
Large floods drive changes in cause-specific mortality in the United States

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1 **Large floods drive changes in cause-specific mortality in the United States**

2 **Supplementary Information**

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Table S1. Total deaths and percent of total deaths by cause of death.

Cause of death	Total deaths	Percent of all deaths (%)
Cardiovascular diseases	13,709,850	38.5
Cancers	9,587,570	26.9
Neuropsychiatric conditions	4,390,885	12.3
Respiratory diseases	4,018,326	11.3
Injuries	2,773,049	7.8
Infectious and parasitic diseases	1,133,718	3.2

Table S2. Median and median maximal number of counties affected per event by flood cause.

Flood cause	Median number of counties affected per flood	Median maximal number of counties affected per flood
Ice jam or dam break	299	353
Heavy rain	126	211
Tropical cyclone	77	173
Snowmelt	54	241

Table S3. Count and percent of total floods by flood cause.

Flood cause	Count	Percent of all floods (%)
Heavy rain	61	65.6
Tropical cyclone	18	19.4
Snowmelt	9	9.7
Ice jam or dam break	5	5.3

Table S4. Flood cause categories used in the analysis derived from the Dartmouth Flood Observatory classifications.

Flood cause	Dartmouth Flood Observatory Classification
Heavy rain	“Heavy rain”, “Brief torrential rain”
Snowmelt	“Heavy rain and snowmelt”, “Snowmelt”
Tropical cyclone	“Tropical storms”, “Hurricane”
Ice jam or dam break	“Ice jams”, “Dam failure”

Table S5. Population exposure thresholds (percent county population exposed) used to categorize flood severity by flood cause.

Flood cause	Mild	Moderate	Severe	Very severe
All floods	> 0	0.0033	0.021	0.1142
Heavy rain	> 0	0.0029	0.0183	0.0984
Tropical cyclone	> 0	0.0043	0.0271	0.1287
Snowmelt	> 0	0.0066	0.0446	0.2268
Ice jam or dam break	> 0	0.0028	0.0161	0.1005

Table S6. Number of county-floods by flood cause and severity.

Flood severity exposure	Heavy rain	Snowmelt	Ice jam or dam break	Tropical cyclone	All floods
Any exposure	12,906	2,166	1,767	3,122	19,961
Mild: < 25 th percentile	3,227	542	442	781	4,992
Moderate: 25 th – 49 th percentile	3,227	542	442	781	4,992
Severe: 50 th – 74 th percentile	3,226	541	442	780	4,989
Very severe: ≥ 75 th percentile	3,226	541	441	780	4,988

Table S7. Median duration and median maximal duration by flood cause and severity type.

	Median duration (days)				Median maximal duration (days)			
Flood cause	Mild	Moderate	Severe	Very severe	Mild	Moderate	Severe	Very severe
Heavy rain	2	2.06	2.35	2.64	3	4	5	7
Tropical cyclone	2	2.21	2.63	4.04	3	5	7	13
Snowmelt	2	2.38	3.59	4.78	3	7	14	23
Ice jam or dam break	2	2.13	2.40	3.05	3	4	6	8

Table S8. Causes of death used in the analysis with ICD-10 codes.

Cause of death	ICD-10
Cancers	C00-C99, D00-D49
Cardiovascular diseases	I00-I99
Infectious and parasitic diseases	A00-A99, B00-B99, G00-G05, G14, N70-N74
Injuries	V00-Y99, W00-W99, X00-X40, X43-44, X46-X99, Y00-Y89
Neuropsychiatric conditions	F00-F99, G06-G13, G15-98, X41-X42, X45
Respiratory diseases	H62-H67, J00-J99

Table S9. Deaths per million (DPM, 95% CrI) for 2018 monthly age-standardized death rates over lag periods (0 – 3 months) by cause of death, flood severity, flood cause.

			Attributable deaths per million (95% CrI)			
Cause of death	Flood severity	Lag (months)	Heavy rain	Ice jams and dam breaks	Snowmelt	Tropical cyclones
Cancers	Mild	0	-0.33 (-1.61, 0.95)	-0.99 (-4.58, 2.59)	1.57 (-1.96, 5.11)	0.27 (-2.12, 2.65)
		1	-0.58 (-1.64, 0.48)	-0.55 (-1.68, 0.57)	-0.41 (-1.51, 0.7)	-0.5 (-1.62, 0.62)
		2	-0.06 (-1.1, 0.99)	-0.21 (-1.31, 0.89)	-0.22 (-1.31, 0.88)	-0.12 (-1.21, 0.98)
		3	-0.77 (-1.82, 0.27)	-0.67 (-1.75, 0.4)	-0.71 (-1.78, 0.37)	-0.71 (-1.78, 0.37)
	Moderate	0	-0.77 (-2.07, 0.53)	-1 (-4.52, 2.51)	1.6 (-2.12, 5.33)	-0.64 (-3.08, 1.81)
		1	-0.01 (-1.08, 1.06)	0.37 (-0.78, 1.52)	0.16 (-0.97, 1.3)	0.33 (-0.81, 1.48)
		2	0.91 (-0.15, 1.97)	0.74 (-0.37, 1.86)	0.77 (-0.34, 1.88)	0.72 (-0.38, 1.83)
		3	-0.12 (-1.18, 0.94)	-0.04 (-1.14, 1.06)	-0.09 (-1.2, 1.01)	-0.05 (-1.15, 1.05)
	Severe	0	-1.35 (-2.59, -0.1)	0.57 (-3.15, 4.29)	0.3 (-2.42, 3.02)	-0.62 (-2.64, 1.41)
		1	0.93 (-0.05, 1.9)	1.06 (0.01, 2.1)	1.03 (0, 2.06)	1.03 (-0.02, 2.07)
		2	0.35 (-0.62, 1.31)	0.44 (-0.56, 1.44)	0.39 (-0.61, 1.39)	0.46 (-0.53, 1.45)
		3	0.59 (-0.37, 1.55)	0.65 (-0.34, 1.64)	0.64 (-0.35, 1.63)	0.63 (-0.36, 1.62)
	Very severe	0	0.17 (-1.22, 1.57)	0.91 (-2.13, 3.95)	4.53 (1.64, 7.43)	1.02 (-1.02, 3.05)
		1	0.91 (-0.14, 1.96)	1.3 (0.15, 2.45)	1.29 (0.16, 2.42)	1.25 (0.1, 2.4)
		2	1.15 (0.11, 2.19)	1.27 (0.19, 2.35)	1.26 (0.18, 2.34)	1.33 (0.27, 2.4)
		3	1.24 (0.22, 2.27)	1.12 (0.06, 2.17)	1.06 (0, 2.12)	1.09 (0.03, 2.15)
Cardiovascular diseases	Mild	0	-0.21 (-1.7, 1.28)	-1.72 (-6.02, 2.58)	16.26 (12.24, 20.27)	-5.2 (-8.19, -2.21)
		1	-0.54 (-1.79, 0.71)	-0.45 (-1.78, 0.88)	-0.42 (-1.74, 0.89)	-0.44 (-1.77, 0.89)

			Attributable deaths per million (95% CrI)			
Cause of death	Flood severity	Lag (months)	Heavy rain	Ice jams and dam breaks	Snowmelt	Tropical cyclones
		2	0.15 (-1.09, 1.39)	0.19 (-1.12, 1.49)	0.15 (-1.15, 1.46)	0.13 (-1.17, 1.43)
		3	1.21 (-0.02, 2.45)	1.33 (0.06, 2.6)	1.24 (-0.03, 2.52)	1.33 (0.06, 2.61)
	Moderate	0	-1.02 (-2.53, 0.5)	-4.62 (-8.89, -0.34)	9.27 (5, 13.54)	-2.62 (-5.65, 0.41)
		1	0.71 (-0.55, 1.97)	0.98 (-0.38, 2.34)	0.94 (-0.41, 2.29)	0.98 (-0.38, 2.34)
		2	1.95 (0.7, 3.21)	1.41 (0.09, 2.72)	1.32 (0, 2.63)	1.41 (0.1, 2.72)
		3	1.85 (0.6, 3.11)	1.84 (0.54, 3.15)	1.72 (0.42, 3.03)	1.87 (0.56, 3.17)
	Severe	0	-0.11 (-1.55, 1.34)	-2 (-6.51, 2.51)	6.7 (3.54, 9.85)	-0.72 (-3.2, 1.77)
		1	0.08 (-1.08, 1.24)	0.76 (-0.49, 2.01)	0.85 (-0.38, 2.08)	0.73 (-0.52, 1.98)
		2	1.59 (0.44, 2.74)	1.85 (0.66, 3.04)	1.7 (0.51, 2.88)	1.63 (0.45, 2.8)
		3	0.83 (-0.31, 1.98)	0.53 (-0.65, 1.71)	0.39 (-0.79, 1.57)	0.5 (-0.68, 1.68)
	Very severe	0	3.65 (2.06, 5.25)	-1.73 (-5.35, 1.89)	8.24 (4.76, 11.72)	-2.03 (-4.52, 0.46)
		1	1.16 (-0.08, 2.4)	1.59 (0.22, 2.96)	1.54 (0.2, 2.88)	1.69 (0.32, 3.06)
		2	1.73 (0.5, 2.96)	2.17 (0.89, 3.45)	1.99 (0.71, 3.27)	1.7 (0.44, 2.97)
		3	0.5 (-0.72, 1.72)	0.44 (-0.81, 1.7)	0.51 (-0.75, 1.78)	0.6 (-0.67, 1.86)
Infectious and parasitic diseases	Mild	0	-0.47 (-0.89, -0.04)	0.43 (-0.72, 1.57)	0.77 (-0.38, 1.92)	-0.34 (-1.11, 0.43)
		1	-0.13 (-0.48, 0.22)	-0.18 (-0.55, 0.19)	-0.13 (-0.49, 0.24)	-0.17 (-0.54, 0.19)
		2	-0.4 (-0.74, -0.05)	-0.41 (-0.77, -0.04)	-0.41 (-0.78, -0.05)	-0.43 (-0.79, -0.06)
		3	0.08 (-0.25, 0.42)	0.1 (-0.25, 0.45)	0.08 (-0.27, 0.43)	0.09 (-0.26, 0.44)

			Attributable deaths per million (95% CrI)			
Cause of death	Flood severity	Lag (months)	Heavy rain	Ice jams and dam breaks	Snowmelt	Tropical cyclones
	Moderate	0	-0.81 (-1.26, -0.37)	-0.89 (-2.09, 0.31)	1.2 (-0.03, 2.42)	0.29 (-0.52, 1.1)
		1	-0.17 (-0.53, 0.19)	-0.14 (-0.53, 0.24)	-0.17 (-0.56, 0.21)	-0.15 (-0.54, 0.23)
		2	-0.44 (-0.8, -0.08)	-0.52 (-0.9, -0.14)	-0.53 (-0.91, -0.15)	-0.55 (-0.93, -0.17)
		3	-0.18 (-0.54, 0.17)	-0.2 (-0.58, 0.17)	-0.21 (-0.58, 0.16)	-0.2 (-0.57, 0.17)
	Severe	0	0.19 (-0.22, 0.6)	-1.5 (-2.83, -0.17)	1.11 (0.23, 1.99)	-0.21 (-0.91, 0.49)
		1	0.05 (-0.27, 0.38)	0.05 (-0.3, 0.4)	0.02 (-0.33, 0.37)	0.04 (-0.31, 0.4)
		2	0.16 (-0.17, 0.48)	0.15 (-0.19, 0.48)	0.13 (-0.21, 0.47)	0.08 (-0.25, 0.42)
		3	-0.02 (-0.34, 0.31)	0 (-0.33, 0.34)	-0.03 (-0.36, 0.31)	-0.02 (-0.35, 0.32)
	Very severe	0	0.55 (0.09, 1.01)	-1.5 (-2.51, -0.49)	1.03 (0.04, 2.03)	0.74 (0.07, 1.41)
		1	0.34 (-0.01, 0.69)	0.58 (0.2, 0.97)	0.64 (0.26, 1.02)	0.58 (0.19, 0.97)
		2	0.4 (0.05, 0.75)	0.31 (-0.05, 0.68)	0.29 (-0.07, 0.66)	0.26 (-0.1, 0.61)
		3	0.37 (0.03, 0.72)	0.32 (-0.04, 0.67)	0.33 (-0.03, 0.69)	0.34 (-0.01, 0.7)
Injuries	Mild	0	-0.38 (-1.26, 0.5)	-0.73 (-3.33, 1.87)	0.84 (-1.68, 3.35)	-0.24 (-1.87, 1.39)
		1	-0.32 (-1.04, 0.41)	-0.05 (-0.81, 0.72)	-0.04 (-0.8, 0.71)	-0.05 (-0.82, 0.71)
		2	-0.53 (-1.25, 0.19)	-0.7 (-1.45, 0.06)	-0.72 (-1.48, 0.04)	-0.73 (-1.48, 0.03)
		3	0.49 (-0.21, 1.2)	0.41 (-0.32, 1.14)	0.4 (-0.33, 1.14)	0.4 (-0.33, 1.14)
	Moderate	0	-0.26 (-1.16, 0.65)	-1.96 (-4.55, 0.63)	3.93 (1.34, 6.51)	-1.53 (-3.2, 0.15)
		1	-0.17 (-0.91, 0.57)	-0.14 (-0.93, 0.66)	-0.14 (-0.92, 0.65)	-0.15 (-0.94, 0.64)
		2	0.33 (-0.4, 1.06)	0.33 (-0.44, 1.1)	0.31 (-0.46, 1.08)	0.35 (-0.42, 1.11)
		3	0.73 (0, 1.45)	0.82 (0.06, 1.57)	0.82 (0.07, 1.58)	0.84 (0.09, 1.6)

			Attributable deaths per million (95% CrI)			
Cause of death	Flood severity	Lag (months)	Heavy rain	Ice jams and dam breaks	Snowmelt	Tropical cyclones
	Severe	0	-0.68 (-1.56, 0.21)	-3.87 (-6.78, -0.96)	1.58 (-0.37, 3.54)	2.09 (0.71, 3.46)
		1	-0.15 (-0.85, 0.54)	-0.03 (-0.77, 0.71)	0.06 (-0.67, 0.79)	-0.02 (-0.76, 0.72)
		2	-0.21 (-0.89, 0.48)	-0.24 (-0.95, 0.48)	-0.27 (-0.98, 0.44)	-0.22 (-0.93, 0.48)
		3	-0.27 (-0.95, 0.41)	-0.39 (-1.09, 0.31)	-0.39 (-1.1, 0.31)	-0.38 (-1.09, 0.32)
	Very severe	0	-0.13 (-1.13, 0.88)	-1.09 (-3.57, 1.4)	1.24 (-0.96, 3.44)	7.3 (5.95, 8.65)
		1	1.47 (0.72, 2.22)	1.91 (1.09, 2.72)	1.74 (0.94, 2.54)	1.96 (1.15, 2.78)
		2	-0.08 (-0.84, 0.67)	-0.22 (-1, 0.57)	-0.22 (-1.01, 0.56)	-0.3 (-1.08, 0.47)
		3	0.31 (-0.43, 1.05)	0.08 (-0.68, 0.85)	0.07 (-0.7, 0.84)	-0.06 (-0.82, 0.71)
Neuropsychiatric conditions	Mild	0	-1.81 (-3.1, -0.51)	-3.48 (-6.89, -0.06)	13.34 (10.27, 16.42)	-4.77 (-6.97, -2.56)
		1	-1.84 (-2.87, -0.8)	-1.53 (-2.61, -0.44)	-1.22 (-2.28, -0.16)	-1.5 (-2.58, -0.41)
		2	0.01 (-1.01, 1.02)	0.04 (-1.03, 1.1)	-0.02 (-1.08, 1.05)	0.06 (-1, 1.12)
		3	-0.35 (-1.36, 0.66)	-0.42 (-1.46, 0.61)	-0.51 (-1.55, 0.52)	-0.44 (-1.47, 0.59)
	Moderate	0	0.48 (-0.81, 1.78)	1.75 (-1.4, 4.9)	11.9 (8.62, 15.19)	-2.2 (-4.42, 0.02)
		1	-0.68 (-1.72, 0.36)	-0.64 (-1.75, 0.46)	-0.6 (-1.69, 0.48)	-0.63 (-1.73, 0.47)
		2	0.07 (-0.96, 1.11)	0.16 (-0.92, 1.24)	0.05 (-1.02, 1.13)	0.12 (-0.96, 1.19)
		3	-0.38 (-1.41, 0.66)	-0.48 (-1.55, 0.59)	-0.54 (-1.61, 0.53)	-0.4 (-1.47, 0.67)
	Severe	0	-0.79 (-2.05, 0.46)	-0.31 (-3.68, 3.06)	10.48 (8.06, 12.89)	-1.08 (-2.96, 0.79)
		1	1.05 (0.1, 2)	1.14 (0.14, 2.15)	1.14 (0.15, 2.12)	1.07 (0.07, 2.07)
		2	0.92 (-0.02, 1.87)	0.75 (-0.23, 1.72)	0.64 (-0.33, 1.61)	0.73 (-0.23, 1.69)

			Attributable deaths per million (95% CrI)			
Cause of death	Flood severity	Lag (months)	Heavy rain	Ice jams and dam breaks	Snowmelt	Tropical cyclones
	Very severe	3	-0.53 (-1.47, 0.41)	-0.52 (-1.49, 0.44)	-0.64 (-1.6, 0.33)	-0.54 (-1.51, 0.43)
		0	0.93 (-0.52, 2.38)	-4.86 (-7.8, -1.91)	8.87 (6.25, 11.48)	-1.79 (-3.73, 0.15)
		1	-0.14 (-1.18, 0.9)	0.66 (-0.47, 1.79)	0.41 (-0.69, 1.51)	0.65 (-0.48, 1.77)
		2	0.69 (-0.35, 1.73)	0.37 (-0.7, 1.45)	0.27 (-0.8, 1.35)	0.22 (-0.84, 1.27)
		3	-0.17 (-1.2, 0.87)	-0.29 (-1.34, 0.77)	-0.29 (-1.35, 0.77)	-0.21 (-1.27, 0.85)
Respiratory diseases	Mild	0	-1.57 (-2.48, -0.66)	-0.79 (-3.25, 1.66)	12.07 (9.93, 14.21)	-0.99 (-2.77, 0.79)
		1	-0.97 (-1.72, -0.21)	-0.47 (-1.27, 0.34)	-0.31 (-1.1, 0.47)	-0.44 (-1.24, 0.36)
		2	0.09 (-0.65, 0.84)	0.23 (-0.55, 1.02)	0.16 (-0.62, 0.94)	0.25 (-0.53, 1.02)
		3	0.77 (0.03, 1.51)	0.87 (0.11, 1.63)	0.79 (0.03, 1.56)	0.86 (0.1, 1.62)
	Moderate	0	-1.26 (-2.17, -0.35)	-3.59 (-6.04, -1.14)	10.98 (8.71, 13.26)	-0.74 (-2.54, 1.06)
		1	-1.1 (-1.86, -0.34)	-0.76 (-1.58, 0.05)	-0.74 (-1.54, 0.07)	-0.72 (-1.54, 0.09)
		2	0.26 (-0.49, 1.01)	0.05 (-0.74, 0.83)	-0.04 (-0.83, 0.74)	0.08 (-0.7, 0.87)
		3	0.6 (-0.16, 1.35)	0.7 (-0.08, 1.48)	0.64 (-0.14, 1.42)	0.71 (-0.07, 1.49)
	Severe	0	-0.73 (-1.61, 0.15)	-1.84 (-4.44, 0.76)	8.19 (6.44, 9.94)	0.03 (-1.48, 1.54)
		1	0.09 (-0.61, 0.79)	0.73 (-0.02, 1.48)	0.62 (-0.12, 1.35)	0.71 (-0.04, 1.45)
		2	1.28 (0.59, 1.97)	1.27 (0.56, 1.99)	1.17 (0.46, 1.88)	1.18 (0.48, 1.89)
		3	0.95 (0.26, 1.64)	1.08 (0.38, 1.79)	1.02 (0.31, 1.73)	1.1 (0.4, 1.81)
	Very severe	0	0.19 (-0.8, 1.18)	-4.42 (-6.63, -2.21)	8.12 (6.2, 10.04)	0.17 (-1.38, 1.71)
		1	0.27 (-0.49, 1.02)	0.93 (0.1, 1.76)	0.87 (0.06, 1.68)	0.96 (0.13, 1.79)

			Attributable deaths per million (95% CrI)			
Cause of death	Flood severity	Lag (months)	Heavy rain	Ice jams and dam breaks	Snowmelt	Tropical cyclones
		2	0.48 (-0.27, 1.24)	0.32 (-0.47, 1.1)	0.18 (-0.6, 0.96)	0.33 (-0.44, 1.11)
		3	0.58 (-0.18, 1.33)	0.48 (-0.29, 1.25)	0.37 (-0.41, 1.14)	0.42 (-0.35, 1.2)

Extended data figure legends

Extended Data Fig. 1 Age-standardized death rates during 2001-2018. Age-standardized death rates per 100,000 by month and year for each cause of death and by sex during 2001-2018.

Extended Data Fig. 2 Count of flood events by month and flood cause during 2001-2018.

Number of flood events by flood cause (heavy rain, tropical cyclone, snowmelt, or ice jam/dam break) and month during 2001-2018.

Extended Data Fig. 3 Percent change in death rates. Percent change in death rates per one higher monthly flood event by cause of death, flood severity, and lag time. Lag time is measured in months after flood. Dots show point estimates and error bars represent 95% credible intervals.

Extended Data Fig. S4 Median flood duration in days. Median flood duration in days by county and flood cause during 2001-2018. Panel A: heavy rain flood events (n=61); Panel B: tropical cyclone flood events (n=18); Panel C: snowmelt flood events (n=9); Panel D: ice jam/dam break flood events (n=5).

Extended Data Fig. 5 Maximum flood duration in days. Maximum flood duration in days by county and flood cause during 2001-2018. Panel A: heavy rain flood events (n=61); Panel B: tropical cyclone flood events (n=18); Panel C: snowmelt flood events (n=9); Panel D: ice jam/dam break flood events (n=5).