Supporting Information

Individual and interactive effects of floods and tropical cyclones on mortality: a multi-country time-series analysis

Wenzhong Huang PhD[1,2,a], Zhengyu Yang PhD[2,3,a], Rongbin Xu PhD[4,5], Prof. Shilu Tong[6,7], Christian Otto PhD[8], Prof. Simon Hales PhD[9], Prof. Michelle L. Bell PhD[10], Francesco Sera PhD[11], Prof. Eric Lavigne PhD[12,13], Veronika Huber[14,15], Yanming Liu PhD[2], Shuang Zhou PhD[2], Pei Yu PhD[2], Yiwen Zhang PhD[2], Wenhua Yu PhD[2], Junwang Huang MSc[2], Yao Wu PhD[2], Bo Wen PhD[2], Zhihu Xu MSc[2], Prof. Shanshan Li PhD[2,*], Prof. Yuming Guo PhD[2,*] on behalf of the MCC Collaborative Research Network[b]

[1]Key Laboratory of Environmental Medicine and Engineering of Ministry of Education, and School of Public Health, Southeast University, Nanjing, Jiangsu, China.
[2]Climate, Air Quality Research Unit, School of Public Health and Preventive Medicine, Monash University, Melbourne VIC 3004, Australia
[3]Department of Urban Planning and Design, the Social Infrastructure for Equity and Wellbeing (SIEW) Lab, and the Hong Kong Base of the State Key Laboratory of Subtropical Building and Urban Science, The University of Hong Kong, Hong Kong SAR 999077, China
[4]Chongqing Emergency Medical Center, Chongqing University Central Hospital, School of Medicine, Chongqing University, Chongqing 400044, China
[5]School of Public Health and Preventive Medicine, Faculty of Medicine, Nursing and Health Sciences, Monash University, Melbourne VIC 3004, Australia
[6]National Institute of Environmental Health, Chinese Center for Disease Control and Prevention, Beijing 100021, China
[7]School of Public Health and Social Work, Queensland University of Technology, Brisbane QLD 4059, Australia
[8]Potsdam Institute for Climate Impact Research, Potsdam 14473, Germany
[9]Department of Public Health, University of Otago, Wellington 6242, New Zealand
[10]School of the Environment, Yale University, New Haven CT 06511, USA
[11]Department of Statistics, Computer Science and Applications "G. Parenti", University of Florence, Florence 50134, Italy
[12]Environmental Health Science and Research Bureau, Health Canada, Ottawa, ON K1A 0K9, Canada
[13]School of Epidemiology and Public Health, University of Ottawa, Ottawa, ON K1G 5Z3, Canada
[14]Doñana Biological Station (EBD), Spanish National Research Council (CSIC), Sevilla 41092, Spain
[15]Institute of Epidemiology, Helmholtz Zentrum München – German Research Center for Environmental Health (GmbH), Neuherberg 85764, Germany
[a]Authors contributed equally to this work
[b]Members are listed in the MCC collaborators in the manuscript

[*]**Address correspondence to:**
Professor Yuming Guo, Climate, Air Quality Research Unit, School of Public Health and Preventive Medicine, Monash University, Melbourne, VIC 3004, Australia. Email: yuming.guo@monash.edu
Professor Shanshan Li, Climate, Air Quality Research Unit, School of Public Health and Preventive Medicine, Monash University, Melbourne, VIC 3004, Australia. Email: shanshan.li@monash.edu

Table of Contents

Supplementary texts S3

Text S1 Mortality data collection and organization S3

Supplementary tables and figures S4

Table S1. Summary of number of locations, total mortality counts, TC and flood exposure days used in the cause-specific models. S4

Table S2. The relative risks and RERI (with 95% CI) for exposures to floods and tropical cyclones on respiratory mortality. S5

Table S3. The percent change in mortality (with 95% CI) for exposures to floods with or without TCs on all-cause, cardiovascular, and respiratory mortality. S6

Table S4. Continent- and region-specific relative risks (with 95% CI) of respiratory mortality associated with flood and tropical cyclone exposures. S7

Table S5. The RRs and RERI (with 95% CI) for exposures to floods and tropical cyclones on all-cause, cardiovascular, and respiratory mortality in the sensitivity analysis by excluding the locations without all-cause mortality data[a] S8

Table S6. The RRs and RERI (with 95% CI) for exposures to floods and tropical cyclones on all-cause, cardiovascular, and respiratory mortality in the sensitivity analysis, with additional adjustment for public holiday effects S9

Table S7. The RRs and RERI (with 95% CI) for exposures to floods and tropical cyclones on all-cause, cardiovascular, and respiratory mortality in the sensitivity analysis by using models with different degrees of freedom for temperature term[a] S10

Table S8. The RRs and RERI (with 95% CI) for exposures to floods and tropical cyclones on all-cause, cardiovascular, and respiratory mortality in the sensitivity analysis by using models with different moving average windows for temperature[a] S11

Table S9. The RRs and RERI (with 95% CI) for exposures to floods and tropical cyclones on all-cause, cardiovascular, and respiratory mortality in the sensitivity analysis by using models with different dfs for the lag effects of TC and flood exposures[a] S12

Table S10. The RRs and RERI (with 95% CI) for exposures to floods and tropical cyclones on all-cause, cardiovascular, and respiratory mortality in the sensitivity analysis by using models with different dfs for controlling long-term trends[a] S13

Table S11. The RRs and RERI (with 95% CI) for exposures to floods and tropical cyclones on all-cause, cardiovascular, and respiratory mortality in the sensitivity analysis by using the locations with tropical cyclone or flood exposure days. S14

Figure S1. The cumulative relative risks (with 95% CI) of all-cause, cardiovascular, and respiratory mortality associated with floods and tropical cyclones over the 60 days after exposures, comparing the main model with a sensitivity model. S15

Figure S2. The cumulative relative risks (with 95% CI) of respiratory mortality associated with floods and tropical cyclones over the 60 days after exposures, by tertiles (low: Q1, medium: Q2, high: Q3) of GDP per capita, government effectiveness, regulatory quality, population density, percentage of population aged ≥ 65 years and percentage of females. S16

References S17

Supplementary texts

Text S1 Mortality data collection and organization

We collected daily mortality data from three well-established data sources:

MCC database: The Multi-Country Multi-City (MCC) Collaborative Research Network is a continuously expanding international network that collects daily mortality counts from relevant authorities of multiple countries globally (https://mccstudy.lshtm.ac.uk/). The MCC dataset have been widely used and described in detail in our previous work.[1-3] Data was obtained from 848 locations from 54 countries or territories in the MCC network. For each location, daily counts of all-cause mortality were collected and non-external causes (International Classification of Diseases [ICD], 9th Revision codes 0–799 or ICD-10 codes A00–R99) mortality were alternatively collected when all-cause mortality was unavailable.

TRACE database: We also collected mortality data from 1226 locations in 6 countries and territories in the Transdisciplinary Research Alliance for Climate Effects (TRACE) Collaborative Network. Specifically, data on all individual deaths (date and cause of death) in Australia between 2009-2019 from the Australian Cause of Death Unit Record File (COD URF)[4], in New Zealand between 2000-2018 from the New Zealand Ministry of Health[5], in Brazil between 1996-2019 from the Brazil Mortality Information System (Sistema de Informação sobre Mortalidade, SIM)[6], in Canada between 1986-2015 from the Vital Statistics Deaths Database of Statistics Canada[7], in Chile between 1986-2015 from the Chilean Ministry of Health Epidemiology Department[8] and in Taiwan between 2000-2018 from the Mortality Collection, Ministry of Health and Welfare of Taiwan.[9] For a time-series analysis, we aggregated the individual death data at location and daily level based on the administrative boundary with a proper area size for each country and territory (Statistical Area Level 3 [SA3] for Australia [n = 341], territorial authority [TA] for New Zealand [n = 66], immediate region for Brazil [n = 510] and Chile [n = 15], second-level administrative divisions [regions or districts within the provinces and territories] for Canada [n = 288] and special municipalities for Taiwan [n = 6]).

INDEPTH database: Mortality data was also collected for each health demographic surveillance systems (HDSS) sites from the International Network for the Demographic Evaluation of Populations and their Health (INDEPTH) Network. The INDEPTH Network provides all-cause mortality counts data in 2000-2016, which were retrieved from 32 health and demographic surveillance systems (HDSS) sites in Africa and Asia that were not overlapped with the MCC database. The health data were representative of the whole population in each HDSS site, and more information had been presented by previous publications[10,11].

MCC locations in Australia, Brazil, Canada, Chile and Taiwan (n = 57) were excluded to avoid duplication. Data prior to 2000 and after 2019 was excluded to ensure consistency with the gridded population dataset (LandScan, 2000–2019) used for exposure assessment and to remove the influence of COVID-19 pandemic. Consequently, the integrated global dataset covers 2049 locations from 69 countries or territories in overlapping periods between Jan 1, 2000 and Dec 31, 2019. Among these locations, 114 locations from 13 countries or territories that experienced at least one tropical cyclone and flood joint exposure day were included in the subsequent analysis.

Supplementary tables and figures

Table S1. Summary of number of locations, total mortality counts, TC and flood exposure days used in the cause-specific models.

Outcome model	No. of locations	Total deaths	Flood-only days	TC-only days	Joint-exposure days[a]
All-cause mortality	114	24,866,731	4900	1123	267
Cardiovascular mortality	113	6,938,803	4867	1116	264
Respiratory mortality	113	3,418,742	4860	1115	264

Abbreviations: TC, tropical cyclone.
[a]Joint event days are defined as days when TC and flood exposures occur simultaneously.

Table S2. The relative risks and RERI (with 95% CI) for exposures to floods and tropical cyclones on respiratory mortality.

	Periods after exposure, RR[a] (95% CI)			
	14 days	30 days	60 days	180 days
None	Reference	Reference	Reference	Reference
Flood	0.98 (0.94, 1.03)	1.00 (0.94, 1.08)	1.00 (0.88, 1.13)	1.02 (0.82, 1.27)
Tropical cyclone	1.06 (0.96, 1.17)	1.09 (0.87, 1.37)	1.07 (0.69, 1.67)	1.03 (0.38, 2.80)
Joint event[b]	0.90 (0.64, 1.26)	0.74 (0.49, 1.11)	0.43 (0.23, 0.83)	0.06 (0.01, 0.50)
RERI[c]	-0.14 (-0.43, 0.22)	-0.36 (-0.74, 0.07)	-0.64 (-1.28, -0.08)	-0.99 (-2.72, -0.19)

[a]Cumulative relative risks (RRs) of mortality risks over the lag period compared to unexposed days (i.e., no TC or flood).
[b]Joint event days are defined as days when both tropical cyclone and flood exposures occur simultaneously.
[c]Relative excess risk due to interaction (RERI) was calculated as: $RR_{11}-RR_{01}-RR_{10}+1$, where RR_{11}, RR_{01} and RR_{10} represented relative risks for concurrent tropical cyclone-flood days, tropical cyclone-only days, and flood-only days, respectively. A RERI greater than 0 indicates a positive additive interaction (synergism), whereas a RERI less than 0 denotes antagonism.

Table S3. The percent change in mortality (with 95% CI) for exposures to floods with or without TCs on all-cause, cardiovascular, and respiratory mortality.

Lag day after exposure	Percent excess mortality (95% CI)		
	All-cause mortality	Cardiovascular mortality	Respiratory mortality
14 days			
Flood with TC	1.3 (0.4, 2.2)	3.3 (1.7, 4.9)	2.2 (-0.4, 4.9)
Flood without TC	0.1 (0.0, 0.2)	0.2 (0.0, 0.3)	-0.1 (-0.3, 0.2)
30 days			
Flood with TC	0.7 (0.1, 1.3)	1.9 (0.9, 3.0)	1.1 (-0.8, 3.0)
Flood without TC	0.1 (0.0, 0.2)	0.1 (0.0, 0.2)	0.0 (-0.2, 0.2)
60 days			
Flood with TC	0.0 (-0.6, 0.6)	0.4 (-0.3, 1.2)	-0.4 (-1.8, 1.1)
Flood without TC	0.0 (0.0, 0.1)	0.0 (-0.1, 0.1)	0.1 (-0.1, 0.3)
90 days			
Flood with TC	-0.2 (-0.8, 0.4)	0.0 (-0.8, 0.7)	-1.0 (-2.4, 0.4)
Flood without TC	0.0 (-0.1, 0.1)	-0.1 (-0.2, 0.0)	0.2 (-0.1, 0.4)

Abbreviations: CI, confidence interval; TC, tropical cyclone.

Table S4. Continent- and region-specific relative risks (with 95% CI) of respiratory mortality associated with flood and tropical cyclone exposures.

Region[a]	RR (95% CI)[b]
America	
None	Reference
Flood	0.74 (0.52, 1.06)
Tropical cyclone	3.92 (0.34, 45.13)
Joint event	3.57 (0.32, 39.90)
Northern America	
None	Reference
Flood	0.78 (0.54, 1.13)
Tropical cyclone	5.96 (0.63, 56.16)
Joint event	3.79 (0.30, 47.09)
Central America and the Caribbean	
None	Reference
Flood	0.28 (0.11, 0.75)
Tropical cyclone	NA[c]
Joint event	NA[c]
Asia/Pacific	
None	Reference
Flood	1.06 (0.93, 1.21)[d]
Tropical cyclone	0.98 (0.62, 1.55)[d]
Joint event	0.38 (0.19, 0.73)[d]
Eastern Asia	
None	Reference
Flood	1.22 (1.08, 1.38)[d]
Tropical cyclone	1.25 (0.97, 1.61)[d]
Joint event	0.32 (0.17, 0.60)[d]
South-eastern Asia	
None	Reference
Flood	0.70 (0.55, 0.90)
Tropical cyclone	0.18 (0.01, 2.63)
Joint event	NA[c]
Australia and New Zealand	
None	Reference
Flood	1.04 (0.26, 4.12)
Tropical cyclone	NA[c]
Joint event	NA[c]

Abbreviations: CI, confidence interval; NA, not available; RR, relative risk.
[a]Regions are defined according to the UN Statistics Division (M49) regional groupings.
[b]Cumulative RRs of mortality risks over the 60 days after exposures.
[c]Reliable estimates were unavailable due to non-convergence of the region- and mortality-specific models.
[d]Additive interaction is statistically significant.

Table S5. The RRs and RERI (with 95% CI) for exposures to floods and tropical cyclones on all-cause, cardiovascular, and respiratory mortality in the sensitivity analysis by excluding the locations without all-cause mortality data[a].

	RR (95% CI)[b]							
	14 days		30 days		60 days		180 days	
	Main model	Sensitivity model	Main model	Sensitivity model	Main model	Sensitivity model	Main model	Sensitivity model
All-cause mortality								
Flood	1.02 (1.01, 1.04)	1.03 (1.01, 1.04)	1.04 (1.02, 1.07)	1.05 (1.02, 1.08)	1.03 (1.00, 1.07)	1.04 (1.00, 1.08)	1.02 (0.95, 1.11)	1.04 (0.96, 1.13)
Tropical cyclone	1.07 (1.03, 1.12)	1.07 (1.03, 1.12)	1.14 (1.07, 1.20)	1.14 (1.07, 1.21)	1.19 (1.08, 1.32)	1.20 (1.09, 1.32)	1.29 (0.97, 1.72)	1.32 (1.05, 1.66)
Joint event[c]	1.08 (0.99, 1.16)	1.09 (1.01, 1.18)	1.12 (0.93, 1.35)	1.16 (0.96, 1.41)	1.01 (0.78, 1.30)	1.02 (0.78, 1.32)	1.07 (0.56, 2.06)	1.02 (0.53, 1.96)
RERI[d]	-0.02 (-0.11, 0.08)	-0.01 (-0.10, 0.10)	-0.06 (-0.27, 0.18)	-0.02 (-0.24, 0.23)	-0.22 (-0.48, 0.09)	-0.22 (-0.48, 0.11)	-0.25 (-0.92, 0.76)	-0.34 (-0.95, 0.61)
Cardiovascular mortality								
Flood	1.03 (1.01, 1.06)	1.04 (1.02, 1.07)	1.05 (1.02, 1.10)	1.07 (1.04, 1.11)	1.00 (0.96, 1.06)	1.02 (0.97, 1.07)	0.92 (0.83, 1.02)	0.96 (0.86, 1.06)
Tropical cyclone	1.05 (0.99, 1.11)	1.05 (0.99, 1.12)	1.18 (1.07, 1.30)	1.18 (1.07, 1.30)	1.26 (1.09, 1.46)	1.25 (1.09, 1.45)	1.69 (1.29, 2.20)	1.65 (1.28, 2.14)
Joint event[c]	1.22 (1.05, 1.42)	1.25 (1.07, 1.46)	1.29 (1.00, 1.67)	1.35 (1.04, 1.74)	1.30 (0.93, 1.80)	1.31 (0.94, 1.82)	3.88 (1.35, 11.13)	4.24 (1.45, 12.41)
RERI[d]	0.14 (-0.05, 0.34)	0.16 (-0.03, 0.37)	0.06 (-0.25, 0.44)	0.10 (-0.23, 0.50)	0.03 (-0.38, 0.55)	0.03 (-0.38, 0.56)	2.27 (-0.31, 9.30)	2.63 (-0.20, 10.54)
Respiratory mortality								
Flood	0.98 (0.94, 1.03)	0.97 (0.93, 1.02)	1.00 (0.94, 1.08)	0.99 (0.92, 1.07)	1.00 (0.88, 1.13)	1.00 (0.87, 1.15)	1.02 (0.82, 1.27)	1.01 (0.79, 1.30)
Tropical cyclone	1.06 (0.96, 1.17)	1.06 (0.95, 1.17)	1.09 (0.87, 1.37)	1.08 (0.86, 1.36)	1.07 (0.69, 1.67)	1.09 (0.70, 1.70)	1.03 (0.38, 2.80)	0.98 (0.38, 2.51)
Joint event[c]	0.90 (0.64, 1.26)	0.91 (0.71, 1.17)	0.74 (0.49, 1.11)	0.77 (0.51, 1.16)	0.43 (0.23, 0.83)	0.44 (0.23, 0.84)	0.06 (0.01, 0.50)	0.08 (0.01, 0.70)
RERI[d]	-0.14 (-0.43, 0.22)	-0.12 (-0.35, 0.16)	-0.36 (-0.74, 0.07)	-0.31 (-0.70, 0.14)	-0.64 (-1.28, -0.08)	-0.65 (-1.32, -0.08)	-0.99 (-2.72, -0.19)	-0.92 (-2.43, -0.07)

Abbreviations: CI, confidence interval; RR, relative risk.

[a]Number of locations excluded = 7.

[b]Cumulative RRs of mortality risks over the lag period after exposures.

[c]Joint event days are defined as days when both tropical cyclone and flood exposures occur simultaneously.

[d]Relative excess risk due to interaction (RERI) was calculated as: $RR_{11}-RR_{01}-RR_{10}+1$, where RR_{11}, RR_{01} and RR_{10} represented relative risks for concurrent tropical cyclone-flood days, tropical cyclone-only days, and flood-only days, respectively. A RERI greater than 0 indicates a positive additive interaction (synergism), whereas a RERI less than 0 denotes antagonism.

Table S6. The RRs and RERI (with 95% CI) for exposures to floods and tropical cyclones on all-cause, cardiovascular, and respiratory mortality in the sensitivity analysis, with additional adjustment for public holiday effects.

	RR (95% CI)[a]							
	14 days		30 days		60 days		180 days	
	Main model	Model + public holiday	Main model	Main model + public holiday	Main model	Main model + public holiday	Main model	Main model + public holiday
All-cause mortality								
Flood	1.02 (1.01, 1.04)	1.02 (1.01, 1.04)	1.04 (1.02, 1.07)	1.04 (1.02, 1.07)	1.03 (1.00, 1.07)	1.03 (1.00, 1.08)	1.02 (0.95, 1.11)	1.02 (0.95, 1.11)
Tropical cyclone	1.07 (1.03, 1.12)	1.07 (1.03, 1.12)	1.14 (1.07, 1.20)	1.13 (1.07, 1.20)	1.19 (1.08, 1.32)	1.19 (1.08, 1.31)	1.29 (0.97, 1.72)	1.29 (0.97, 1.71)
Joint event[b]	1.08 (0.99, 1.16)	1.08 (0.99, 1.16)	1.12 (0.93, 1.35)	1.12 (0.92, 1.35)	1.01 (0.78, 1.30)	1.00 (0.78, 1.30)	1.07 (0.56, 2.06)	1.07 (0.55, 2.06)
RERI[c]	-0.02 (-0.11, 0.08)	-0.02 (-0.11, 0.08)	-0.06 (-0.27, 0.18)	-0.06 (-0.27, 0.18)	-0.22 (-0.48, 0.09)	-0.22 (-0.48, 0.09)	-0.25 (-0.92, 0.76)	-0.25 (-0.92, 0.76)
Cardiovascular mortality								
Flood	1.03 (1.01, 1.06)	1.03 (1.01, 1.06)	1.05 (1.02, 1.10)	1.05 (1.02, 1.10)	1.00 (0.96, 1.06)	1.00 (0.96, 1.06)	0.92 (0.83, 1.02)	0.92 (0.83, 1.02)
Tropical cyclone	1.05 (0.99, 1.11)	1.05 (0.99, 1.11)	1.18 (1.07, 1.30)	1.17 (1.06, 1.29)	1.26 (1.09, 1.46)	1.26 (1.09, 1.45)	1.69 (1.29, 2.20)	1.68 (1.29, 2.19)
Joint event[b]	1.22 (1.05, 1.42)	1.22 (1.04, 1.41)	1.29 (1.00, 1.67)	1.29 (1.00, 1.66)	1.30 (0.93, 1.80)	1.30 (0.93, 1.80)	3.88 (1.35, 11.13)	3.90 (1.36, 11.19)
RERI[c]	0.14 (-0.05, 0.34)	0.14 (-0.05, 0.34)	0.06 (-0.25, 0.44)	0.06 (-0.25, 0.44)	0.03 (-0.38, 0.55)	0.03 (-0.38, 0.56)	2.27 (-0.31, 9.30)	2.29 (-0.30, 9.36)
Respiratory mortality								
Flood	0.98 (0.94, 1.03)	0.98 (0.94, 1.03)	1.00 (0.94, 1.08)	1.00 (0.94, 1.07)	1.00 (0.88, 1.13)	1.00 (0.88, 1.13)	1.02 (0.82, 1.27)	1.02 (0.82, 1.27)
Tropical cyclone	1.06 (0.96, 1.17)	1.06 (0.96, 1.17)	1.09 (0.87, 1.37)	1.09 (0.87, 1.37)	1.07 (0.69, 1.67)	1.07 (0.69, 1.66)	1.03 (0.38, 2.80)	1.03 (0.38, 2.79)
Joint event[b]	0.90 (0.64, 1.26)	0.90 (0.64, 1.26)	0.74 (0.49, 1.11)	0.73 (0.48, 1.10)	0.43 (0.23, 0.83)	0.43 (0.23, 0.83)	0.06 (0.01, 0.50)	0.06 (0.01, 0.50)
RERI[c]	-0.14 (-0.43, 0.22)	-0.14 (-0.43, 0.23)	-0.36 (-0.74, 0.07)	-0.36 (-0.74, 0.07)	-0.64 (-1.28, -0.08)	-0.64 (-1.28, -0.08)	-0.99 (-2.72, -0.19)	-0.99 (-2.72, -0.19)

Abbreviations: CI, confidence interval; df, degree of freedom; RR, relative risk.

[a]Cumulative RRs of mortality risks over the lag periods after exposures.

[b]Joint event days are defined as days when both tropical cyclone and flood exposures occur simultaneously.

[c]Relative excess risk due to interaction (RERI) was calculated as: $RR_{11}-RR_{01}-RR_{10}+1$, where RR_{11}, RR_{01} and RR_{10} represented relative risks for concurrent tropical cyclone-flood days, tropical cyclone-only days, and flood-only days, respectively. A RERI greater than 0 indicates a positive additive interaction (synergism), whereas a RERI less than 0 denotes antagonism.

Table S7. The RRs and RERI (with 95% CI) for exposures to floods and tropical cyclones on all-cause, cardiovascular, and respiratory mortality in the sensitivity analysis by using models with different degrees of freedom for temperature term[a].

	RR (95% CI)[b]				
	Main model[c]	df = 3	df = 4	df = 5	df = 6
All-cause mortality					
Flood	1.03 (1.00, 1.07)	1.04 (1.00, 1.08)	1.03 (0.99, 1.07)	1.03 (0.99, 1.07)	1.04 (1.00, 1.08)
Tropical cyclone	1.19 (1.08, 1.32)	1.20 (1.08, 1.32)	1.19 (1.08, 1.32)	1.20 (1.09, 1.32)	1.18 (1.07, 1.30)
Joint event[d]	1.01 (0.78, 1.30)	1.11 (0.85, 1.45)	1.04 (0.79, 1.36)	1.01 (0.78, 1.30)	0.96 (0.74, 1.24)
RERI[e]	-0.22 (-0.48, 0.09)	-0.12 (-0.41, 0.23)	-0.19 (-0.46, 0.15)	-0.22 (-0.48, 0.09)	-0.26 (-0.51, 0.04)
Cardiovascular mortality					
Flood	1.00 (0.96, 1.06)	1.02 (0.97, 1.07)	1.00 (0.95, 1.05)	1.00 (0.95, 1.05)	1.01 (0.96, 1.06)
Tropical cyclone	1.26 (1.09, 1.46)	1.27 (1.10, 1.47)	1.26 (1.10, 1.46)	1.27 (1.10, 1.45)	1.25 (1.08, 1.44)
Joint event[d]	1.30 (0.93, 1.80)	1.49 (1.07, 2.07)	1.28 (0.92, 1.78)	1.30 (0.94, 1.81)	1.21 (0.87, 1.68)
RERI[e]	0.03 (-0.38, 0.55)	0.20 (-0.26, 0.79)	0.02 (-0.39, 0.53)	0.04 (-0.38, 0.56)	-0.05 (-0.44, 0.44)
Respiratory mortality					
Flood	1.00 (0.88, 1.13)	1.01 (0.89, 1.15)	0.99 (0.87, 1.13)	0.99 (0.87, 1.13)	1.00 (0.88, 1.14)
Tropical cyclone	1.07 (0.69, 1.67)	1.07 (0.70, 1.66)	1.07 (0.69, 1.67)	1.06 (0.68, 1.65)	1.03 (0.67, 1.60)
Joint event[d]	0.43 (0.23, 0.83)	0.52 (0.27, 0.97)	0.44 (0.22, 0.86)	0.42 (0.22, 0.82)	0.37 (0.19, 0.72)
RERI[e]	-0.64 (-1.28, -0.08)	-0.57 (-1.22, 0.02)	-0.63 (-1.28, -0.05)	-0.63 (-1.27, -0.08)	-0.67 (-1.28, -0.15)

Abbreviations: CI, confidence interval; df, degree of freedom; RR, relative risk.

[a]Sensitivity analyses were performed by using a natural cubic B-spline with varying dfs to model the non-linear effects of temperature in the model.

[b]Cumulative RRs of mortality risks over the 60 days after exposures.

[c]The temperature term in the main model was modeled using a natural cubic B-spline with three internal knots placed at the 10th, 75th, and 90th percentiles of location-specific temperature distributions.

[d]Joint event days are defined as days when both tropical cyclone and flood exposures occur simultaneously.

[e]Relative excess risk due to interaction (RERI) was calculated as: $RR_{11}-RR_{01}-RR_{10}+1$, where RR_{11}, RR_{01} and RR_{10} represented relative risks for concurrent tropical cyclone-flood days, tropical cyclone-only days, and flood-only days, respectively. A RERI greater than 0 indicates a positive additive interaction (synergism), whereas a RERI less than 0 denotes antagonism.

Table S8. The RRs and RERI (with 95% CI) for exposures to floods and tropical cyclones on all-cause, cardiovascular, and respiratory mortality in the sensitivity analysis by using models with different moving average windows for temperature[a].

	RR (95% CI)[b]				
	21 days (main)	14 days	30 days	60 days	180 days
All-cause mortality					
Flood	1.03 (1.00, 1.07)	1.03 (0.99, 1.07)	1.04 (1.00, 1.08)	1.04 (1.00, 1.08)	1.07 (1.02, 1.11)
Tropical cyclone	1.19 (1.08, 1.32)	1.19 (1.08, 1.31)	1.19 (1.08, 1.31)	1.17 (1.06, 1.29)	1.16 (1.05, 1.28)
Joint event[c]	1.01 (0.78, 1.30)	1.02 (0.79, 1.32)	1.02 (0.79, 1.32)	1.05 (0.80, 1.38)	0.92 (0.70, 1.20)
RERI[d]	-0.22 (-0.48, 0.09)	-0.20 (-0.47, 0.11)	-0.20 (-0.46, 0.11)	-0.16 (-0.44, 0.18)	-0.31 (-0.56, -0.01)
Cardiovascular mortality					
Flood	1.00 (0.96, 1.06)	1.00 (0.95, 1.05)	1.01 (0.96, 1.07)	1.02 (0.97, 1.08)	1.05 (0.99, 1.11)
Tropical cyclone	1.26 (1.09, 1.46)	1.23 (1.08, 1.41)	1.26 (1.09, 1.46)	1.21 (1.02, 1.43)	1.21 (1.02, 1.42)
Joint event[c]	1.30 (0.93, 1.80)	1.30 (0.94, 1.80)	1.33 (0.96, 1.85)	1.38 (0.97, 1.95)	1.38 (0.92, 2.07)
RERI[d]	0.03 (-0.38, 0.55)	0.07 (-0.34, 0.58)	0.06 (-0.37, 0.60)	0.14 (-0.32, 0.73)	0.12 (-0.38, 0.82)
Respiratory mortality					
Flood	1.00 (0.88, 1.13)	1.01 (0.89, 1.14)	1.00 (0.88, 1.14)	1.02 (0.89, 1.16)	1.06 (0.92, 1.21)
Tropical cyclone	1.07 (0.69, 1.67)	1.08 (0.70, 1.67)	1.06 (0.68, 1.65)	1.12 (0.73, 1.71)	1.11 (0.73, 1.70)
Joint event[c]	0.43 (0.23, 0.83)	0.45 (0.24, 0.84)	0.44 (0.22, 0.86)	0.48 (0.25, 0.92)	0.32 (0.17, 0.61)
RERI[d]	-0.64 (-1.28, -0.08)	-0.64 (-1.28, -0.08)	-0.63 (-1.27, -0.06)	-0.65 (-1.31, -0.06)	-0.85 (-1.48, -0.35)

Abbreviations: CI, confidence interval; RR, relative risk.

[a]Sensitivity analyses were performed by using moving averages of temperature with different window lengths to account for the delayed effects.

[b]Cumulative RRs of mortality risks over the 60 days after exposures.

[c]Joint event days are defined as days when both tropical cyclone and flood exposures occur simultaneously.

[d]Relative excess risk due to interaction (RERI) was calculated as: $RR_{11}-RR_{01}-RR_{10}+1$, where RR_{11}, RR_{01} and RR_{10} represented relative risks for concurrent tropical cyclone-flood days, tropical cyclone-only days, and flood-only days, respectively. A RERI greater than 0 indicates a positive additive interaction (synergism), whereas a RERI less than 0 denotes antagonism.

Table S9. The RRs and RERI (with 95% CI) for exposures to floods and tropical cyclones on all-cause, cardiovascular, and respiratory mortality in the sensitivity analysis by using models with different dfs for the lag effects of TC and flood exposures[a]

	RR (95% CI)[b]		
	df = 2 (main)	df = 3	df = 4
All-cause mortality			
Flood	1.03 (1.00, 1.07)	1.03 (0.99, 1.08)	1.03 (0.99, 1.08)
Tropical cyclone	1.19 (1.08, 1.32)	1.19 (1.08, 1.31)	1.19 (1.08, 1.31)
Joint event[c]	1.01 (0.78, 1.30)	0.96 (0.73, 1.27)	0.96 (0.72, 1.27)
RERI[d]	-0.22 (-0.48, 0.09)	-0.26 (-0.52, 0.06)	-0.27 (-0.54, 0.06)
Cardiovascular mortality			
Flood	1.00 (0.96, 1.06)	1.00 (0.95, 1.06)	1.00 (0.95, 1.06)
Tropical cyclone	1.26 (1.09, 1.46)	1.25 (1.09, 1.44)	1.25 (1.08, 1.44)
Joint event[c]	1.30 (0.93, 1.80)	1.20 (0.86, 1.68)	1.17 (0.84, 1.64)
RERI[d]	0.03 (-0.38, 0.55)	-0.05 (-0.44, 0.44)	-0.08 (-0.46, 0.41)
Respiratory mortality			
Flood	1.00 (0.88, 1.13)	0.99 (0.86, 1.13)	0.98 (0.85, 1.12)
Tropical cyclone	1.07 (0.69, 1.67)	1.05 (0.66, 1.64)	1.02 (0.64, 1.61)
Joint event[c]	0.43 (0.23, 0.83)	0.38 (0.20, 0.74)	0.37 (0.19, 0.73)
RERI[d]	-0.64 (-1.28, -0.08)	-0.65 (-1.29, -0.12)	-0.62 (-1.25, -0.10)

Abbreviations: CI, confidence interval; df, degree of freedom; RR, relative risk.

[a]Sensitivity analyses were performed by using a varying df for the lag effects of tropical cyclone and flood exposure.

[b]Cumulative RRs of mortality risks over the 60 days after exposures.

[c]Joint event days are defined as days when both tropical cyclone and flood exposures occur simultaneously.

[d]Relative excess risk due to interaction (RERI) was calculated as: $RR_{11}-RR_{01}-RR_{10}+1$, where RR_{11}, RR_{01} and RR_{10} represented relative risks for concurrent tropical cyclone-flood days, tropical cyclone-only days, and flood-only days, respectively. A RERI greater than 0 indicates a positive additive interaction (synergism), whereas a RERI less than 0 denotes antagonism.

Table S10. The RRs and RERI (with 95% CI) for exposures to floods and tropical cyclones on all-cause, cardiovascular, and respiratory mortality in the sensitivity analysis by using models with different dfs for controlling long-term trends[a].

	RR (95% CI)[b]				
	df = 3 (main)	df = 2	df = 4	df = 5	df = 6
All-cause mortality					
Flood	1.03 (1.00, 1.07)	1.03 (0.99, 1.07)	1.03 (0.99, 1.08)	1.03 (0.99, 1.07)	1.04 (1.00, 1.08)
Tropical cyclone	1.19 (1.08, 1.32)	1.19 (1.08, 1.32)	1.19 (1.08, 1.31)	1.18 (1.05, 1.32)	1.17 (1.05, 1.29)
Joint event[c]	1.01 (0.78, 1.30)	1.01 (0.78, 1.30)	0.97 (0.75, 1.26)	1.00 (0.77, 1.29)	1.03 (0.79, 1.35)
RERI[d]	-0.22 (-0.48, 0.09)	-0.22 (-0.48, 0.09)	-0.25 (-0.51, 0.05)	-0.21 (-0.48, 0.10)	-0.17 (-0.44, 0.16)
Cardiovascular mortality					
Flood	1.00 (0.96, 1.06)	1.00 (0.96, 1.06)	1.00 (0.95, 1.05)	1.00 (0.95, 1.05)	1.00 (0.96, 1.06)
Tropical cyclone	1.26 (1.09, 1.46)	1.26 (1.09, 1.46)	1.26 (1.09, 1.46)	1.24 (1.07, 1.43)	1.23 (1.06, 1.42)
Joint event[c]	1.30 (0.93, 1.80)	1.30 (0.93, 1.80)	1.24 (0.89, 1.74)	1.19 (0.85, 1.66)	1.23 (0.86, 1.76)
RERI[d]	0.03 (-0.38, 0.55)	0.03 (-0.38, 0.55)	-0.02 (-0.43, 0.50)	-0.05 (-0.44, 0.44)	-0.00 (-0.42, 0.54)
Respiratory mortality					
Flood	1.00 (0.88, 1.13)	1.00 (0.88, 1.13)	1.02 (0.90, 1.16)	1.03 (0.90, 1.17)	1.03 (0.90, 1.18)
Tropical cyclone	1.07 (0.69, 1.67)	1.07 (0.69, 1.67)	1.05 (0.69, 1.58)	1.11 (0.73, 1.69)	1.04 (0.75, 1.44)
Joint event[c]	0.43 (0.23, 0.83)	0.43 (0.23, 0.83)	0.40 (0.20, 0.76)	0.44 (0.23, 0.85)	0.49 (0.25, 0.94)
RERI[d]	-0.64 (-1.28, -0.08)	-0.64 (-1.28, -0.08)	-0.67 (-1.26, -0.15)	-0.69 (-1.33, -0.13)	-0.59 (-1.08, -0.05)

Abbreviations: CI, confidence interval; df, degree of freedom; RR, relative risk.

[a]Sensitivity analyses were performed by using a cubic B spline with varying dfs for time to model long term trends.

[b]Cumulative RRs of mortality risks over the 60 days after exposures.

[c]Joint event days are defined as days when both tropical cyclone and flood exposures occur simultaneously.

[d]Relative excess risk due to interaction (RERI) was calculated as: $RR_{11}-RR_{01}-RR_{10}+1$, where RR_{11}, RR_{01} and RR_{10} represented relative risks for concurrent tropical cyclone-flood days, tropical cyclone-only days, and flood-only days, respectively. A RERI greater than 0 indicates a positive additive interaction (synergism), whereas a RERI less than 0 denotes antagonism.

Table S11. The RRs and RERI (with 95% CI) for exposures to floods and tropical cyclones on all-cause, cardiovascular, and respiratory mortality in the sensitivity analysis by using the locations with tropical cyclone or flood exposure days.

	RR (95% CI)[b]							
	14 days		30 days		60 days		180 days	
	Main model	Sensitivity model[a]	Main model	Sensitivity model[a]	Main model	Sensitivity model[a]	Main model	Sensitivity model[a]
All-cause mortality								
Flood	1.02 (1.01, 1.04)	1.02 (1.01, 1.02)	1.04 (1.02, 1.07)	1.03 (1.02, 1.04)	1.03 (1.00, 1.07)	1.04 (1.03, 1.05)	1.02 (0.95, 1.11)	1.06 (1.04, 1.08)
Tropical cyclone	1.07 (1.03, 1.12)	1.06 (1.02, 1.10)	1.14 (1.07, 1.20)	1.15 (1.09, 1.22)	1.19 (1.08, 1.32)	1.25 (1.13, 1.38)	1.29 (0.97, 1.72)	1.64 (1.20, 2.25)
Joint event[c]	1.08 (0.99, 1.16)	1.08 (0.99, 1.16)	1.12 (0.93, 1.35)	1.12 (0.93, 1.35)	1.01 (0.78, 1.30)	1.01 (0.78, 1.30)	1.07 (0.56, 2.06)	1.07 (0.56, 2.06)
RERI[d]	-0.02 (-0.11, 0.08)	-0.00 (-0.09, 0.09)	-0.06 (-0.27, 0.18)	-0.06 (-0.27, 0.17)	-0.22 (-0.48, 0.09)	-0.28 (-0.54, 0.03)	-0.25 (-0.92, 0.76)	-0.63 (-1.42, 0.42)
Cardiovascular mortality								
Flood	1.03 (1.01, 1.06)	1.01 (1.00, 1.02)	1.05 (1.02, 1.10)	1.02 (1.00, 1.03)	1.00 (0.96, 1.06)	1.02 (1.00, 1.03)	0.92 (0.83, 1.02)	1.00 (0.98, 1.03)
Tropical cyclone	1.05 (0.99, 1.11)	1.05 (1.00, 1.11)	1.18 (1.07, 1.30)	1.18 (1.07, 1.31)	1.26 (1.09, 1.46)	1.28 (1.09, 1.51)	1.69 (1.29, 2.20)	1.86 (1.35, 2.57)
Joint event[c]	1.22 (1.05, 1.42)	1.22 (1.05, 1.42)	1.29 (1.00, 1.67)	1.29 (1.00, 1.67)	1.30 (0.93, 1.80)	1.30 (0.93, 1.80)	3.88 (1.35, 11.13)	3.88 (1.35, 11.13)
RERI[d]	0.14 (-0.05, 0.34)	0.16 (-0.02, 0.36)	0.06 (-0.25, 0.44)	0.09 (-0.22, 0.47)	0.03 (-0.38, 0.55)	-0.00 (-0.42, 0.52)	2.27 (-0.31, 9.30)	2.01 (-0.61, 9.02)
Respiratory mortality								
Flood	0.98 (0.94, 1.03)	1.02 (1.01, 1.04)	1.00 (0.94, 1.08)	1.05 (1.03, 1.07)	1.00 (0.88, 1.13)	1.08 (1.05, 1.11)	1.02 (0.82, 1.27)	1.16 (1.11, 1.22)
Tropical cyclone	1.06 (0.96, 1.17)	1.05 (0.96, 1.15)	1.09 (0.87, 1.37)	1.12 (0.93, 1.35)	1.07 (0.69, 1.67)	1.13 (0.79, 1.60)	1.03 (0.38, 2.80)	1.07 (0.47, 2.45)
Joint event[c]	0.90 (0.64, 1.26)	0.90 (0.64, 1.26)	0.74 (0.49, 1.11)	0.74 (0.49, 1.11)	0.43 (0.23, 0.83)	0.43 (0.23, 0.83)	0.06 (0.01, 0.50)	0.06 (0.01, 0.50)
RERI[d]	-0.14 (-0.43, 0.22)	-0.18 (-0.45, 0.19)	-0.36 (-0.74, 0.07)	-0.43 (-0.77, -0.03)	-0.64 (-1.28, -0.08)	-0.77 (-1.29, -0.27)	-0.99 (-2.72, -0.19)	-1.18 (-2.53, -0.45)

Abbreviations: CI, confidence interval; RR, relative risk.

[a]Sensitivity analyses were conducted using locations with at least one tropical cyclone or flood exposure day (n = 1696), rather than only those with at least one joint event exposure day (n = 114).

[b]Cumulative RRs of mortality risks over the lag period after exposures.

[c]Joint event days are defined as days when both tropical cyclone and flood exposures occur simultaneously.

[d]Relative excess risk due to interaction (RERI) was calculated as: $RR_{11}-RR_{01}-RR_{10}+1$, where RR_{11}, RR_{01} and RR_{10} represented relative risks for concurrent tropical cyclone-flood days, tropical cyclone-only days, and flood-only days, respectively. A RERI greater than 0 indicates a positive additive interaction (synergism), whereas a RERI less than 0 denotes antagonism.

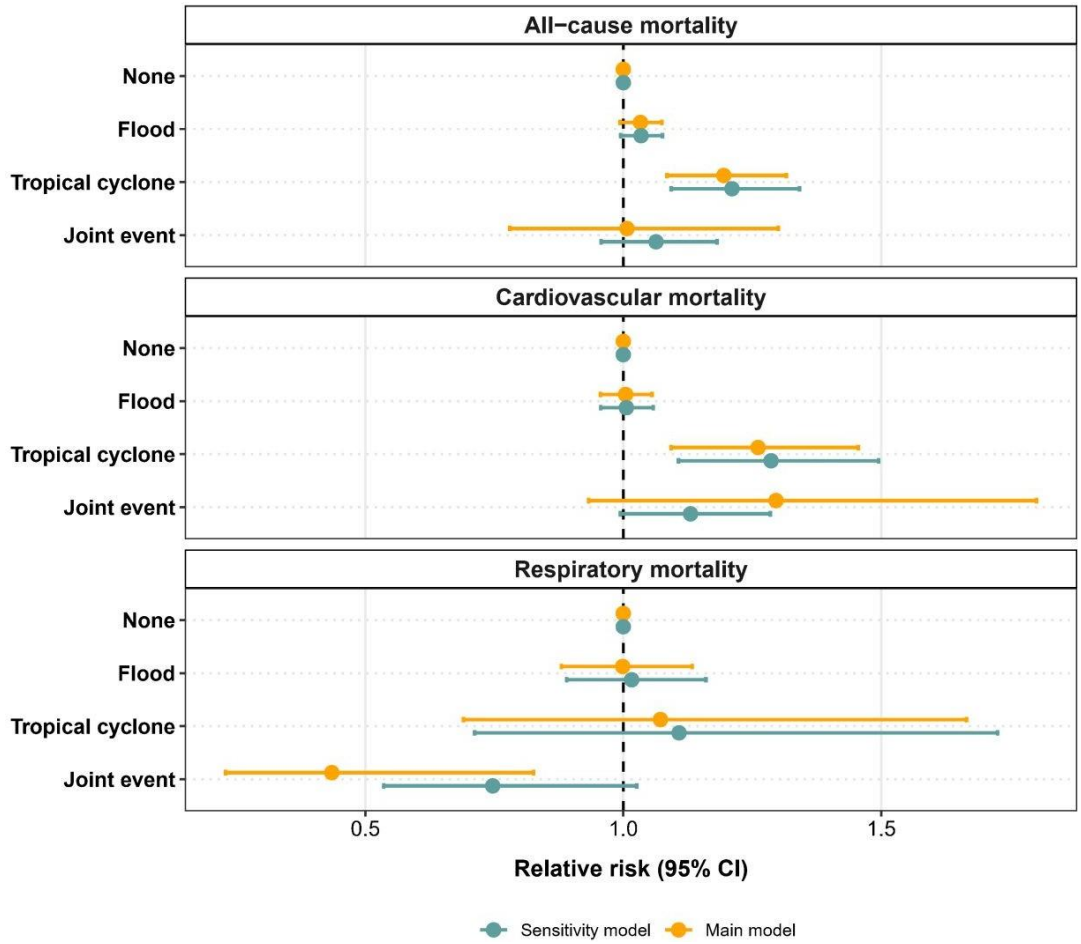


Figure S1. The cumulative relative risks (with 95% CI) of all-cause, cardiovascular, and respiratory mortality associated with floods and tropical cyclones over the 60 days after exposures, comparing the main model with a sensitivity model.

The "Main model" defines a joint exposure day as the co-occurrence of a flood and a tropical cyclone exposure day. The "Sensitivity model" redefines the joint exposure days as flooding days occurring either on the same day as TC day or within three days thereafter. Abbreviations: CI, confidence interval.

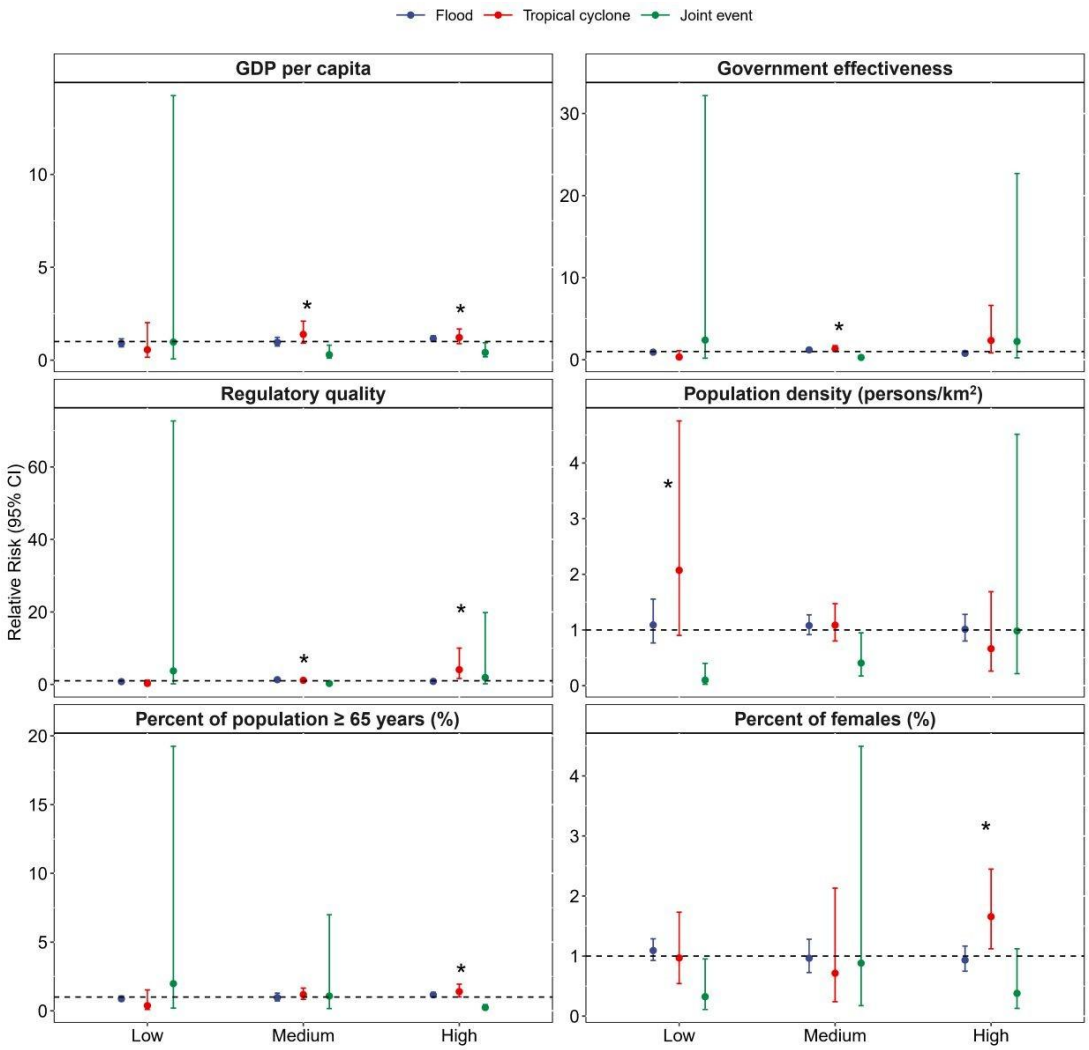


Figure S2. The cumulative relative risks (with 95% CI) of respiratory mortality associated with floods and tropical cyclones over the 60 days after exposures, by tertiles (low: Q1, medium: Q2, high: Q3) of GDP per capita, government effectiveness, regulatory quality, population density, percentage of population aged ≥ 65 years and percentage of females.

Relative risks were derived from the primary four-category analytical framework, where the reference group is days without any flood or TC exposure. Abbreviations: CI, confidence interval; GDP, Gross Domestic Product. **P* for difference between events was < 0.05.

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