on the black market was a strategy to get food (Fegert, 2017) (ID 8)
	2nd drought	High drought awareness due to implemented monitoring systems and daily media reports (Erfurt et al. 2019) (ID 8)	Open-access 10-day and seasonal agrometeorological forecast, warning system on Roshydromet website – MeteoAlarm service. For state water management	Public management organisation for droughts exists, drought emergency plans available, volume of water redirected to Don	In the case of a disaster on a national scale (like in the case of the drought 2018), the federal government of Germany provides financial assistance for forestry and agriculture

			company legislatively fixed critical water levels and early warning alarms when water levels are close to threshold (ID 25)	irrigation system 1,1 km³ per year, no watering of streets from June till September (ID 25)	(BMEL, 2019). Private insurances (yield guarantee insurances and damage-based insurances) exist for agriculture and forestry (BMEL, 2017) (ID 8)
Small decrease (-1)	1st drought	Mild awareness campaign to limit unnecessary water use (Jansen & Schulz 2006) (ID 44)	20% reduction in water allocation for domestic uses implemented by the City of Cape Town (Jacobs et al. 2007) (ID 44)	National and Local Water Demand Management; Level 3 or 4 Domestic Water Restriction in Cape Town Metropolitan Area up to 105 litres/per day (Jansen & Schulz 2006) (ID 44)	No insurance or governmental compensation (ID 7)
	2nd drought	Aggressive awareness campaign (Day Zero) to considerably reduce domestic and agricultural water consumption (Ziervogel 2019, Robins 2019, Rodina 2019) (ID 44)	Water use restrictions up to 60% for agriculture and 45% for domestic water (Ziervogel 2019, Robins 2019, Rodina 2019) (ID 44)	National, Local and International task force with emergency plan; Level 6 Domestic Water Restriction in Cape Town Metropolitan Area up to 50 litres/per day, Sanction, Tariff increase and Water Management Devices (Ziervogel 2019, Robins 2019, Rodina 2019) (ID 44)	Since 1982, law on compensation for victims of natural disasters (Law n°82-600, July 13, 1982). Farmers are advised to take private insurance (ID 7)
No change (0)	1st drought	High drought awareness in population (ID 6)	Early warning system did not exist (Aras et al., 2019) (ID 26)	No crisis management enacted (ID 23)	No drought insurance available (ID 37)
	2nd drought	High drought awareness in population (ID 6)	Early warning system did not exist (Aras et al., 2019), it is within the future program of public organizations. (ID 26)	No crisis management enacted (ID 23)	Insurance mechanisms proposed for hydrologic drought insurance under water demand and climate change scenarios in a Brazilian context (Mohor & Mendiondo, 2017), but not yet implemented (ID 37)
Small increase (+1)	1st drought	NA	NA	NA	Damage costs in agricultural and shipping sector mainly covered by higher prices: payed by consumer (Peters, 2003) (ID 38)
	2nd drought	NA	NA	NA	Resources in agricultural sector were not sufficient to cope with the consequences (Ecorys, 2019) (ID 38)

Large increase (+2)	1st drought	NA	NA	NA	NA
	2nd drought	NA	NA	NA	NA
Management shortcomings					
Indicators of management shortcomings for floods					
		Problems with water management infrastructure	**Insufficient risk management**		
Large decrease (-2)	1st flood	The design discharges of the levees were half the event discharges, all levees failed (Veatch, 1952) (ID 2)	Limited risk management activities and response capacity (French and Mechler 2017) (ID 13)		
	2nd flood	No levee failures occurred, following upgrading based on 1951 event (Lovelace & Strauser, 1996; United States General Accounting Office, 1995) (ID 2)	Much improved risk management and response capacity, including newly established government institutes (CENEPRED, INDECI) (French and Mechler 2017) (ID 13)		
Small decrease (-1)	1st flood	The combined capacity of the Portage Diversion (operated over design capacity during the flood event) and the dikes downstream of Portage La Prairie was not enough to contain peak flows, prompting the Province to construct an emergency controlled outlet at Hoop and Holler Bend (Blais et al. 2016; MIT, 2013) (ID 31)	No consistent large-scale flood hazard and risk mapping available before the event in 2002 (ID 15)		
	2nd flood	Directly following 2011 flood, an emergency outlet channel on the end of Lake St. Martin was constructed and operated over the winter to prepare for spring runoff. The operating rules for the Fairford Water Control Structure were also modified to allow maximum possible discharge to lower lakes levels between 2011-2014 (Ahmari et al. 2016); During the 2014 flood, the Portage Diversion was again operated over capacity (Ahmari et al. 2016). The emergency outlet at Hoop and Holler Bend was not required (ID 31)	Flood hazard mapping initiated following the EU Flood Directive launched in 2007; Floodplain restoration at lowland Danube tributaries in Germany and Austria since 2004 increased storage capacity (e.g. storage capacities at Salzach near Niedernsill, Austria) (BLFUW, 2006) (ID 15)		
No change (0)	1st flood	Issues with combined sewage system, Spillepengen pumping station out of order due to overload (Sörensen & Mobini, 2017) (ID 45)	Limited access to floodplain and flood risk maps (Henstra at al., 2019; Henstra & Thistlethwaite, 2018). Ontario guidelines for hydrologic modelling, floodproofing standards and floodplain mapping based on approaches from the 1980s, now		

			considered outdated (McNeil, 2019) (ID 41)
	2nd flood	Issues with combined and separate sewage system, Turbinen pumping out of order due to flooding (Sörensen & Mobini, 2017) (ID 45)	Still limited access to floodplain and flood risk maps (Henstra at al., 2019; Henstra & Thistlethwaite, 2018); Federal Floodplain mapping Framework containing guidelines for mapping projects released by government as part of National Disaster Mitigation Program (NRCan & Public Safety Canada, 2018). Government of Quebec announced CAD $24 million for updated flood zone maps after the 2017 event. Updated maps were released in June 2019, a month after the event (CTV Montreal, 2018; Anhoury, 2019). Federal Liberal government also earmarked CAD $2 billion to be spent over 11 years on risk mitigation and disaster prevention, but none of the approved projects were completed by 2019 floods (Press, 2017; Press, 2019a) (ID 41)
Small increase (+1)	1st flood	No dyke breaches (DKKV 2015) (ID 15)	NA
	2nd flood	Dyke failure along the Bavarian Danube and Isar resulted in extensive inundation at Deggendorf (24 km^2) (DKKV 2015) (ID 15)	NA
Large increase (+2)	1st flood	NA	NA
	2nd flood	NA	NA
Indicators of management shortcomings for droughts			
		Problems with water management infrastructure	**Insufficient risk management**
Large decrease (-2)	1st drought	System of reservoirs available to manage droughts (ID 35)	NA
	2nd drought	In 1984 the Thomson Reservoir was completed, which increased the existing storage capacity by 250% (Low et al. 2015) (ID 35)	NA

Small de-crease (-1)	1st drought	The activation of stand-by sources and the granting of drought permits (EA 2004) to allow, for instance, additional abstraction to supplement dwindling reservoir stocks played an important role (Marsh, 2004) (ID 23)	Drought Monitoring Council Upgraded to Drought Management Advisory Council (NC DMAC 2020a) (ID 33)
	2nd drought	Some reservoirs were temporarily switched to non-consumptive mode (Marsh, 2007). Reduced water demand in 2006 meant that the major-pumped storage reservoirs for London were well sufficient (Marsh, 2007) (ID 23)	Requirement of local water providers to have Water Shortage Response Plans (North Carolina General Assembly 2007) (ID 33)
No change (0)	1st drought	Total retention capacity: 171,136 thousand m³; usable capacity of water reservoirs for melioration is 57,782 thousand m³ (ID 21)	Spray irrigation restrictions widely applied (Marsh, 2004). All the water companies in England and Wales revised their drought plans early in 2003 and the Environment Agency reported to Ministers on these in June 2003 (EA, 2004). Nearly all drought plans from companies were made public (EA, 2004). No hosepipe bans or restrictions on non- essential water use were applied (Marsh, 2004) (ID 23)
	2nd drought	Total retention capacity: 189,881 thousand m³; usable capacity of water reservoirs for melioration 53,878 thousand m³ (ID 21)	Spray irrigation restrictions widely applied. Introduction of a range of drought mitigation measures (e.g. publicity campaigns to moderate demand, local water transfers, reductions in compensation flows). Hosepipe bans, as well as appeals to save water, have been assessed by water companies to have reduced customers' demand for water by 5–15 per cent in 2006 (ID 23)
Small in-crease (+1)	1st drought	Well organised irrigation system (Hydrometeorological Center 1973, 1976; Dzhamalov et al. 2017) (ID 25)	NA
	2nd drought	Old and damaged irrigation system, no investment during last 30 years (Dzhamalov et al. 2017) (ID 25)	NA

Large increase (+2)	1st drought	NA	NA	
	2nd drought	NA	NA	

* NA – not such example available in dataset of paired events (i.e. in Key_data_table.xlsx)

4. File description

4.1. File inventory

The dataset contains the following three files:

- **2023-001_Kreibich-et-al_PairedEventReports.pdf:** PDF document containing the paired event reports (346 pages). The paired event reports are between 3 and 18 pages long and are structured in the following sections: 1) short description of events with a focus on impacts; 2) descriptions of processes between events with a focus on risk management 3) event comparison in respect to hazard; 4) event comparison in respect to exposure; 5) event comparison in respect to vulnerability; 6) summary; 7) references. For each paired event report, 1-4 co-authors are responsible, they are the experts best placed to answer specific questions about the events. They are listed at the beginning of the individual paired event reports. All authors of reports are co-authors of this data publication.
- **2023-001_Kreibich-et-al_Key_data_table.xlsx**: Excel file containing the key data separated into the following 2 spreadsheets: 1) "key data", which contains the data of the flood and drought paired events, including citations leading to the source of the data where possible; 2) "references", which contains the references cited in the key data spreadsheet, separated by paired events. All references related to the same paired event (indicated by the same paired event ID) are sorted alphabetically.
- **2023-001_Kreibich-et-al_Indicators_of_change.CSV**: CSV file containing the indicators-of-change for the flood and drought paired events. These indicators-of-change represent the differences between the first event used as baseline to the second event, categorised as large decreases/increases (-2/2), small decreases/increases (-1/1) and no change (0).

4.2. Description of data tables

4.2.1. 2023-001_Kreibich-et-al_Key_data_table.xlsx

Spreadsheet: key data

Always 2 rows belong to one paired event, i.e. the information in the first columns that identify and roughly characterise the paired event and study area "Paired event ID", "Event type", "Area: Catchment/region", "Area: Country", contain the same information. The first line contains the information of the first event in the then following columns, the second line contains the information of the second event.

Column header	***Description***
Paired event ID	ID of paired event
Event type	Text describing the event type of the paired event (e.g. pluvial flood, meteorological drought). Events of a pair are always of the same type.
Area: Catchment/region	Text describing the catchment or region of paired event occurrence
Area: Country	Text describing the country of paired event occurrence

Year of event	Year or multi-year period in which the event occurred. Usually one single year for floods, as floods are usually shorter than one year (e.g. 2012). Usually a multi-year period for droughts, as droughts usually last several years (e.g. 2003-2006).
The columns with the following headers contain the key data including citations of the sources of data where possible (this is every second column)	
Management: Problems with water management infrastructure Management: Non-structural risk management shortcomings Hazard: Duration of meteo drought (only meteo droughts) Hazard: Severity of meteo drought (only meteo droughts) Hazard: Duration of soil moisture drought (only soil moisture droughts) Hazard: Severity of soil moisture drought (only soil moisture droughts) Hazard: Duration of hydro drought (only hydro droughts) Hazard: Severity of hydro drought (only hydro droughts) Hazard: Tidal level (only coastal floods) Hazard: Storm surge (only coastal floods) Hazard: Antecedent conditions (only pluvial & riverine floods) Hazard: Precipitation / weather severity (only floods) Hazard: Severity of flood (only floods) Exposure: People/area/assets exposed Exposure: Exposure hotspots Vulnerability: Lack of awareness and precaution Vulnerability: Lack of preparedness Vulnerability: Imperfect official emergency / crisis management Vulnerability: Imperfect coping capacity Impacts: Number of fatalities (only floods) Impacts: Direct economic impacts Impacts: Indirect impacts Impacts: Intangible impacts	Data i.e. variables and textual descriptions, characterizing the indicators for management shortcomings, hazard, exposure, vulnerability and impacts. Citations of the sources of data are provided where possible (mainly for scientific studies and reports).. NA: not available (unknown, not measured) NR: not relevant (for the specific event type)
The columns with the following header contain the category of the data source, each related to the data in the column before (this is every second column). This shall give data users the opportunity to judge the quality of the data themselves.	
Category of data source *(this is every second column)*	Category of the source of data according to personal assessment of the authors in descending quality: scientific study (peer reviewed paper and PhD thesis), report (by governments, administrations, NGOs, research organisations, projects), own analysis by authors, based on database (e.g. official statistics, monitoring data such as weather, discharge data, etc.), newspaper article, expert judgement

Spreadsheet: references

Column header	*Description*
Paired event ID	ID of paired event (used to link the citations provided in the spreadsheet "key data" to the references).
DOI	If possible, DOIs are given, especially for scientific papers.
Web-link	For data sources for which there is no DOI, the web link is given if possible, this is often possible for reports.
Accessed (web-link)	Date on which the data source provided via a web-link was last accessed.
References	References for the citations provided in the spreadsheet "key data".

4.2.2. 2023-001_Kreibich-et-al_Indicators_of_change.CSV

Column header	*Description*
Paired event ID	ID of paired event
Event type	Text describing the event type of the paired event (e.g. pluvial flood, meteorological drought). Events of a pair are always of the same type.
Area: Catchment/region	Text describing the catchment or region of paired event occurrence
Area: Country	Text describing the country of paired event occurrence
Years of events	Years or multi-year periods in which the two events occurred, separated by "and". Usually single years for floods, as floods are usually shorter than one year (e.g. 2012 and 2016). Usually multi-year periods for droughts, as droughts usually last several years (e.g. 2003-2006 and 2010-2012).
The columns with the following headers contain the Indicators-of-change	

Management: Problems with water management infrastructure Management: Non-structural risk management shortcomings Management: Summary management shortcomings Hazard: Duration of drought (only droughts) Hazard: Severity of drought (only droughts) Hazard: Tidal level (only coastal floods) Hazard: Storm surge (only coastal floods) Hazard: Antecedent conditions (only pluvial & riverine floods) Hazard: Precipitation / weather severity (only floods) Hazard: Severity of flood (only floods) Hazard: Summary hazard Exposure: People/area/assets exposed Exposure: Exposure hotspots Exposure: Summary exposure Vulnerability: Lack of awareness and precaution Vulnerability: Lack of preparedness Vulnerability: Imperfect official emergency / crisis management Vulnerability: Imperfect coping capacity Vulnerability: Summary vulnerability Impacts: Number of fatalities (only floods) Impacts: Direct economic impacts Impacts: Indirect impacts Impacts: Intangible impacts Impacts: Summary impacts	Indicator-of-change: -2: large decrease -1: small decrease 0: no change +1: small increase +2: large increase NA: not available (unknown, not measured) NR: not relevant (for the specific event type)

5. References

Kreibich, H., Blauhut, V., Aerts, J. C. J. H., Bouwer, L. M., Van Lanen, H. A. J., Mejia, A., Mens, M., Van Loon, A. F. (2019): How to improve attribution of changes in drought and flood impacts. - Hydrological Sciences Journal - Journal des Sciences Hydrologiques, 64, 1, 1-18. https://doi.org/10.1080/02626667.2018.1558367

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., Do, T. C., Cortès, M., Gain, A. K., Giampá, V., Kuhlicke, C., Kundzewicz, Z. W., Llasat, M. C., Mård, J., Matczak, P., Mazzoleni, M., Molinari, D., Nguyen, D., Petrucci, O., Schröter, K., Slager, K., Thieken, A. H., Ward, P. J., Merz, B. (2017): Adaptation to flood risk - results of international paired flood event studies. - Earth's Future, 5, 10, 953-965. https://doi.org/10.1002/2017EF000606

6. Attachment: Templates for the collection of socio-hydrological data on paired events of floods and droughts

Template for comprehensive paired event description

Event type: Floods[1]

The comparison shall be about 2-3 pages plus 1-2 figures/tables plus references to scientific and grey literature (e.g. official reports, technical notes, newspapers)

Paired flood events: *0000 (event-year1) and 0000 (event-year2) floods[2] in the xx catchment, xx city, or xx (coastal) region[3] in country*

Authors and Affiliations

Short description of both events with a focus on impacts: *limited to hazard type, city/region affected and impacts, e.g. fatalities, affected people, destroyed houses, direct economic impacts/monetary damage, indirect and intangible damage (see Table 1) (Note that all other description will be in the event comparison on hazard, exposure and vulnerability aspects below)*

Description of processes between events with a focus on risk management[4]: *e.g. changes/improvements in risk management, deficits in infrastructure maintenance, changes in early warning systems, infrastructure projects, changes in the drainage system, risk communication campaigns, legal developments, land use change, changes in city planning/design, increase/decrease in population density or wealth, external drivers are for instance large scale events like the economic crisis in 2008 or ebola/birds flu, which may influence investments in adaptation*

Event comparison in respect to pluvial flood hazard (key aspects): *information on antecedent conditions (e.g. water infrastructure down for maintenance, inlets clogged by leaves, saturated or frozen soils), precipitation/weather typology, severity (probability of precipitation, intensity, duration and extend of precipitation relative to assets), infrastructure failures, potentially with figure providing hazard overview of both events*

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[1] Types of floods may be coastal floods caused by storm surges, inland pluvial floods, riverine floods, and flash floods, which are usually caused by heavy precipitation, sometimes in combination with snowmelt, ice jams, high soil moisture, or high groundwater levels. In case of compound events, we attempt to isolate the direct effect of the floods from those of concurrent phenomena (e.g. windstorm) on hazard, exposure and impact, based on expert knowledge of the events. The two events of a pair must be comparable and thus belong to the same flood type.

[2] Specify the specific flood type of both events.

[3] Appropriate area descriptions for the respective flood type shall be used.

[4] In this section, processes/developments between the events shall be described, important are changes in risk management. In the sections “event comparison” below, event characteristics and facts (which might be consequences or manifestations of these processes) shall be described.

Event comparison in respect to exposure (key aspects): *e.g. number of people exposed, buildings/area/assets exposed, exposure hotspots (e.g. city center, critical infrastructure, cultural heritage)*

Event comparison in respect to vulnerability (key aspects)*: e.g. awareness and precaution (experience, information campaigns, precautionary measures), preparedness (e.g. specific pluvial flood early warning system available, emergency/risk communication, private emergency measures), organisational emergency management (governmental crisis management), coping capacity (e.g. private/state insurance and risk transfer, duration to recover, fatigue, long-term impacts)*

Summary *including evaluation of important drivers of change and their interactions, phenomenon driving the general development, e.g. Adaptation effect (Frequent extreme events increase coping capacities thereby reducing social vulnerability, e.g. Kreibich et al. 2017, http://doi.org/10.1002/2017EF000606); Safe-development paradox (protection measures generate a false sense of security that reduce coping capacities (e.g. Di Baldassarre et al. 2018, http://doi.org/10.5194/hess-22-5629-2018)*

Table 1: Semi-quantitative comparison of the paired pluvial flood events

		Paired flood[5] events in the xx region)[6]	
		0000 (event-year1)	**0000 (event-year2)**
Management aspects[7]	**Problems with water management infrastructure**		
	Non-structural risk management shortcomings *(e.g. risk assessment, recovery aspects)*		
Hazard	**Tidal level (only coastal floods)**		
	Storm surge (only coastal floods		
	Antecedent conditions (only pluvial & riverine floods) *(e.g. water infrastructure down for maintenance, inlets clogged by leaves, saturated or frozen soils)*		

[5] Specify the specific flood type of both events

[6] It is extremely important, that comparable information is provided for both events, i.e. the same variables or measurement results are provided! For all information provide the respective references.

[7] Since management aspects may influence hazard, exposure and vulnerability, it is treated as a separate category.

	Precipitation / weather severity		
	Severity of flood *(e.g. probability of precipitation, intensity, duration and extend of precipitation relative to assets)*		
Exposure	**People/area/assets exposed (***Number of buildings exposed, Settlement area exposed, amount of assets exposed***)**		
	Exposure hotspots *(e.g. city center, critical infrastructure, cultural heritage)*		
Vulnerability	**Lack of awareness and precaution** *(e.g. flood experience, information campaigns, precautionary measures)*		
	Lack of preparedness *(e.g. early warning, lead times, risk communication, private emergency measures)*		
	Imperfect official emergency management *(e.g. disaster management, civil protection)*		
	Imperfect coping capacity *(e.g. private/state insurance and risk transfer, duration to recover, fatigue, long-term impacts)*		
Impacts	**Number of fatalities**		
	Direct economic impacts *(monetary damage)*		
	Indirect impacts *(e.g. disruption of supply chains, interruption of infrastructure (electricity, water, road or train network)*		
	Intangible impacts *(e.g. health/psychological aspects, damage to cultural heritage, damage to the environment)*		

References

Template for comprehensive paired event description

Event type: Droughts[8]

[8] **Meteorological drought** refers to a precipitation deficiency, possibly combined with increased potential evapotranspiration, extending over a large area and spanning an extensive period of time. **Soil moisture drought** is a deficit of soil moisture (mostly in the root zone), reducing the supply of moisture to vegetation. **Hydrological drought** is a broad term related to negative anomalies in surface and subsurface water. Examples are below-normal groundwater levels or water levels in lakes, declining wetland area, and decreased river discharge. Groundwater drought and streamflow drought are sometimes defined separately as below-normal

The comparison shall be about 2-3 pages plus 3 tables (and possibly 1-2 figures) and references to scientific papers and/or grey literature (e.g. official reports, technical notes, newspapers)

Paired drought events: *0000(-0000) (event-year(s)1) and 0000(-0000) (event-year(s)2) droughts in the xx catchment (or xx region) in country/continent*

Authors and Affiliations

Short description of both events with a focus on impacts: *limited to event type (meteorological, soil moisture and/or hydrological drought), catchment/region affected and impacts, e.g. negative impacts for agriculture, direct economic impacts/monetary damage, water shortages in cities, indirect and intangible damage (see Table 1). (Note that all other description will be in the event comparison on hazard, exposure and vulnerability aspects below.)*

Description of processes between events with a focus on risk management[9]: *e.g. changes/improvements in risk management, water conservation measures, changes in water/reservoir management, water infrastructure projects, deficits in infrastructure maintenance, introduction/changes of early warning systems for droughts, risk communication campaigns, water awareness campaigns, legal developments, land use change, changes in agricultural systems*

Event comparison in respect to drought hazard (key aspects): *Indices for meteorological, soil moisture and/or hydrological droughts[1]: threshold-based indices giving duration and severity of drought in precipitation, soil moisture, river discharge, groundwater, lakes, and/or reservoirs, or duration and severity from standardized precipitation index (SPI), standardized precipitation evaporation index (SPEI), soil moisture anomaly (SMA), standardized groundwater index (SGI) and/or standardized runoff index (SRI) (potentially with a figure providing an overview of both events, in time and space)*

Event comparison in respect to exposure (key aspects): *e.g. number of people exposed, area exposed, exposure hotspots (crop production hotspots, cities, industrial areas, critical infrastructure, water exploitation index), object characteristics (water users, crop types, drinking water supply system, building/household/company characteristics)*

Event comparison in respect to vulnerability (key aspects): *e.g. awareness (drought perception, private precaution undertaken by e.g. farmers); preparedness (drought early warning*

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groundwater levels and below-normal river discharge, respectively. Definitions from *Van Loon (Wires Water, 2015)* available at https://onlinelibrary.wiley.com/doi/pdf/10.1002/wat2.1085. In case of compound events, we attempt to isolate the direct effect of the droughts from those of concurrent phenomena on hazard, exposure and impact, based on expert knowledge of the events. For instance, in case that fatalities during drought events were not caused by a lack of water, but by the concurrent heatwave, these are not considered to be drought impacts. The two events of a pair must be comparable and thus belong to the same drought types.

[9] In this section, processes/developments between the events shall be described, important are changes in risk management. In the sections "event comparison" below, event characteristics and facts (which might be consequences or manifestations of these processes) shall be described.

systems, use of seasonal forecasts, precautionary measures); crisis management (water-use restrictions, public management organization, emergency plans); coping capacity (private/state insurance and risk transfer, duration to recover, fatigue, long-term impacts).

Summary *including evaluation of important drivers of change and their interactions, phenomenon driving the general development, e.g Adaptation effect (Frequent extreme events increase coping capacities thereby reducing social vulnerability, e.g. Kreibich et al. 2017,* http://doi.org/10.1002/2017EF000606*); Rebound effect (Increasing the efficiency leads to higher consumptions. Dumont et al., 2013,* https://doi.org/10.1016/j.aqpro.2013.07.006*); Safe-development paradox (protection measures generate a false sense of security that reduce coping capacities (e.g. Di Baldassarre et al. 2018, https://doi.org/10.1038/s41893-018-0159-0)*

Please complete Table 1, 2 and/or 3, dependent on which of the drought types you wish to compare.

Table 1: Semi-quantitative comparison of the paired meteorological drought[10] events

		Paired meteorological drought events in the xx catchment (or xx region)[11]	
		0000 (event-year1 or years)	**0000 (event-year2 or years)**
Management[12]	**Aspects of water management infrastructure** *(e.g. reservoirs, reservoir management)*		
	Non-structural risk management aspects *(e.g. risk assessment, introduction/changes of early warning systems for droughts, risk communication campaigns, water awareness campaigns, recovery aspects)*		
Hazard	**Duration of meteorological drought** *(name the (or more) respective indicator(s) the duration estimate is based on)*		

[10] Since exposure, vulnerability and impacts differ in respect to the drought type, this table is provided 3 times, in case the drought events comprise meteorological, soil moisture and hydrological droughts. In these cases, please fill in all three tables.
[11] It is extremely important, that comparable information is provided for both events, i.e. the same variables or measurement results are provided! For all information provide the respective references.
[12] Since management aspects may influence hazard, exposure and vulnerability, it is treated as a separate category.

	Severity of meteorological drought *(name the (or more) respective indicator(s) the severity estimate is based on)*		
Exposure	**People/area/assets exposed**		
	Exposure hotspots *(e.g. crop production hotspots, cities, industrial areas, critical infrastructure, water exploitation index)*		
Vulnerability	**Lack of awareness and precaution** *(e.g. drought perception, private precaution undertaken)*		
	Lack of preparedness *(e.g. drought early warning systems, use of seasonal forecasts, precautionary measures)*		
	Imperfect official crisis management *(e.g. public management organization, emergency plans)*		
	Imperfect coping capacity *(e.g. private/state insurance and risk transfer, duration to recover, fatigue, long-term impacts)*		
Impacts	**Direct economic impacts** *(Monetary damage e.g. agricultural losses)*		
	Indirect impacts *(e.g. disruption of agricultural supply chains, reduction of tourism)*		
	Intangible impacts *(e.g. health/psychological aspects, damage to the environment)*		

Table 2: Semi-quantitative comparison of the paired soil moisture drought events

		Paired soil moisture drought events in the xx catchment (or xx region)	
		0000 (event-year1 or years)	**0000 (event-year2 or years)**
Management	**Problems with water management infrastructure** *(e.g. reservoirs, changes in irrigation management, irrigation infrastructure projects, deficits in irrigation infrastructure maintenance)*		

	Non-structural risk management aspects *(e.g. risk assessment, water conservation measures, introduction/changes of early warning systems for droughts, risk communication campaigns, water awareness campaigns, recovery aspects)*		
Hazard	**Duration of soil moisture drought** *(name the (or more) respective indicator(s) the duration estimate is based on)*		
	Severity of soil moisture drought *(name the (or more) respective indicator(s) the severity estimate is based on)*		
Exposure	**People/area/assets exposed**		
	Exposure hotspots *(e.g. crop production hotspots, critical infrastructure / ecosystems, water exploitation index)*		
Vulnerability	**Lack of awareness and precaution** *(e.g. drought perception, private precaution undertaken by e.g. farmers)*		
	Lack of preparedness *(e.g. drought early warning systems, use of seasonal forecasts, precautionary measures, e.g. changing crop type)*		
	Imperfect official crisis management *(e.g. water-use restrictions, public management organization, emergency plans, e.g. fallowing land)*		
	Imperfect coping capacity *(e.g. private/state insurance and risk transfer, duration to recover, fatigue, long-term impacts)*		
Impacts	**Direct economic impacts** *(Monetary damage e.g. to agriculture)*		
	Indirect impacts *(e.g. disruption of agricultural supply chains, reduction of tourism)*		
	Intangible impacts *(e.g. health/psychological aspects, damage to the environment)*		

Table 3: Semi-quantitative comparison of the paired hydrological drought events

		Paired hydrological drought events

		in the xx catchment (or xx region)	
		0000 (event-year1 or years)	**0000 (event-year2 or years)**
Management	**Problems with water management infrastructure** *(e.g. changes in water/reservoir management, water infrastructure projects, deficits in infrastructure maintenance)*		
	Non-structural risk management shortcomings *(e.g. risk assessment, water conservation measures, introduction/changes of early warning systems for droughts, risk communication campaigns, water awareness campaigns, recovery aspects)*		
Hazard	**Duration of hydrological drought** *(name the (or more) respective indicator(s) the duration estimate is based on)*		
	Severity of hydrological drought *(name the (or more) respective indicator(s) the severity estimate is based on)*		
Exposure	**People/area/assets exposed**		
	Exposure hotspots *(e.g. cities, industrial areas, critical infrastructure, water exploitation index)*		
Vulnerability	**Lack of awareness and precaution** *(e.g. drought perception, private precaution undertaken)*		
	Lack of preparedness *(e.g. drought early warning systems, use of seasonal forecasts, precautionary measures)*		
	Imperfect official crisis management *(e.g. water-use restrictions, public management organization, emergency plans)*		
	Imperfect coping capacity *(e.g. private/state insurance and risk transfer, duration to recover, fatigue, long-term impacts)*		
Impacts	**Direct economic impacts** *(Monetary damage e.g. due to water shortages in cities, navigation / electricity production)*		

	Indirect impacts *(e.g. lack of electricity, transportation problems due to interruption of navigation, reduction of tourism)*		
	Intangible impacts *(e.g. health/psychological aspects, damage to the environment)*		