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Flood exposure and suicide risk in Japan, 2008–2022: a nationwide study

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ABSTRACT

Flooding is a major climate-related hazard whose frequency and severity are increasing globally, yet evidence linking flood exposure to suicide remains limited. We aimed to evaluate the association between prefecture-level flood exposure and suicide in Japan. In this nationwide ecological longitudinal study, we analyzed monthly panel data from all 47 prefectures in Japan (2008–2022). Suicide counts were obtained from the Vital Statistics of Japan and flood exposure (number of flood days) from the Dartmouth Flood Observatory. Associations between flood days and suicide risk over the subsequent 0–18 months were estimated with a two-stage distributed lag non-linear model (prefecture-specific quasi-Poisson models pooled by multivariate random-effects meta-analysis). Among 8460 prefecture-months, 380,224 suicides were recorded, and 42 (89.4%) of 47 prefectures were flood-affected. One flood day versus none was associated with an increase in suicide risk over 0–18 months (cumulative relative risk 1.112, 95% CI 1.011–1.222), with significant elevation from lag 6 to 14 months and a decline thereafter. Flood exposure corresponded to an attributable fraction of 0.54% of suicides (95% CI 0.06–1.02%), an annual average attributable number of 105 (95% CI 11–200), and an attributable number rate of 0.11 per 100,000 person-years (95% CI 0.01–0.20). These exploratory findings suggest flood-related suicide risk may persist beyond the acute phase and warrant further investigation.

1. Introduction

Flooding is the most common environmental hazard in the world, accounting for approximately 40% of all global natural disasters (Alderman et al., 2012; Ohl and Tapsell, 2000; Rentschler et al., 2022), and its frequency and intensity have increased over the past century and are expected to rise further with climate change (Kim et al., 2023; Khraishah et al., 2022; Knutson et al., 2020). Flooding affects health through multiple pathways, including direct harms such as drowning, injuries, and hypothermia, as well as indirect consequences including contaminated water supplies, infectious disease transmission, disruption of health services, and population displacement (Alderman et al., 2012; Ohl and Tapsell, 2000; Lynch et al., 2025; Wettstein et al., 2025). These disruptions may further exacerbate chronic disease conditions and contribute to adverse mental health outcomes, including psychological distress, depression, and suicidal behavior (Palinkas and Wong, 2020; Cianconi et al., 2020; Morganstein and Ursano, 2020; Goldmann and Galea, 2014). Japan is one of the most flood-prone nations in the world, making it an important setting in which to examine the downstream mental health consequences of flood exposure (Kim et al., 2023). Japan also has a persistently high suicide rate among high-income countries (Motohashi, 2012; World Health Organization, 2021), so disaster-related mental health consequences there fall on a population already at elevated risk. Post-disaster mental health support in Japan is concentrated in the acute phase: Disaster Psychiatric Assistance Teams deploy within about 48 h and consultation activity peaks within the first weeks. No established criteria define how long such support should be sustained, however, and no standing mechanism exists for longer-term mental health surveillance of disaster-affected populations (Takahashi et al., 2020; Suzuki and Kim, 2012; Kunii et al., 2022).

Existing evidence has linked floods and other climate-related disasters to a range of adverse mental and behavioral health outcomes, including psychological distress, depression, posttraumatic stress, and substance use (Palinkas and Wong, 2020; Cianconi et al., 2020; Morganstein and Ursano, 2020; Goldmann and Galea, 2014; Li et al., 2019; Hikichi et al., 2021; Gerstner et al., 2020; Leppold et al., 2022; Yip et al., 2025; Spriggs et al., 2026). Yet suicide remains understudied (Krug et al., 1998; Matsubayashi et al., 2013; Reifels et al., 2024). Much of this literature has focused on single disaster events or short-term health outcomes rather than suicide (Krug et al., 1998; Matsubayashi et al., 2013; Wu et al., 2024). In Japan, studies following the 2011 Great East Japan Earthquake documented psychological distress and

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adverse health outcomes persisting for years among affected residents (Suzuki and Kim, 2012; Kunii et al., 2022; Li et al., 2019; Hikichi et al., 2021), and suicide rates in disaster-stricken areas shifted in the years following major disasters (Matsubayashi et al., 2013). Population-level evidence on whether flood exposure is associated with subsequent suicide remains limited, particularly in nationwide longitudinal studies capable of examining delayed effects over the months following exposure (Lynch et al., 2025; Wu et al., 2024; Chu et al., 2025).

This gap is important because an incomplete understanding of the longer-term mental health consequences of flooding may hinder risk assessment, public health planning, and the development of sustained post-disaster suicide prevention and mental health response strategies (Reifels et al., 2024; North and Pfefferbaum, 2013; Xue et al., 2024). To address these gaps and inform disaster preparedness in an era of increasing climate-related hydrological extremes, we conducted a nationwide ecological longitudinal study examining the association between prefecture-level flood exposure and suicide across all 47 Japanese prefectures from 2008 to 2022. Using monthly panel data, we characterized the lagged pattern of this association, explored potential variation across prefecture-level socioeconomic and health resource characteristics, by macro-region and by season of exposure, and estimated the attributable suicide burden and monetized mortality burden.

2. Methods

2.1. Study design and setting

This nationwide longitudinal study used monthly prefecture-level panel data from all 47 prefectures in Japan from January 2008 to December 2022. This study was determined to be exempt from review and the need for informed consent because of the use of publicly available, deidentified aggregate data. This study followed the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) reporting guideline (von et al., 2007; Vandenbroucke et al., 2014).

2.2. Exposure

The primary exposure was prefecture-level monthly flood exposure, measured as the number of flood-exposed days in each prefecture-month. Flood events in Japan during 2008–2022 were identified from the Dartmouth Flood Observatory (DFO), a global archive that compiles event information from news reports, government records, and instrumental sources and uses satellite observations to map and validate the spatial extent of major floods (Yang et al., 2023). Each event record includes a mapped flood footprint, start and end dates, and severity information. A prefecture was classified as flood-exposed when its geographic centroid fell within the event footprint (a centroid-in-polygon rule), following the approach used in previous multi-location studies (Lynch et al., 2025). Event days were then aggregated to a monthly count of flood-exposed days for each prefecture, with concurrent events affecting the same prefecture-day counted once. The archive has been used to define flood exposure in multi-country epidemiological studies that include Japan (Yang et al., 2023), and flood maps built from its event catalogue agree with independent flood catalogues and modelled flood exposure (Pearson $r = 0.89$) (Tellman et al., 2021).

2.3. Outcome

The primary outcome was the monthly suicide count for each prefecture, obtained from the Vital Statistics of Japan maintained by the Ministry of Health, Labour and Welfare, with suicides identified using ICD-10 codes X60 to X84 and Y87.0. The published tabulations are released only for this combined category. Prefecture-level annual population, obtained from the Statistics Bureau of Japan, was included as a log-offset to estimate suicide rates (Lynch et al., 2025; Spriggs et al., 2026).

2.4. Covariates

Monthly mean 2-m air temperature and relative humidity were obtained from the ERA5 global atmospheric reanalysis (Hersbach et al., 2020), which provides hourly estimates at approximately 31-km spatial resolution; prefecture-level monthly means were computed by averaging grid cells within each prefecture boundary. Temperature was included as a time-varying confounder given its documented association with suicide (Burke et al., 2018). Monthly daylight hours (sunshine duration) were obtained from Japan Meteorological Agency observations. Annual gross domestic product per capita was included to adjust for socioeconomic confounding. Because missingness was limited and several covariates were not measured monthly, we did not interpolate or impute missing covariate values (Hughes et al., 2019).

2.5. Statistical analysis

Analyses covered January 2008 to December 2022. To evaluate the prefecture-level association between monthly flood-exposed days and suicide, we applied a two-stage distributed lag nonlinear modeling framework (Gasparrini et al., 2010, 2015; Gasparrini, 2014). In Stage 1, prefecture-specific quasi-Poisson generalized linear models were fitted to monthly suicide counts. The exposure-response was specified as a natural cubic spline in flood days with one internal knot at 3 days, and the lag-response as a natural cubic spline with 3 degrees of freedom across a 0- to 18-month lag window. Each model included the following terms modelled as natural cubic splines: calendar year (6 df) for long-term secular trend, monthly mean temperature (4 df) and daylight hours (4 df) for meteorological confounding, and calendar month (3 df) for residual within-year seasonality. Annual population was included as a logarithmic offset. In Stage 2, prefecture-specific cross-basis coefficients and their variance-covariance matrices were pooled across the analytic prefectures by multivariate random-effects meta-analysis, with between-prefecture heterogeneity assessed by the multivariate extension of the Cochran Q test and the I^2 statistic. Prefecture-specific estimates, convergence, and leave-one-out analyses are in the Supplement (Fig. S4; Table S6, Table S8 and Table S10).

2.6. Subgroup analysis

Effect modification by ten prefecture-level and exposure-level characteristics (GDP per capita, aging, urbanization, livelihood recipient rate, divorce rate, psychiatric bed density, job-vacancy ratio, crime rate, macro-region, and season of exposure) was assessed primarily by multivariate random-effects meta-regression, with an omnibus Wald test for each modifier on the prefecture-specific cumulative log relative risks; continuous modifiers were scaled per interquartile range and the binary macro-region contrast set Western against Eastern Japan, and P values were corrected across the ten modifiers using the Benjamini-Hochberg false-discovery rate. Macro-region grouped Hokkaido, Tohoku, Kanto and Chubu as Eastern Japan and Kinki, Chugoku, Shikoku and Kyushu-Okinawa as Western Japan; season of exposure was the share of a prefecture's flood-exposed days falling in March to August, which contrasts predominantly summer with predominantly autumn flooding. As sensitivity analyses, the two-stage approach was re-fitted within strata of each characteristic, tertiles for the continuous characteristics and the two macro-regions, and within tertiles of flood-event severity, and between-stratum heterogeneity was assessed by a Cochran Q statistic on the stratum-specific log cumulative relative risks (Gasparrini et al., 2015) (Table S7).

2.7. Attributable burden

Flood-attributable suicide burden was estimated by forward attribution (Gasparrini and Leone, 2014; Gao et al., 2024), applying each prefecture's cumulative exposure-response to its observed flood-day history to obtain the attributable number (AN) relative to a no-flood counterfactual. Attributable fraction (AF) was defined as the total AN divided by total observed suicides; attributable number rate (ANR) was AN divided by total person-years at risk, expressed per 100,000 person-years (Gasparrini and Leone, 2014). The burden was also decomposed by prefecture subgroup and by season of exposure, by applying the same pooled association to each stratum's own exposure history (Table S9).

2.8. Monetized mortality burden

The monetized mortality burden associated with flood-attributable suicides was estimated using a value-of-statistical-life (VSL) approach (Belova et al., 2022; OECD, 2012). A year-specific Japanese VSL was obtained by transferring the US Environmental Protection Agency base value to the Japanese context, adjusting for the ratio of Japanese to US per capita gross domestic product raised to an income elasticity of 0.8, consistent with OECD benefit-transfer recommendations (Botzen et al., 2019; Ding et al., 2016; Hammitt, 2000; Landrigan, 2018; Markandya et al., 2018). This national VSL was then scaled to each prefecture by the ratio of prefecture to national per capita gross domestic product raised to the same elasticity, and the prefecture- and year-specific attributable numbers were multiplied by the corresponding VSL and summed to obtain the total, which is reported as an illustrative benefit-transfer estimate.

2.9. Sensitivity analyses

To assess the robustness of the primary findings, a prespecified grid of sensitivity analyses were conducted across four domains: (1) model specification, including alternative lag windows (0–6, 0–12, 0–24 and 0–30 months), alternative lag bases (natural cubic splines with 4 to 7 degrees of freedom, and a third-degree polynomial) (Gasparrini et al., 2010; Marrie et al., 2009), first-order Fourier seasonal terms, a stronger seasonal and meteorological specification; (2) covariate adjustment, including omission of meteorological covariates, addition of monthly precipitation, and additional adjustment for displacement, taken as the number of evacuees recorded for each event in the Dartmouth Flood Observatory archive and entered linearly; (3) sample restriction, including exclusion of 2020 (COVID-19 year) (Ehlman et al., 2022), and stricter Stage-1 eligibility ($\geq$5 flood-positive months); and (4) alternative footprint-to-prefecture coverage rules (area-based and population-weighted) (Table S6). The prespecified 0–18 month window was additionally compared with the 0–24 and 0–30 month windows by quasi-Akaike and quasi-Bayesian information criteria computed on a common set of observations (Gasparrini et al., 2010), and by approximate tests of the difference between the cumulative estimates (Table S11). Influence and falsification analyses comprised a leave-one-prefecture-out analysis (Table S6) and a leave-one-event-out analysis (Table S10). Falsification analyses included a future-flood negative-control analysis (future flooding at forward leads modelled as the exposure while adjusting for the actual flood exposure) (Flanders et al., 2011) (Table S6). All statistical analyses were performed in R 4.4.1 using the gnm, dlnm, mvmeta, and aod packages (Gasparrini et al., 2010; Gasparrini, 2014).

3. Results

3.1. Study characteristics and flood exposure

The study panel comprised 8460 prefecture-months across all 47 Japanese prefectures from January 2008 to December 2022, during which 380,224 suicides were recorded (mean [SD], 44.9 [42.7] per prefecture-month) (Table 1). Of the 47 prefectures, 42 (89.4%) experienced at least one flood-exposed day over the study period, during which Japan experienced 24 flood events. Flood exposure was distributed similarly between the two halves of the country, with 421 flood-

Table 1
Prefecture-level descriptive statistics, Japan, 2008–2022.

Prefecture	Total suicides	Monthly mean (SD)	Flood-positive months	Flood-exposed days
National total (n = 47)	380,224	44.9 (42.7)	214	822
Hokkaido (n=1)				
Hokkaido	18,131	100.7 (24.6)	0	0
Tohoku (n=6)				
Akita	4502	25.0 (7.6)	3	16
Aomori	5204	28.9 (10.0)	1	2
Fukushima	6576	36.5 (10.9)	6	25
Iwate	5494	30.5 (8.9)	2	5
Miyagi	6972	38.7 (10.6)	5	16
Yamagata	3824	21.2 (7.1)	5	24
Kanto (n=7)				
Chiba	17,411	96.7 (19.7)	4	17
Gunma	6706	37.3 (10.4)	6	24
Ibaraki	8798	48.9 (13.1)	5	19
Kanagawa	21,889	121.6 (27.2)	5	20
Saitama	20,929	116.3 (24.5)	7	27
Tochigi	6761	37.6 (10.1)	6	25
Tokyo	38,344	213.0 (35.3)	0	0
Chubu (n=9)				
Aichi	20,069	111.5 (21.9)	8	30
Fukui	2361	13.1 (4.7)	6	16
Gifu	6393	35.5 (9.1)	9	32
Ishikawa	3278	18.2 (5.7)	4	11
Nagano	6694	37.2 (9.7)	7	28
Niigata	8623	47.9 (12.1)	3	9
Shizuoka	11,446	63.6 (13.8)	7	27
Toyama	3594	20.0 (6.7)	7	22
Yamanashi	4193	23.3 (6.5)	7	28
Kinki (n=7)				
Hyogo	16,403	91.1 (18.6)	6	23
Kyoto	7212	40.1 (9.4)	10	39
Mie	4382	24.3 (8.9)	8	29
Nara	3638	20.2 (6.0)	5	26
Osaka	23,378	129.9 (32.1)	6	30
Shiga	4073	22.6 (7.0)	9	32
Wakayama	3469	19.3 (6.5)	1	4
Chugoku (n=5)				
Hiroshima	8213	45.6 (11.1)	2	9
Okayama	5183	28.8 (7.6)	5	20
Shimane	2412	13.4 (5.4)	2	5
Tottori	2127	11.8 (4.4)	5	20
Yamaguchi	4557	25.3 (7.0)	2	5
Shikoku (n=4)				
Ehime	4098	22.8 (7.7)	0	0
Kagawa	2602	14.5 (4.9)	2	7
Kochi	2581	14.3 (5.4)	0	0
Tokushima	1797	10.0 (4.8)	1	4
Kyushu–Okinawa (n=8)				
Fukuoka	15,616	86.8 (19.2)	9	40
Kagoshima	5608	31.2 (8.5)	1	1
Kumamoto	5465	30.4 (8.6)	7	25
Miyazaki	3791	21.1 (6.9)	6	23
Nagasaki	4756	26.4 (7.4)	1	1
Oita	3585	19.9 (6.2)	6	23
Okinawa	4320	24.0 (7.4)	0	0
Saga	2766	15.4 (5.0)	7	33

Total suicides reflect the cumulative number of recorded suicides from January 2008 to December 2022. Flood months indicate the number of prefecture-months with at least one flood-exposed day; flood days indicate the cumulative number of flood-exposed days. Prefectures are grouped by region (region names shown in bold); the first row gives the national total across all 47 prefectures. Flood exposure data were obtained from the Dartmouth Flood Observatory; suicide data were obtained from the Vital Statistics of Japan.

exposed days in Eastern Japan and 389 in Western Japan among the analytic prefectures, and Kyoto Prefecture recording the greatest number of flood-positive months (n = 10). All flood-exposed days fell between June and October, with July the peak exposure month; 519 fell in the spring-summer half of the year (March to August) and 291 in the autumn-winter half (September to February). Several years during the study period recorded no flood-positive months. Several prefectures exhibited spatial co-occurrence of high flood exposure and elevated suicide rates (Fig. 1; Fig. S1; Table S1 and Table S2).

3.2. Association between flood exposure and suicide risk

Flood exposure was associated with increased suicide risk over the 0- to 18-month lag window. The lag-response curve rose progressively, peaking at month 10 (RR, 1.008; 95% CI 1.001–1.015), and declined thereafter, reaching 0.998 (95% CI 0.988–1.009) at month 18. Statistically significant elevation was observed from lag 6 through 14 months. The cumulative relative risk for a single flood day versus none over the entire window was 1.112 (95% CI 1.011–1.222; Cochran Q = 227.7; $I^2 = 5.1\%$) (Fig. 2; the accumulating lag-response and the cumulative exposure-response curve are shown in Figs. S3 and S5).

3.3. Attributable burden

Over the 15-year study period, flood exposure corresponded to an attributable fraction of 0.54% (95% CI 0.06%–1.02%) of suicides among the 42 flood-exposed prefectures, or 0.42% (95% CI 0.04%–0.79%) referenced to all 47 prefectures, and an attributable number rate of 0.11 per 100,000 person-years (95% CI 0.01–0.20); this was equivalent to an illustrative annual average of 105 attributable suicides (95% CI 11–200).

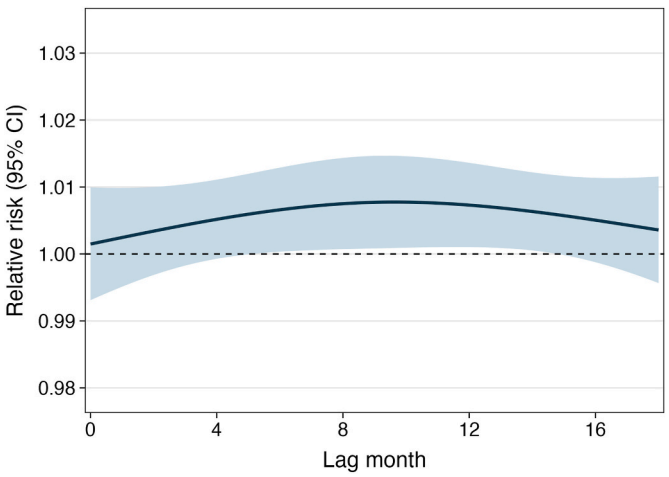


Fig. 2. Pooled lag-response association between flood exposure and suicide in Japan, 2008–2022.
Pooled lag-specific relative risks for a flood-exposed day relative to none across the 0- to 18-month lag window. The solid line indicates point estimates; the shaded area, 95% CIs; the dashed line, the null value (relative risk = 1.0). Estimates were derived from a two-stage distributed lag nonlinear model with random-effects (REML) pooling across the 42 flood-exposed prefectures using a natural cubic spline (df = 3) lag basis. The curve peaks around 10 months and declines thereafter. Values above 1.0 indicate elevated suicide risk associated with flood exposure.

3.4. Monetized mortality burden

The associated monetized mortality burden, based on a prefecture-level value-of-statistical-life approach, was illustratively estimated at approximately US$10,510 million over the study period. The

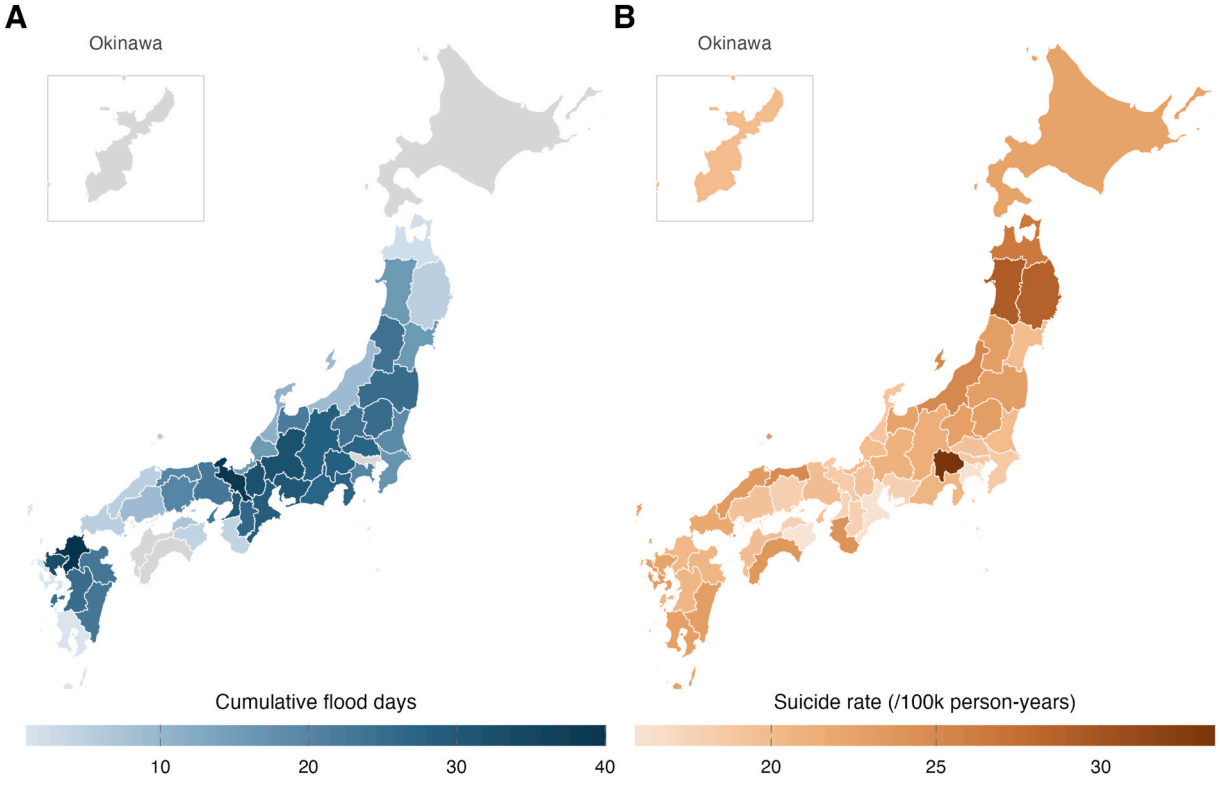


Fig. 1. Spatial distribution of cumulative flood exposure and suicide rates across 47 Japanese prefectures, 2008–2022.
A, Cumulative counts of flood-exposed days by prefecture over the 15-year study period. B, Prefecture-level suicide rate per 100,000 person-years over the study period. Gray shading indicates prefectures with no recorded flood exposure during the study period. The designations employed and the presentation of material on this map do not imply the expression of any opinion concerning the legal status of any territory or the delimitation of its frontiers or boundaries.

attributable burden was greatest in years and prefectures with the most extensive flood exposure, with the highest single-year attributable numbers in 2017, 2010, and 2018 and the largest prefecture-level attributable numbers in Aichi, Saitama, and Hyogo; the highest attributable fractions were observed in Gifu (1.02%), Shiga (0.99%), and Kyoto (0.95%) (Fig. 3; Fig. S2; Table S3; Table S4; Table S5).

3.5. Subgroup analyses

The flood-attributable burden was unevenly distributed across prefecture subgroups (Fig. 4; Table S9 in the Supplementary material). In attributable-fraction terms it was largest in the prefectures with the fewest psychiatric beds, reaching 0.65% against 0.29% in those with the most, a contrast that follows from those prefectures having accumulated the most flood-exposed months (88 against 57), and it was somewhat higher in the more urbanised and economically developed prefectures and lower in the most aged; in absolute and monetized terms it concentrated in the most populous and heavily exposed prefectures, which carry the largest at-risk populations. Eastern Japan carried 1031 of the 1579 attributable suicides against 547 in Western Japan, reflecting its larger population and slightly greater exposure. Decomposed by season of exposure, floods in the autumn-winter half of the year accounted for 944 attributable suicides against 636 for the spring-summer half, despite carrying fewer flood-exposed days (291 against 519). This follows from the flattening of the exposure-response curve at higher daily counts.

3.6. Sensitivity analyses

Across a prespecified grid of sensitivity analyses, the cumulative relative risk estimates were directionally consistent with the primary finding, with all point estimates above the null, although the association was less precise under some specifications (Table S6). The estimate was essentially unchanged under alternative lag bases. The cumulative

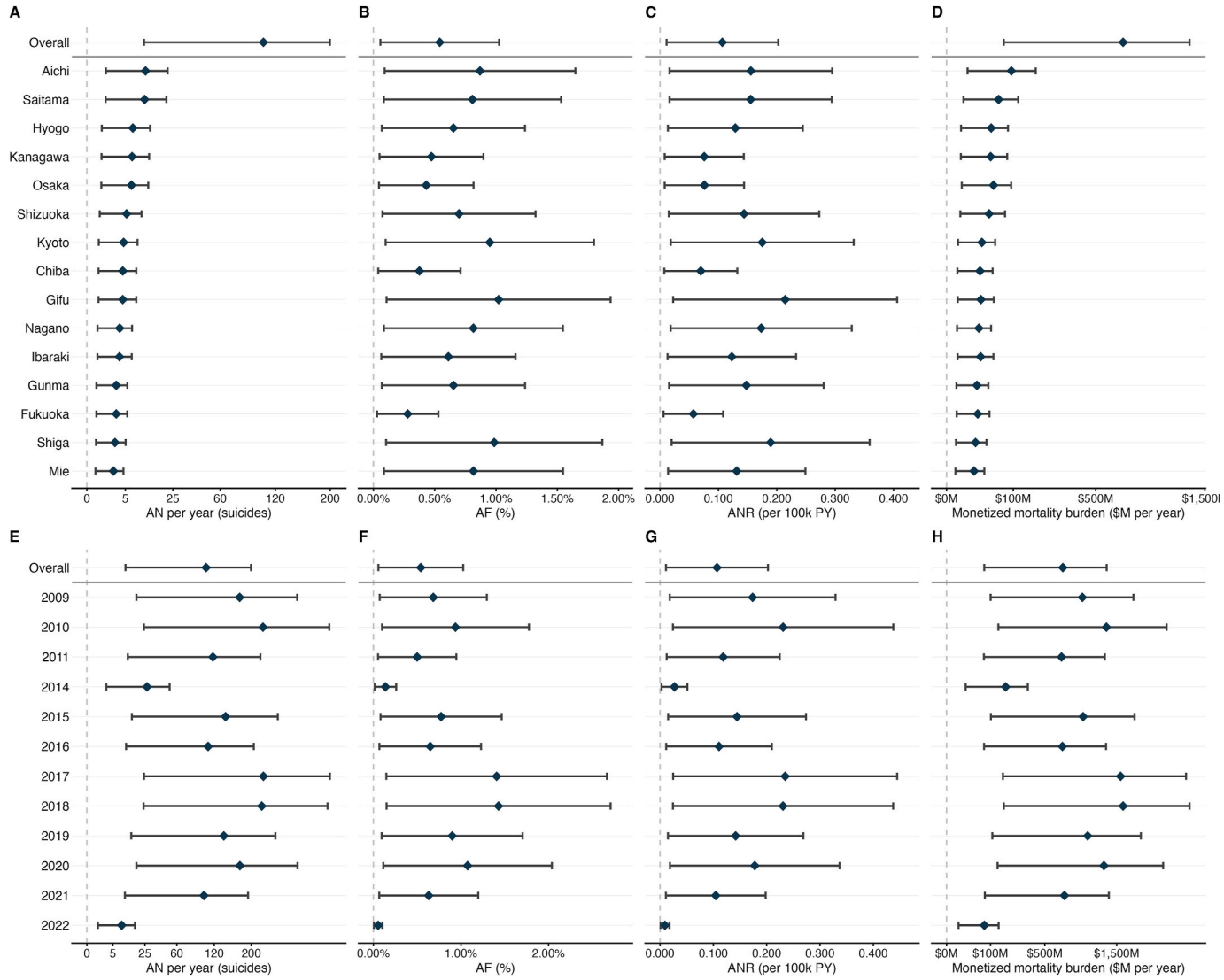
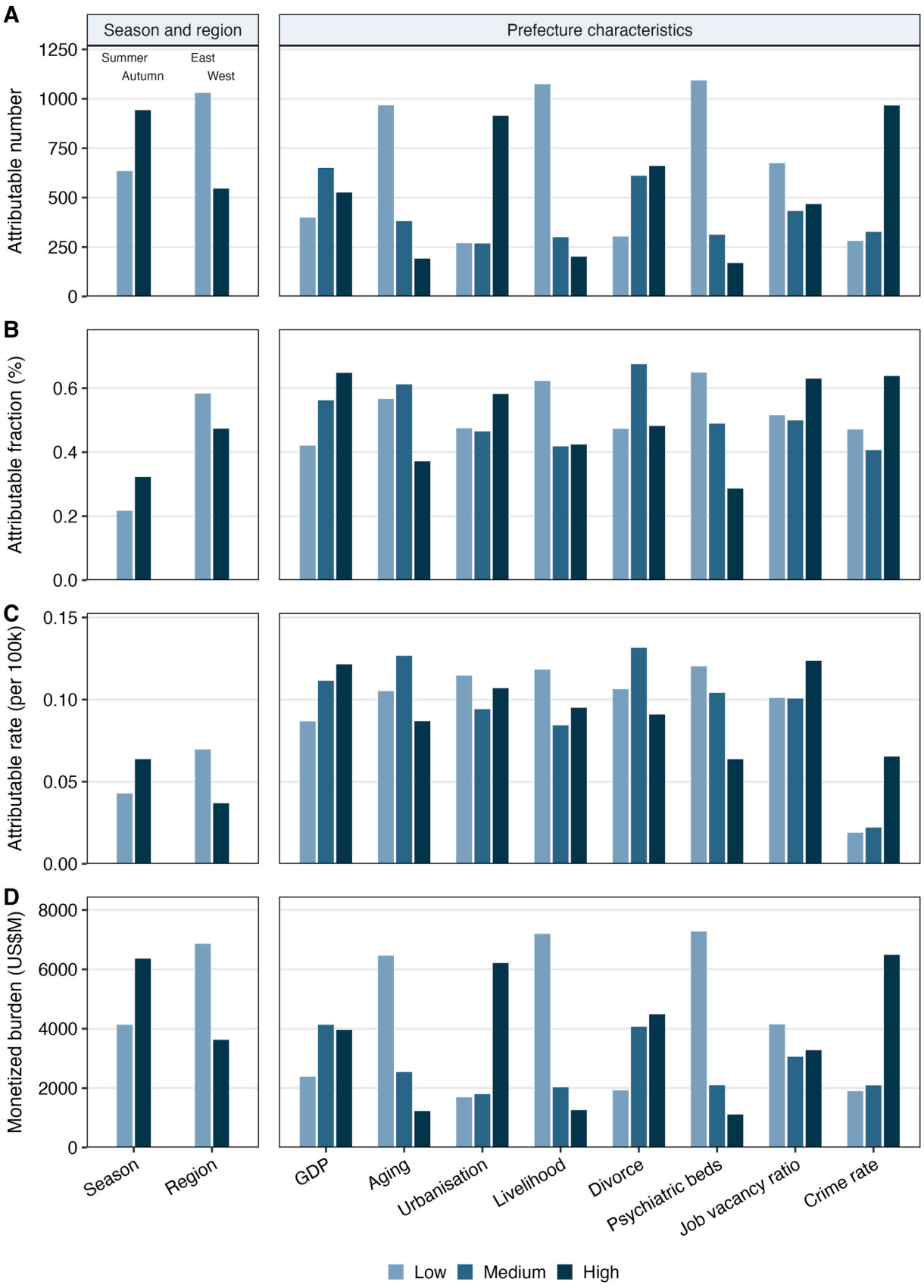


Fig. 3. Estimated suicide burden associated with flood exposure, by prefecture and year, Japan, 2008–2022.
Forest plots show the estimated suicide burden associated with flood exposure, obtained by forward attribution, following a previously described approach (Gasparrini and Leone, 2014). Panels A through D show the attributable number (A), attributable fraction (B), attributable number rate (C), and monetized mortality burden (D) for the 15 prefectures with the greatest attributable burden, together with the overall estimate. The attributable number and the monetized burden are expressed per year throughout, obtained for the prefecture panels by dividing the 15-year totals by the number of study years. Panels E through H show the corresponding estimates for each year with attributable burden and the overall estimate. Points indicate point estimates; horizontal lines, 95% CIs. Negative point estimates and confidence limits were truncated at zero, so the prefecture- and year-specific estimates do not sum exactly to the overall estimate. The horizontal axes of the attributable-number and monetized-burden panels use a square-root scale.



(caption on next page)

Fig. 4. Stratified decomposition of the estimated suicide burden associated with flood exposure across prefecture-level subgroups, Japan, 2008–2022. Bars indicate the estimated suicide burden associated with flood exposure within each subgroup, obtained by applying the overall pooled cumulative association to the flood exposure history of each subgroup. Panels A through D show the attributable number, the attributable fraction, the attributable number rate and the illustrative monetized mortality burden. The left block holds the two strata that describe when and where the exposure fell: season, for which the bars are the spring-summer and autumn-winter halves of the year and are labelled summer and autumn because every flood-exposed day fell between June and October, and region, for which they are Eastern and Western Japan. The right block holds tertiles (low, medium, high) of 2015 prefecture-level GDP, aging level, urbanization, livelihood recipient rate, divorce rate, psychiatric bed density, job-vacancy ratio and crime rate. Attributable fractions are within-stratum for the prefecture subgroups and for macro-region; for season of exposure they are the share of all suicides in the analytic prefectures, since a season has no within-stratum denominator. Full values are in Table S9 in the Supplementary material. Because subgroups differ only in exposure history and baseline suicide counts and not in estimated risk, these differences describe where the burden concentrates rather than effect modification.

estimate rose and fell with the maximum lag window, without differing significantly across windows (Table S11). Estimates were similar when meteorological covariates were omitted, when monthly precipitation was added, and when displacement was additionally adjusted for. Alternative seasonal controls left the estimate essentially unchanged. Estimates were similar under the exclusion of 2020 and under stricter Stage-1 eligibility. Alternative coverage rules requiring substantial footprint overlap gave estimates close to the primary result. Leave-one-prefecture-out and leave-one-event-out analyses produced point estimates that remained above the null throughout, with no single prefecture or flood event accounting for the pooled association, with precision varying across refits (Table S6 and Table S10). In the future-flood negative-control analysis, estimates were generally close to the null and showed no consistent pattern across forward leads after adjustment for actual flood exposure (Table S6).

4. Discussion

In this nationwide longitudinal study in Japan from 2008 to 2022, one flood day versus none was associated with a small but sustained increase in suicide risk that rose progressively across the post-exposure window, peaked around 10 months after exposure, and declined thereafter, with a pooled cumulative relative risk of 1.112 (95% CI 1.011–1.222) from 0 to 18 month window. This association corresponded to an attributable fraction of 0.54% (95% CI 0.06–1.02%) of suicides among the 42 flood-exposed prefectures, equivalent to an annual average of 105 attributable suicides (95% CI 11–200) and a monetized mortality burden of approximately US$701 million per year based on a prefecture-scaled value of a statistical life. Several prior studies have examined the health consequences of flood exposure, but few have isolated suicide risk at the population level. A nested case-control study using individual-level UK Biobank data reported an odds ratio of 1.018 (95% CI 1.008–1.028) per unit increase in annual flood exposure index for suicide, strongest in the current year and attenuating by lag year 5. Our findings align with this study in direction, but the cumulative association we observed for suicide in Japan was numerically larger and more sustained, with the lag profile peaking at approximately 10 months, and consistent with the longer time required for psychological and socioeconomic sequelae to translate into completed suicide. These differences likely stem from variations in spatial scale, exposure assessment, and outcome definition across studies. We interpreted these comparisons in the light of the Japanese context. More than 20,000 suicides were registered in every year of the study period, and suicide prevention has been a statutory national priority since the Basic Act on Suicide Countermeasures of 2006, under which suicide is coded consistently in the national vital statistics (Motohashi, 2012; Jeon et al., 2016). Attitudes toward mental distress and help-seeking in Japan also differ from those in the settings of the comparison studies, which may bear on both underlying risk and the completeness of ascertainment (Kanehara et al., 2015).

The association we observe is a prefecture-level phenomenon, and the pathways set out below are inferred from its timing. Such pathways are nevertheless plausible at the individual level, where flood exposure has been associated with persistent post-traumatic stress, depression, and suicidality (Yakubu et al., 2026; Mulchandani et al., 2020; Kessler et al., 2008; Zortea et al., 2025). Flood exposure may plausibly elevate suicide risk through three overlapping phases of disaster-related psychosocial harm. In an acute phase spanning the first months after exposure, direct traumatic experiences, including bereavement, property loss, displacement, and disruption of daily routines, generate intense psychological distress and may initiate suicide-risk pathways involving acute stress reactions, depression, and posttraumatic stress disorder (Morganstein and Ursano, 2020; Goldmann and Galea, 2014; Li et al., 2019; Hikichi et al., 2021; Gerstner et al., 2020; Martínez-Alés et al., 2022). Risk accumulates progressively into a chronic-stressor phase between approximately months 8 and 14, when secondary stressors such as livelihood disruption, debt accumulation, breakdown of social support networks, and interruption of mental health and primary-care services appear to compound and produce the observed plateau in elevated suicide risk (Morganstein and Ursano, 2020; Leppold et al., 2022; Botzen et al., 2019). Beyond month 14, the gradual decline of the association is consistent with adaptive recovery, social-support restoration, and the resolution of post-disaster economic disruptions, and is corroborated by a future-flood negative-control analysis showing no association between future flooding at forward leads and current-month suicide after adjustment for the actual flood exposure. This three-phase framework aligns with prior evidence that acute stress responses, if unaddressed, can evolve into persistent depressive disorders and heightened suicide vulnerability over subsequent months (North and Pfefferbaum, 2013; McFarlane, 2010), and with the observation that the peak risk window in our data falls well outside the conventional acute emergency response period. In Japan specifically, where suicide rates have historically been particularly responsive to economic and employment-related shocks (Matsubayashi et al., 2013; Jeon et al., 2016; Steelesmith et al., 2019), the protracted lag pattern further underscores the importance of extending post-disaster mental health surveillance and intervention capacity through and beyond the chronic-stressor window (Reifels et al., 2024; North and Pfefferbaum, 2013; Xue et al., 2024).

The flood-attributable burden was unevenly distributed across prefectures, between the eastern and western halves of the country and between the two halves of the year, but this reflects where and when flood exposure and population coincide rather than any difference in susceptibility, since the same pooled association was applied throughout. In proportional terms the largest attributable fractions fell in the prefectures with the fewest psychiatric beds, which had accumulated the most flood-exposed months, while in absolute and monetized terms the burden fell on the most populous and heavily exposed prefectures (Morganstein and Ursano, 2020; Goldmann and Galea, 2014). Stratified estimates by psychiatric bed density ran counter to the expectation that provision is protective, being largest in the highest-density stratum, but effect modification was not significant. In Japan, the regional distribution of psychiatric beds largely reflects historical supply policy rather than current mental-health need (Kasai et al., 2017; Organisation for Economic Co-operation and Development, 2015; Okumura et al., 2019; Watts et al., 2011), and post-disaster mental-health support is delivered mainly by outreach teams (Takahashi et al., 2020; Takagi et al., 2021), so bed density is best read as a contextual marker rather than a measure of the care available after a flood. Post-flood mental-health support may need to extend well beyond

the acute emergency phase given the delayed timing of the association (Spriggs et al., 2026; Wu et al., 2024).

4.1. Policy implications

Our findings have important implications for post-disaster public health planning in Japan. Health service providers in flood-prone prefectures should anticipate a sustained elevation in suicide risk extending several months beyond the acute disaster phase, and strengthen outpatient mental health capacity and outreach services during this delayed window. Public health institutions should integrate suicide surveillance into standard post-disaster monitoring protocols, recognizing that the peak risk period falls well outside the conventional emergency response timeline (Reifels et al., 2024; North and Pfefferbaum, 2013; Xue et al., 2024). More broadly, conventional flood-impact assessments that focus on direct physical harms may substantially underestimate the full societal cost of flooding when delayed mental health consequences are not accounted for.

4.2. Limitations

This study has several limitations, although we took steps to address each. First, we relied on the Dartmouth Flood Observatory, which captures large, severe flood events according to its established criteria. As a result, smaller or more localized floods may be underrepresented in our exposure measure (Yang et al., 2023; Tellman et al., 2021), and some events recorded in national damage statistics are not reflected in the archive. We nevertheless derived exposure from this single archive throughout so that its definition would remain consistent across years, since adding national records for individual years would introduce inconsistency across the study period; combining the two sources is a direction for future work. Because this underrepresentation is unlikely to be related to suicide outcomes, it would more plausibly weaken than strengthen the observed association (Armstrong, 1998), suggesting that the true effect may be somewhat larger than we observed. Five prefectures, namely Hokkaido, Tokyo, Ehime, Kochi and Okinawa, were never covered by a catalogued flood footprint during the study period and therefore contribute no exposure contrast. Second, because we used an ecological design, we cannot establish individual-level causation. We therefore conducted extensive robustness and falsification analyses, including a prespecified grid of sensitivity analyses and a future-flood negative-control test at forward leads. These analyses were directionally consistent with a temporal association between flood exposure and suicide, although precision varied across specifications. Third, our ecological design yields wider confidence intervals and somewhat lower precision than individual-level data. Even so, our relative-risk estimates are concordant with prior individual-level studies; the attributable estimates should be interpreted as indicative of scale and warrant confirmation in future studies with individual-level data. Fourth, we obtained suicide counts from official vital statistics. As with any administrative data source, we cannot fully exclude some degree of measurement error in recorded suicide counts. The counts are aggregate prefecture-month totals with no breakdown by age, sex, or psychiatric history, so demographic subgroups and populations with pre-existing mental illness could not be examined, and the value of a statistical life we apply is a population average that cannot be age-adjusted. The same caution applies to the assumptions underlying our value-of-a-statistical-life economic estimates. Fifth, some socioeconomic and meteorological indicators we used at the regional scale may differ from internationally standardized measures. This could introduce residual measurement error into our covariate adjustment.

In this nationwide panel study of Japan, flood exposure was associated with increased suicide risk in the months following exposure. These findings support the integration of sustained suicide prevention and mental health surveillance into post-disaster response planning in flood-prone regions.

CRediT authorship contribution statement

Gengchao Lin: Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Yuhao Xu:** Writing – review & editing, Investigation, Data curation. **Bingda Liao:** Writing – review & editing, Investigation, Data curation. **Hang Yu:** Writing – review & editing, Supervision, Funding acquisition, Conceptualization.

Ethics declaration

This study was performed in compliance with relevant laws, regulatory frameworks and guidelines where the research took place. Ethics committee approval was not required under relevant laws and institutional guidelines. This study analyzed only publicly available, de-identified, aggregate prefecture-level data (national vital statistics from the Ministry of Health, Labour and Welfare, public flood event records, and official socioeconomic statistics). No individual-level data, human participants, or human tissue were involved. Under the Japanese Ethical Guidelines for Medical and Biological Research Involving Human Subjects, research using only such anonymised, publicly available aggregate statistics does not require ethics committee review or informed consent.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used Claude (Opus 4.8; Anthropic) to check and improve the grammar and language of the manuscript. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the integrity and accuracy of all content in this publication.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.envres.2026.125600.

Data availability

Monthly prefecture-level suicide data were obtained from the Vital Statistics of Japan maintained by the Ministry of Health, Labour and

Welfare and made publicly accessible through the Portal Site of Official Statistics of Japan (e-Stat; https://www.e-stat.go.jp/en/statistics/00450011). Flood event records were obtained from the Dartmouth Flood Observatory (https://floodobservatory.colorado.edu/). Prefecture-level population denominators, demographic structure, and socioeconomic indicators (including gross domestic product, urbanization, job vacancy ratio, and livelihood recipient rate) were obtained from the Statistics Bureau of Japan (https://www.stat.go.jp/english/) and the Cabinet Office Annual Report on Prefectural Accounts (https://www.esri.cao.go.jp/en/sna/menu.html). Psychiatric inpatient bed density was derived from the Survey of Medical Institutions maintained by the Ministry of Health, Labour and Welfare (https://www.mhlw.go.jp/english/database/). Temperature data were obtained from the European Centre for Medium-Range Weather Forecasts (https://cds.climate.copernicus.eu/datasets/reanalysis-era5-land?tab=overview and https://www.ecmwf.int/en/forecasts/datasets/set-iii). Year- and prefecture-specific values of a statistical life (VSL) for Japan were derived using the US Environmental Protection Agency benefit-transfer approach (https://www.epa.gov/environmental-economics/mortality-risk-valuation) with an income elasticity of 0.8, consistent with Organisation for Economic Co-operation and Development recommendations (https://www.oecd.org/environment/tools-evaluation/mortalityriskvaluationinenvironmenthealthandtransportpolicies.htm). Analysis code for the data processing and statistical analyses is provided in the Supplementary material.

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