

Beyond biological threats: A global ecological study of International Health Regulations (2005) core capacities and multi-hazard disaster outcomes, 2015–2023

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Article

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Abstract

The International Health Regulations (IHR, 2005) apply an all-hazards approach to public health risks irrespective of origin. This study examined whether IHR core capacities, previously studied mainly in relation to infectious diseases, were associated with multi-hazard disaster outcomes. Across 196 States Parties from 2015 to 2023, an ecological panel linked nine cross-cutting IHR capacities and a study-specific *IHR average score* to Sendai Framework Monitor (SFM) and Emergency Events Database (EM-DAT) mortality and morbidity. Associations were estimated with Poisson regression models adjusted for country and year fixed effects, population size, and socioeconomic factors. Analyses were repeated for 2020–2023. A 10-point increase in *IHR average score* corresponded to 39.1% and 40.7% lower SFM and EM-DAT mortality rates during 2020–2023, but not across 2015–2023. *Laboratory* was associated with lower mortality in both datasets. For disaster morbidity, a 10-point increase in *IHR average score* was associated with 44.7% lower SFM morbidity rates across 2015–2023, but not during 2020–2023 or in EM-DAT. Higher *IHR Coordination, Surveillance, and Risk communication* scores were associated with lower SFM morbidity across 2015–2023. Linking harmonized IHR self-assessment scores with two global disaster datasets indicates the relevance of IHR (2005) core capacities beyond biological threats.

1 Introduction

The International Health Regulations (IHR, 2005) provide a legally binding framework within global health security governance [1]. They require States Parties to develop and maintain core capacities for detecting, assessing, reporting, and responding to public health events with potential international implications [2]. Article 54 requires implementation to be monitored through the IHR Monitoring and Evaluation Framework, of which the States Parties Self-Assessment Annual Reporting (SPAR) tool is one component [3].

Under its all-hazards approach, the scope of the IHR (2005) covers public health risks irrespective of origin or source [2]. Accordingly, several capacities assessed by IHR monitoring tools, including coordination, surveillance, laboratory, workforce, emergency management, health-service provision, and risk communication [3], can apply across emergency contexts. This applicability is also reflected in existing literature, which identified capabilities relevant to infectious disease outbreaks and natural hazards, ranging from leadership and workforce preparedness to continuity of health services [4, 5].

When disasters occur, health systems may face increased demand for care and reduced service capacity at the same time. Floods and storms, for example, can undermine community access to care by damaging health facilities and infrastructure [6], while earthquakes can cause large numbers of injuries and impair hospital functionality [7]. Managing these concurrent pressures requires coordination, timely information, and continuity of essential services [8], alongside trained and deployable health personnel, and facility preparedness [9]. These requirements overlap with functions assessed through the IHR SPAR tools, providing a rationale to examine whether higher IHR capacity scores are associated with lower disaster outcomes.

This overlap is reflected in disaster risk and global health policy. The Sendai Framework for Disaster Risk Reduction (SFDRR, 2015–2030) aims to reduce global disaster losses in lives, livelihoods and health, including disaster mortality and the number of affected people [10]. The Bangkok Principles call for the systematic integration of health into disaster risk-reduction policies and plans, and strengthened implementation of the IHR [11]. The World Health Organization (WHO) Health Emergency and Disaster Risk Management Framework (Health EDRM) similarly positions health systems as central across the emergency management cycle [12].

Despite this policy alignment, empirical analyses of IHR capacities have focused mainly on infectious disease outcomes. Across the 28 European Union Member States observed from 2010 to 2016, each 10-point increase in a composite IHR capacity score was associated with a 19% lower rate of cross-border infectious disease threat events [13]. In a separate cross-national analysis of 2016 outbreak reports, lower self-reported IHR scores were associated with worse infectious disease control outcomes [14]. However, empirical evidence linking these capacities to outcomes from other hazards remains limited.

This study addresses this gap by examining the associations between IHR (2005) core capacities and disaster-attributed mortality and morbidity across 196 States Parties from 2015 to 2023. It was hypothesized that higher IHR capacity scores would be associated with lower disaster mortality and morbidity rates, thereby highlighting the potential relevance of IHR core capacities beyond biological threats.

2 Methods

2.1 Study design and setting

This study employed a retrospective global longitudinal ecological design. The analysis panel covered 196 States Parties to the IHR (2005) from 2015 through 2023. The study period started from 2015, aligning with the adoption of the SFDRR (2015–2030), and ended in 2023, the most recent year with complete data across sources. Datasets were merged using the International Organization for Standardization (ISO) 3166-1 alpha-3 country codes and the observation year, giving the country-year (e.g., DZA-2015) as the unit of analysis. Datasets were accessed from May to December 2025.

2.2 Dependent variables

The dependent variables were the annual country-level counts of disaster mortality and morbidity. While disaster indicators are commonly reported as rates per 100,000 population, this study modeled annual country-level counts and included the natural logarithm of total population as an offset. As a result, coefficients are interpretable as rate ratios within count-based regression models [15].

Disaster mortality and morbidity data were retrieved from the SFM, the official reporting platform used to report and monitor national disaster statistics against the SFDRR global targets [16]. Two indicators were selected: *Target A-2* (number of deaths attributed to disasters) and *Target B-2* (number of injured or

ill people attributed to disasters). These indicators are reported as national annual totals and cannot be disaggregated by hazard type. A reported value of zero was retained as zero. A blank or unsubmitted value was treated as missing. These data were voluntarily reported by the United Nations Member States to the SFM platform on an annual basis. COVID-19 statistics were not included in the SFM mortality and morbidity indicators [17, 18].

Given broader concerns about the comparability and completeness of disaster-loss data [19, 20], complementary data were sourced from EM-DAT, the Emergency Events Database [21]. EM-DAT is maintained by the Centre for Research on the Epidemiology of Disasters (CRED) and compiles records from multiple sources, including UN agencies, non-governmental organizations, reinsurance companies, research institutes, and press agencies. These sources are manually reviewed and cross-checked during compilation. Events were included based on four criteria: at least ten deaths; at least 100 people affected; a call for international assistance; or a formal declaration of emergency [22].

For comparison with the SFM indicators, the EM-DAT *Total Deaths* and *Number of Injured* indicators were selected to represent disaster mortality and morbidity, respectively. The EM-DAT *Total Deaths* indicator combines total fatalities and missing persons, while the *Number of Injured* indicator captures the number of people with physical injuries, trauma, or illness requiring immediate medical assistance due to the disaster. EM-DAT data were extracted on 6 October 2025. During data processing, all biological events under the EM-DAT natural hazard category were excluded; the remaining natural and technological events records were assigned to their start year and aggregated by country-year.

2.3 Independent variables

The independent variables were the IHR (2005) core capacity scores, measured on a 0 to 100 scale and retrieved from the WHO Global Health Observatory database [23]. The scores are derived from the States Parties Self-Assessment Annual Reporting (SPAR) tool, which requires States Parties to report annually under Article 54 of the IHR. SPAR indicators are assessed using five capacity levels and converted to percentage scores, with each capacity score calculated as the mean of its assigned indicators [3, 24, 25].

During the 2015–2023 period, WHO published three related monitoring series: the IHR monitoring questionnaire (2010–2017), the first edition of SPAR (2018–2020), and the second edition of SPAR (2021 onward) [3, 24, 25]. To enable longitudinal analysis, IHR core capacities were harmonized across these revisions using a conceptual crosswalk designed for this study (Supplementary Fig. S1). The resulting scores were matched to disaster outcomes from the same calendar year.

Nine IHR core capacities were retained for analysis because they represented cross-cutting public health system functions with relevance across a broader range of disaster contexts. They were *C.1 Policy, legal and normative instruments to implement IHR (IHR Policy)*; *C.2 IHR coordination, National IHR Focal Point functions and advocacy (IHR Coordination)*; *C.4 Laboratory*; *C.5 Surveillance*; *C.6 Human resources*; *C.7 Health emergency management*; *C.8 Health services provision*; *C.10 Risk communication and community*

engagement (RCCE); and *C.11 Points of entry and border health (Points of entry)*. Capacities tied to specific event types, including *C.12 Zoonotic diseases*, *C.13 Food safety*, *C.14 Chemical events*, and *C.15 Radiation emergencies*, were excluded. *C.3 Financing* and *C.9 Infection prevention and control* were also omitted because they were introduced as standalone capacities with the second edition of SPAR in 2021. This limits historical comparability with the two earlier IHR monitoring instruments across the 2015–2023 study period. For each country-year observation, an arithmetic mean of non-missing values among the nine selected capacity scores was calculated as a study-specific *IHR average score*.

2.4 Socioeconomic controls

Socioeconomic data were obtained from the World Development Indicators database [26] to adjust for structural factors associated with both IHR capacities and disaster outcomes. Gross domestic product (GDP) per capita (constant 2015 USD) was selected as a proxy for structural economic capability, given that disaster mortality is associated with national income, geography, and institutional conditions [27–29]. Population density (people per sq. km of land area) and urban population (% of total population) were also included to account for settlement structure, exposure concentration, and urban disaster vulnerability [30]. GDP per capita and population density were log-transformed to address right-skewed distributions and limit leverage from extreme values.

2.5 Statistical analysis

The merged dataset formed an unbalanced country-year panel because variables were not uniformly available across all countries and years. Zero disaster mortality and morbidity counts were retained as valid observations. Unreported or missing data were handled using model-specific listwise deletion. Accordingly, the analytic sample varied across models and study periods. Descriptive statistics were calculated to examine variable distributions. Bivariate associations were summarized using Spearman's rank correlation coefficients because disaster data distributions were highly right-skewed with extreme tail values.

Associations were estimated using the Poisson pseudo-maximum likelihood (PPML) estimator. PPML was selected over standard log-linear models because it provides consistent estimates in the presence of heteroskedasticity and accommodates the high frequency of zero counts in disaster data [31, 32]. The models included country fixed effects to absorb time-invariant differences across countries, and year fixed effects to account for global shocks and common temporal trends. Year fixed effects additionally absorbed any common shift in reported IHR scores coinciding with the transitions between monitoring instruments. The natural logarithm of the total population was included as an offset, allowing coefficient estimates to be interpreted as log rate ratios for disaster mortality or morbidity. Standard errors were clustered at the country level to account for serial correlation within countries over time [33].

Analyses were conducted for four outcome series (SFM mortality, EM-DAT mortality, SFM morbidity, and EM-DAT morbidity) for two time periods (2015–2023 and 2020–2023). Three model types were estimated: (i) an aggregate model containing the *IHR average score*, (ii) nine individual-capacity models in which each IHR capacity was estimated separately, and (iii) a joint-capacity model in which all nine

IHR capacities were estimated simultaneously. All models included log-transformed GDP per capita and population density, together with urban population percentage, as socioeconomic controls. All statistical tests were two-tailed, and statistical significance was assessed at $\alpha = 0.05$.

The three model types were re-estimated for the 2020–2023 period, during which countries experienced the COVID-19 pandemic along with other disasters. Because the 2020–2023 country-year observations were also included in the full-period estimates, the two sets are not independent and were not formally compared.

The individual-capacity models comprised 36 separate estimations (nine capacities $\times$ two datasets $\times$ two periods) and were not adjusted for multiple comparisons. These capacity-level estimates are therefore exploratory, and greater weight is given to estimates that replicate across the SFM and EM-DAT datasets.

For the joint-capacity models, collinearity among the nine IHR capacity scores and socioeconomic controls was assessed using variance inflation factors (VIF). Four sensitivity analyses were conducted for the *IHR average score* to test the robustness of the estimates. The analyses included (1) clustering standard errors by country and year to address potential temporal dependence; (2) excluding socioeconomic controls to assess whether estimates were sensitive to the adjustment set; (3) trimming the top 1% of dependent variable values to examine sensitivity to extreme disasters; and (4) re-estimating the models using an intersection sample with complete data across all variables to check for potential selection bias driven by data availability.

2.6 Statistical software

Analyses were conducted in R version 4.5.2 [34]. Poisson pseudo-maximum likelihood models were estimated using the *fixest* package version 0.12.1 [35]. Variance inflation factors were obtained with *car* package version 3.1-3 [36], and data were processed using the *tidyverse collection* version 2.0.0 [37]. Figure 1 was produced using *ggplot2* version 3.5.2 [38], *sf* version 1.0–23 [39] and *patchwork* version 1.3.2 [40]. Country boundary geometry at the 1:50 million scale was obtained from the public-domain Natural Earth [41] map dataset using *rnaturalearth* version 1.1.0 [42].

2.7 Code availability

The analysis code is deposited in the figshare repository together with the dataset. The repository link and access conditions, including the EM-DAT redistribution restriction, are described in the Data availability statement. The reproducible workflow comprises twelve numbered R scripts and a README describing the folder structure, execution order, and required packages.

3 Results

3.1 Descriptive characteristics

Table 1 presents descriptive statistics for IHR core capacity scores, disaster-attributed mortality and morbidity, and socioeconomic controls. The analytic dataset contained 1,764 country-year observations for 196 States Parties to the IHR (2005) from 2015 to 2023. SFM data were available for approximately 50–54% of country-years, whereas EM-DAT coverage was higher, ranging from approximately 70–89%. Across both datasets, disaster mortality and morbidity counts displayed highly right-skewed distributions with many zeros. Specifically, zero-count observations accounted for 31% and 35% of the available SFM mortality and morbidity observations, respectively, compared with 38% and 48% in the EM-DAT dataset. Median mortality values were low in both datasets: 15 deaths in SFM and 11 deaths in EM-DAT. Median morbidity values diverged more sharply, with 32 injured or ill persons reported in SFM, compared with 2 injured persons in EM-DAT.

Table 1

Descriptive statistics for IHR core capacity scores, disaster-attributed mortality and morbidity, and socioeconomic controls (196 countries, 2015–2023)

Variable	Available country-year, n (%)	Median [IQR]
Disaster mortality (persons)		
SFM	953 (54%)	15 [0–157]
EM-DAT	1,567 (89%)	11 [0–78]
Disaster morbidity (persons)		
SFM	889 (50%)	32 [0–565]
EM-DAT	1,226 (70%)	2 [0–63]
IHR core capacity (0–100 scale)		
Policy, legal and normative instruments to implement IHR	1,483 (84%)	67 [40–93]
IHR coordination, National IHR Focal Point functions and advocacy	1,515 (86%)	73 [53–90]
Laboratory	1,516 (86%)	76 [60–92]
Surveillance	1,517 (86%)	80 [70–95]
Human resources	1,476 (84%)	60 [40–80]
Health emergency management	1,511 (86%)	73 [53–87]
Health services provision	1,516 (86%)	73 [53–93]
Risk communication and community engagement	1,513 (86%)	73 [47–87]
Points of entry and border health	1,499 (85%)	60 [40–87]
IHR average score	1,517 (86%)	70 [56–85]
Socioeconomic controls		
GDP per capita (constant 2015 USD)	1,693 (96%)	5,815 [1,948–17,365]
Population density (people per sq. km of land area)	1,737 (98%)	84 [34–204]

Note. n (%) indicates the number and percentage of available data out of 1,764 possible country-year observations. Values are reported as medians with interquartile ranges [IQR] because distributions were right-skewed. Disaster mortality and morbidity values are annual country-level counts of persons, as defined by each data source. The IHR average score was calculated as the arithmetic mean of the nine selected capacities. IHR refers to the International Health Regulations (2005), SFM to the Sendai Framework Monitor, EM-DAT to the Emergency Events Database, and GDP to gross domestic product.

Variable	Available country-year, n (%)	Median [IQR]
Disaster mortality (persons)		
Urban population (% of total population)	1,737 (98%)	59 [41–78]
<i>Note.</i> n (%) indicates the number and percentage of available data out of 1,764 possible country-year observations. Values are reported as medians with interquartile ranges [IQR] because distributions were right-skewed. Disaster mortality and morbidity values are annual country-level counts of persons, as defined by each data source. The IHR average score was calculated as the arithmetic mean of the nine selected capacities. IHR refers to the International Health Regulations (2005), SFM to the Sendai Framework Monitor, EM-DAT to the Emergency Events Database, and GDP to gross domestic product.		

IHR core capacity scores were available for 84–86% of the country-year observations. On the 0 to 100 scale, IHR capacity scores clustered in the 60 to 80 range, and the median *IHR average score* was 70. Among retained capacities, *Surveillance* and *Laboratory* had the highest medians, whereas *Human resources* and *Points of entry* were comparatively lower.

Figure 1 maps the global distribution of the *IHR average score* (Panel **a**) alongside average annual rates of disaster mortality (Panels **b** and **c**) and morbidity (Panels **d** and **e**) in SFM and EM-DAT across 2015–2023. Grey areas indicate that SFM mortality data were missing for 36 countries (Panel **b**), and SFM morbidity data for 44 countries (Panel **d**), compared with zero (Panel **c**) and one country (Panel **e**) in EM-DAT. The two mortality panels followed broadly similar geographic patterns, although 11 countries fell in the highest mortality class (> 10 per 100,000) in SFM against three in EM-DAT. The morbidity panels differed more substantially, with 24 countries in the two highest morbidity classes (> 100 per 100,000) in SFM against none in EM-DAT. The figure shows a different picture of disaster outcomes for the same countries and years, particularly for morbidity.

Note

Grey indicates countries or territories with no available data or not included in the analytic sample. Class intervals differ between the mortality panels (**b**, **c**) and the morbidity panels (**d**, **e**). Shading is therefore not comparable between the two groups. Maps were generated by the authors in R; country boundaries derive from Natural Earth (public domain). Map lines delineate study areas and do not necessarily depict accepted national boundaries.

3.2 Bivariate associations and collinearity diagnostics

Bivariate Spearman's rank correlations between IHR core capacities and population-adjusted disaster mortality and morbidity are reported in Supplementary Table S1. The coefficient values (ρ) were small but predominantly negative, with all absolute correlation coefficients below 0.190. The *IHR average score* was negatively correlated with SFM mortality ($\rho = -0.133$, $p < 0.001$), EM-DAT mortality ($\rho = -0.067$, $p < 0.05$), and SFM morbidity ($\rho = -0.109$, $p < 0.01$). Among individual capacities, *Laboratory* ($\rho = -0.189$, $p <$

0.001) and *Health services provision* ($\rho = -0.184$, $p < 0.001$) showed the largest negative correlations with SFM mortality, and *Points of entry* ($\rho = -0.105$, $p < 0.001$) showed the largest with EM-DAT mortality. Collinearity diagnostics indicated no evidence of multicollinearity among the IHR capacities and socioeconomic controls, with a maximum VIF value of 3.04 in the joint-capacity models.

3.3 Multivariable associations with disaster-attributed mortality

In the disaster mortality aggregate model presented in Table 2, Panel A, a higher *IHR average score* was associated with lower disaster mortality during 2020–2023. Each 10-point increase corresponded to a 39.1% lower SFM mortality rate ($\beta = -0.050$, $p < 0.01$) and a 40.7% lower EM-DAT mortality rate ($\beta = -0.052$, $p < 0.05$). The estimates for 2015–2023 were smaller and not statistically significant.

In the individual-capacity models (Table 2, Panel B), *Points of entry* was the only statistically significant capacity across 2015–2023, with a 10-point increase corresponding to a 13.7% lower EM-DAT mortality rate ($\beta = -0.015$, $p < 0.05$). During 2020–2023, *Laboratory* was associated with lower mortality in both datasets with a 34.5% lower SFM mortality rate ($\beta = -0.042$, $p < 0.05$) and a 33.8% lower EM-DAT mortality rate ($\beta = -0.041$, $p < 0.01$). Higher scores for *Human resources* and *Points of entry* were also associated with 28.0% ($\beta = -0.033$, $p < 0.05$) and 40.0% ($\beta = -0.051$, $p < 0.001$) lower SFM mortality rates, respectively.

With all nine capacities estimated simultaneously (Table 2, Panel C), no capacity was statistically associated with mortality in either dataset across 2015–2023. The negative *Points of entry* estimate observed in the individual-capacity EM-DAT model attenuated from 13.7% ($\beta = -0.015$) to 9.4% ($\beta = -0.010$) lower rate and was no longer statistically significant. *Human resources* and *Points of entry* retained negative associations with SFM mortality during 2020–2023, at 26.8% ($\beta = -0.031$, $p < 0.05$) and 38.8% ($\beta = -0.049$, $p < 0.001$) lower rates, respectively. In EM-DAT, *Laboratory* remained negatively associated with a 34.2% lower mortality rate ($\beta = -0.042$, $p < 0.05$).

Sensitivity analyses for the aggregate *IHR average score* models with disaster mortality are presented in Supplementary Table S2. Across 2015–2023, excluding the top 1% of outcome values produced a statistically significant negative association with 22.1% lower SFM mortality rate ($\beta = -0.025$, $p < 0.01$). For 2020–2023, the negative association with SFM mortality remained statistically significant in all four sensitivity analyses, with coefficients ranging from $\beta = -0.035$ (29.5% lower) to -0.050 (39.1% lower). In EM-DAT, the association remained statistically significant under two-way clustering, exclusion of socioeconomic controls, and restriction to the intersection sample, but attenuated and no longer significant after removing the top 1% of outcome values ($\beta = -0.030$, 25.9% lower).

Table 2
Associations of IHR core capacity scores with disaster-attributed mortality rates

Variable	I	II	III	IV
	SFM disaster mortality		EM-DAT disaster mortality	
Period	2015–2023	2020–2023	2015–2023	2020–2023
Estimate	β (SE)	β (SE)	β (SE)	β (SE)
Panel A: Aggregate model				
IHR average score	–0.005 (0.021)	–0.050** (0.018)	–0.013 (0.023)	–0.052* (0.021)
Country-year observations	708	273	1,180	553
Panel B: Individual-capacity models				
Policy, legal and normative instruments to implement IHR	0.001 (0.010)	–0.006 (0.014)	–0.006 (0.008)	–0.009 (0.009)
IHR coordination, National IHR Focal Point functions and advocacy	0.008 (0.011)	0.005 (0.022)	0.003 (0.011)	–0.013 (0.014)
Laboratory	–0.012 (0.012)	–0.042* (0.018)	–0.009 (0.018)	–0.041** (0.014)
Surveillance	–0.002 (0.012)	–0.008 (0.016)	0.014 (0.016)	–0.015 (0.023)
Human resources	–0.001 (0.010)	–0.033* (0.016)	0.010 (0.010)	0.004 (0.011)
Health emergency management	–0.000 (0.011)	–0.029 (0.018)	–0.008 (0.010)	–0.016 (0.012)
Health services provision	–0.005 (0.010)	–0.013 (0.020)	–0.010 (0.010)	–0.016 (0.011)
Risk communication and community engagement	–0.003 (0.008)	–0.009 (0.012)	–0.018 (0.014)	–0.035 (0.021)
Points of entry and border health	–0.007 (0.009)	–0.051*** (0.013)	–0.015* (0.007)	–0.016 (0.010)
<i>Note.</i> β values are Poisson pseudo-maximum likelihood (PPML) log-rate coefficients. Standard errors clustered at the country level are reported in parentheses. Estimates discussed in the text are transformed into a 10-point increase as $RR_{10} = \exp(10\beta)$, with percentage differences calculated as $100 \times (RR_{10} - 1)$. All models adjust for socioeconomic controls. Country-year observations are not shown for Panel B because each IHR capacity was estimated in a separate model with varying analytic samples. IHR refers to the International Health Regulations (2005), SFM to the Sendai Framework Monitor, and EM-DAT to the Emergency Events Database.				

Variable	I	II	III	IV
	SFM disaster mortality		EM-DAT disaster mortality	
Panel C: Joint-capacity model				
Policy, legal and normative instruments to implement IHR	−0.003 (0.008)	−0.018 (0.009)	−0.009 (0.006)	−0.001 (0.010)
IHR coordination, National IHR Focal Point functions and advocacy	0.020 (0.011)	0.024 (0.022)	0.009 (0.011)	0.015 (0.020)
Laboratory	−0.015 (0.011)	−0.042 (0.026)	−0.004 (0.010)	−0.042* (0.020)
Surveillance	−0.009 (0.013)	0.011 (0.015)	0.019 (0.013)	0.006 (0.022)
Human resources	0.001 (0.007)	−0.031* (0.014)	0.012 (0.008)	0.006 (0.010)
Health emergency management	0.006 (0.011)	0.013 (0.018)	−0.007 (0.013)	0.013 (0.017)
Health services provision	−0.006 (0.009)	−0.002 (0.017)	−0.004 (0.007)	−0.005 (0.013)
Risk communication and community engagement	−0.006 (0.006)	0.016 (0.015)	−0.018 (0.015)	−0.030 (0.024)
Points of entry and border health	−0.006 (0.009)	−0.049*** (0.012)	−0.010 (0.008)	−0.004 (0.010)
Country-year observations	685	273	1,127	553
<i>Note.</i> β values are Poisson pseudo-maximum likelihood (PPML) log-rate coefficients. Standard errors clustered at the country level are reported in parentheses. Estimates discussed in the text are transformed into a 10-point increase as $RR_{10} = \exp(10\beta)$, with percentage differences calculated as $100 \times (RR_{10} - 1)$. All models adjust for socioeconomic controls. Country-year observations are not shown for Panel B because each IHR capacity was estimated in a separate model with varying analytic samples. IHR refers to the International Health Regulations (2005), SFM to the Sendai Framework Monitor, and EM-DAT to the Emergency Events Database.				

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

3.4 Multivariable associations with disaster-attributed morbidity

In the disaster morbidity aggregate models (Table 3, Panel A), a 10-point increase in the *IHR average score* was associated with 44.7% lower SFM morbidity across 2015–2023 ($\beta = -0.059$, $p < 0.05$). The EM-DAT estimate showed a 12.1% lower rate ($\beta = -0.013$) but did not reach statistical significance. Neither

the SFM estimate ($\beta = -0.047$) nor the EM-DAT estimate ($\beta = -0.039$) reached statistical significance during 2020–2023.

Three capacities, *IHR Coordination*, *Surveillance*, and *RCCE*, showed statistically significant negative associations with SFM morbidity across 2015–2023 when estimated separately (Table 3, Panel B). Each 10-point increase in these capacity scores corresponded to 44.6% ($\beta = -0.059$, $p < 0.01$), 27.6% ($\beta = -0.032$, $p < 0.05$), and 31.0% ($\beta = -0.037$, $p < 0.05$) lower SFM morbidity rates, respectively. For 2020–2023, *Health services provision* was the only statistically significant capacity in the SFM models, associated with an 84.2% lower morbidity rate ($\beta = -0.184$, $p < 0.01$). No individual IHR capacity was statistically associated with EM-DAT morbidity in either period.

The joint-capacity models demonstrate a different pattern of morbidity associations (Table 3, Panel C). Across 2015–2023, *IHR Coordination* held its negative SFM morbidity association and strengthened, from 44.6% lower rate when estimated separately ($\beta = -0.059$) to 60.2% lower rate in the joint-capacity model ($\beta = -0.092$). *Surveillance* and *RCCE* were no longer statistically significant. *Laboratory* changed direction from 3.2% lower when estimated alone ($\beta = -0.003$) to 69.4% higher rate in the joint-capacity model ($\beta = 0.053$). *Human resources* increased from 10.3% ($\beta = 0.010$) to 25.3% higher ($\beta = 0.023$) morbidity rate and became statistically significant ($p < 0.05$). In EM-DAT, *Surveillance* was associated with a 46.4% higher morbidity rate ($\beta = 0.038$, $p < 0.01$).

For *IHR Policy*, the SFM estimate became more negative, from 9.0% lower in the individual-capacity model ($\beta = -0.009$) to 68.3% lower in the joint-capacity model ($\beta = -0.115$, $p < 0.01$) during 2020–2023. *Human resources* changed direction from 7.6% lower to 58.7% higher morbidity rate ($\beta = 0.046$, $p < 0.05$). The *Points of entry* estimate increased from 107.8% higher ($\beta = 0.073$) to 318.6% higher ($\beta = 0.143$) morbidity rate and became statistically significant ($p < 0.05$). The *Health services provision* estimate remained negative but was no longer statistically significant. No capacity was statistically associated with EM-DAT morbidity during this period.

Supplementary Table S2 reports sensitivity analyses for the aggregate *IHR average score* models with disaster morbidity. The SFM association survived only in the intersection sample across 2015–2023, at a 45.7% lower morbidity rate ($\beta = -0.061$, $p < 0.05$). The SFM estimate for 2020–2023 was statistically significant only after excluding socioeconomic controls, at an 84.3% lower morbidity rate ($\beta = -0.185$, $p < 0.01$). No sensitivity-analysis estimate was statistically significant for EM-DAT morbidity in either period.

Table 3
Associations of IHR core capacity scores with disaster-attributed morbidity rates

Variable	I	II	III	IV
	SFM disaster morbidity		EM-DAT disaster morbidity	
Period	2015–2023	2020–2023	2015–2023	2020–2023
Estimate	β (SE)	β (SE)	β (SE)	β (SE)
Panel A: Aggregate model				
IHR average score	–0.059* (0.029)	–0.047 (0.094)	–0.013 (0.032)	–0.039 (0.052)
Country-year observations	611	241	769	338
Panel B: Individual-capacity models				
Policy, legal and normative instruments to implement IHR	–0.026 (0.014)	–0.009 (0.023)	0.001 (0.013)	0.000 (0.017)
IHR coordination, National IHR Focal Point functions and advocacy	–0.059** (0.019)	0.094 (0.060)	–0.011 (0.013)	–0.015 (0.024)
Laboratory	–0.003 (0.025)	0.078 (0.078)	–0.000 (0.018)	–0.048 (0.033)
Surveillance	–0.032* (0.013)	0.020 (0.025)	0.013 (0.021)	0.011 (0.032)
Human resources	0.010 (0.014)	–0.008 (0.019)	0.012 (0.013)	–0.019 (0.022)
Health emergency management	–0.030 (0.020)	–0.067 (0.044)	–0.008 (0.017)	–0.024 (0.030)
Health services provision	–0.044 (0.024)	–0.184** (0.058)	–0.010 (0.016)	0.002 (0.025)
Risk communication and community engagement	–0.037* (0.016)	–0.008 (0.027)	–0.016 (0.013)	–0.020 (0.021)
Points of entry and border health	0.013 (0.021)	0.073 (0.063)	–0.015 (0.009)	0.028 (0.028)
<i>Note.</i> β values are Poisson pseudo-maximum likelihood (PPML) log-rate coefficients. Standard errors clustered at the country level are reported in parentheses. Estimates discussed in the text are transformed into a 10-point increase as $RR_{10} = \exp(10\beta)$, with percentage differences calculated as $100 \times (RR_{10} - 1)$. All models adjust for socioeconomic controls. Country-year observations are not shown for Panel B because each IHR capacity was estimated in a separate model with varying analytic samples. IHR refers to the International Health Regulations (2005), SFM to the Sendai Framework Monitor, and EM-DAT to the Emergency Events Database.				

Variable	I	II	III	IV
	SFM disaster morbidity		EM-DAT disaster morbidity	
Panel C: Joint-capacity model				
Policy, legal and normative instruments to implement IHR	0.008 (0.019)	−0.115** (0.035)	0.000 (0.013)	0.003 (0.020)
IHR coordination, National IHR Focal Point functions and advocacy	−0.092* (0.043)	0.077 (0.058)	−0.015 (0.014)	0.005 (0.032)
Laboratory	0.053* (0.025)	0.023 (0.046)	−0.011 (0.015)	−0.053 (0.032)
Surveillance	0.017 (0.028)	0.032 (0.042)	0.038** (0.013)	0.027 (0.037)
Human resources	0.023* (0.009)	0.046* (0.021)	0.023 (0.014)	−0.017 (0.022)
Health emergency management	−0.024 (0.021)	−0.081 (0.045)	−0.011 (0.020)	−0.005 (0.031)
Health services provision	−0.025 (0.031)	−0.219 (0.126)	0.015 (0.020)	−0.001 (0.033)
Risk communication and community engagement	−0.011 (0.015)	−0.034 (0.053)	−0.017 (0.015)	−0.018 (0.021)
Points of entry and border health	0.017 (0.016)	0.143* (0.062)	−0.006 (0.010)	0.034 (0.031)
Country-year observations	586	241	729	338
<i>Note.</i> β values are Poisson pseudo-maximum likelihood (PPML) log-rate coefficients. Standard errors clustered at the country level are reported in parentheses. Estimates discussed in the text are transformed into a 10-point increase as $RR_{10} = \exp(10\beta)$, with percentage differences calculated as $100 \times (RR_{10} - 1)$. All models adjust for socioeconomic controls. Country-year observations are not shown for Panel B because each IHR capacity was estimated in a separate model with varying analytic samples. IHR refers to the International Health Regulations (2005), SFM to the Sendai Framework Monitor, and EM-DAT to the Emergency Events Database.				

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

4 Discussion

To the best of the authors' knowledge, this is the first global study to link annual IHR self-assessment scores, harmonized across three monitoring instruments, with disaster mortality and morbidity. The use of two complementary disaster datasets was particularly valuable, as SFM and EM-DAT differ in their reporting sources, definitions, and inclusion criteria. Estimating aggregate, individual-capacity, and joint-capacity models further distinguishes system-level associations from those attributable to a single

capacity. The hypothesis that higher IHR capacity scores would be associated with lower disaster outcomes was supported at the aggregate level for mortality in both datasets during 2020–2023, and for morbidity in SFM across 2015–2023.

4.1 Disaster-attributed mortality

In the aggregate model, a higher *IHR average score* was associated with lower SFM and EM-DAT mortality during 2020–2023 and remained statistically significant in all four SFM and three of four EM-DAT sensitivity analyses. The direction of this association is consistent with earlier work linking higher IHR capacity scores to fewer cross-border infectious disease events [13] and better infectious disease outcomes [14]. The present study extends this evidence to multi-hazard disaster outcomes.

This association may further indicate system-level preparedness across multiple public health functions rather than the contribution of any individual capacity. Several functions required to manage infectious disease outbreaks, including leadership, workforce readiness, and service continuity, have been identified as relevant during natural hazards [4, 5]. When emergencies overlap, these functions may need to operate simultaneously as response systems face concurrent pressures on governance, communication, and resource allocation [43]. This provides one possible explanation for the concentration of mortality associations during 2020–2023, a period marked by increased demands on cross-cutting functions as countries responded to the COVID-19 pandemic along with other disasters.

In the individual-capacity models, *Laboratory* was the only capacity associated with lower mortality in both datasets during 2020–2023. A recent systematic review found that damaged infrastructure and disrupted utilities, together with delayed deliveries and supply shortages, constrained laboratory operations across different disaster contexts [44]. Disasters may also shift substantial testing workloads to laboratories that remain operational [45]. In one integrated laboratory network in the United States, the ability to redistribute testing across multiple sites was reported to maintain service continuity under these conditions [46]. This suggests that the *Laboratory* score may reflect diagnostic and response functions relevant to disasters, but the analysis cannot identify the underlying mechanisms.

When nine IHR capacities were estimated jointly, the SFM mortality associations with *Human resources* and *Points of entry* remained statistically significant with similar magnitudes. For *Human resources*, a systematic review of hospital surge capacity during disasters identified staffing as one of four preparedness domains, and described strategies for mobilizing, recalling, training, and sharing personnel during emergencies [47]. The *Points of entry* capacity, in turn, assesses routine capacities and emergency response at airports, ports, and ground crossings, together with risk-based measures and all-hazards contingency planning [3]. Taken together, these associations suggest that institutional and operational preparedness functions established before emergencies are relevant to variations in disaster mortality.

4.2 Disaster-attributed morbidity

In the aggregate model, a higher *IHR average score* was associated with lower SFM morbidity across 2015–2023, though this association remained statistically significant in only one of four sensitivity analyses. The same association was not observed in SFM for 2020–2023 or in EM-DAT during either period. The absence of morbidity associations in the EM-DAT dataset should be considered in the context of known variation in the collection procedures and completeness of disaster-loss data [19, 20]. With a median of 2 injured persons and zero counts in 48% of observations, the EM-DAT morbidity outcome provided limited variation for detecting associations with IHR capacity scores.

Associations between individual IHR capacities and disaster morbidity differed across datasets, periods, and models. Some capacities were associated with lower morbidity rates and others with higher rates. Of these, *IHR Coordination* was the only capacity associated with lower disaster morbidity in both individual- and joint-capacity SFM models for 2015–2023. One possible interpretation concerns the role of coordination in disaster management. An analysis of the response to Hurricane Katrina found that failures to recognize and communicate the severity of the threat undermined coordination across jurisdictional levels [48]. A synthesis of 26 reports from 11 countries covering floods, drought, COVID-19, and other shocks also identified examples in which weak coordination contributed to delayed action or funding, while regular coordination supported faster, more efficient relief [49].

In the individual-capacity models, *Health services provision* produced the largest statistically significant negative estimate, with an 84.2% lower SFM morbidity rate during 2020–2023. An overview of 114 reviews found that extreme weather events disrupt emergency transport and access to pre-hospital care through damage to facilities and road networks [50]. A separate review reported increases in injuries, infectious diseases, and chronic conditions after floods and storms, which were likely to increase demand for emergency and routine care [6]. These reviews indicate how disasters can disrupt service delivery while increasing healthcare needs, highlighting the relevance of service continuity and access during disasters.

Contrary to the hypothesis, four IHR capacities in the joint-capacity model were associated with higher rather than lower morbidity: *Laboratory*, *Surveillance*, *Human resources*, and *Points of entry*. For *Laboratory* and *Surveillance*, more complete detection or reporting is one possible explanation. During acute disaster response, public health laboratories can strengthen outbreak detection and surveillance [44]. Using standardized surveillance tools can also make post-disaster morbidity data available sooner and more comparable across jurisdictions [51]. This explanation is less directly applicable to *Human resources* and *Points of entry*. Higher morbidity associations could also arise from time-varying hazard burden, changes in measurement or reporting, model dependence, or other unmeasured factors. Because these alternatives were not tested, estimates should not be interpreted as evidence that stronger capacities increased underlying morbidity.

4.3 Limitations

Several limitations should be acknowledged. First, the ecological study design supports inference only at the country level, and associations cannot be interpreted as causal or extrapolated to sub-national

populations. Second, complete-case analysis and the removal of all-zero fixed-effect groups produced outcome-specific analytic samples, meaning results are conditional on data availability. Third, IHR scores were derived from self-reported monitoring instruments and required harmonization across three versions. Changes in sub-indicators and scoring may limit longitudinal comparability. Lastly, EM-DAT assigns a hazard classification to each event, whereas the SFM indicators are national annual totals. Biological events were excluded from EM-DAT but could not be excluded from SFM. SFM outcomes may include biological events other than COVID-19. Analyses were conducted at the multi-hazard level in both datasets, and the estimates cannot determine whether associations differ by hazard type.

4.4 Policy implications

Stronger cross-cutting IHR core capacities were associated with lower disaster mortality across two disaster datasets. This provides empirical support for the Bangkok Principles, which call for integrating health instruments into disaster risk reduction frameworks, and for the WHO Health EDRM framework, which links IHR (2005) capacities to disaster risk management functions [11, 12].

One practical implication is that IHR core capacities can be considered a component of multisectoral disaster preparedness. States Parties report annually to WHO under Article 54 of the IHR (2005), and SPAR scores could be reviewed alongside hazard, exposure, vulnerability, and disaster-loss information when developing disaster risk reduction policies and plans. Multi-hazard preparedness assessments should also avoid relying on a single data source because disaster indicators differ by construction. The two sources used here broadly agreed on median mortality but differed sixteen-fold in median morbidity, indicating that interpretations of disaster morbidity may depend on the dataset consulted.

5 Conclusion

Across 196 States Parties, SFM and EM-DAT disaster mortality rates were approximately 40% lower for each 10-point increase in the *IHR average score* during 2020–2023. Higher *Laboratory* capacity was also associated with lower mortality in both datasets during the same period. Disaster morbidity associations were observed mainly in SFM with both lower and higher morbidity rates across the 2015–2023 and 2020–2023 periods. *IHR Coordination* was the exception, being associated only with lower morbidity in SFM for 2015–2023. These findings indicate that capacities monitored under the IHR (2005) are relevant to multi-hazard disaster outcomes beyond biological threats. Cross-cutting IHR core capacities can therefore be considered a component of multisectoral disaster preparedness. Future studies should examine whether these associations persist beyond the study period and whether they differ by hazard types, regions, or income groups.

Declarations

Data availability

The dataset generated and analyzed for this study is available in the figshare repository, <https://doi.org/10.6084/m9.figshare.33440020> [52]. Disaster mortality and morbidity data from EM-DAT are subject to the provider's conditions of use, which do not permit redistribution, and are therefore excluded from the deposited dataset. The EM-DAT data are freely available to academic users from <https://public.emdat.be> following registration. The figshare deposit includes a script that reconstructs the complete analysis panel once an EM-DAT extract has been obtained. IHR self-assessment monitoring scores are available from the WHO Global Health Observatory (<https://www.who.int/data/gho>). Sendai Framework Monitor data are available from <https://sendaimonitor.undrr.org>, and socioeconomic indicators are available from the World Bank World Development Indicators (<https://databank.worldbank.org/source/world-development-indicators>).

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Author contributions

T.T.H. and F.J.T. conceptualized the study. T.T.H. curated the data, developed the methodology, conducted the formal analysis, prepared the tables and figures, and wrote the original draft of the manuscript. F.J.T. supervised the research and validated the analysis. Both authors reviewed, revised, and approved the final version of the manuscript.

Additional information

Competing interests

The authors declare no competing interests.

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Ethics declarations

This study analyzed publicly available, aggregated, country-level secondary data containing no personally identifiable information, and did not require ethical approval.

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Figures

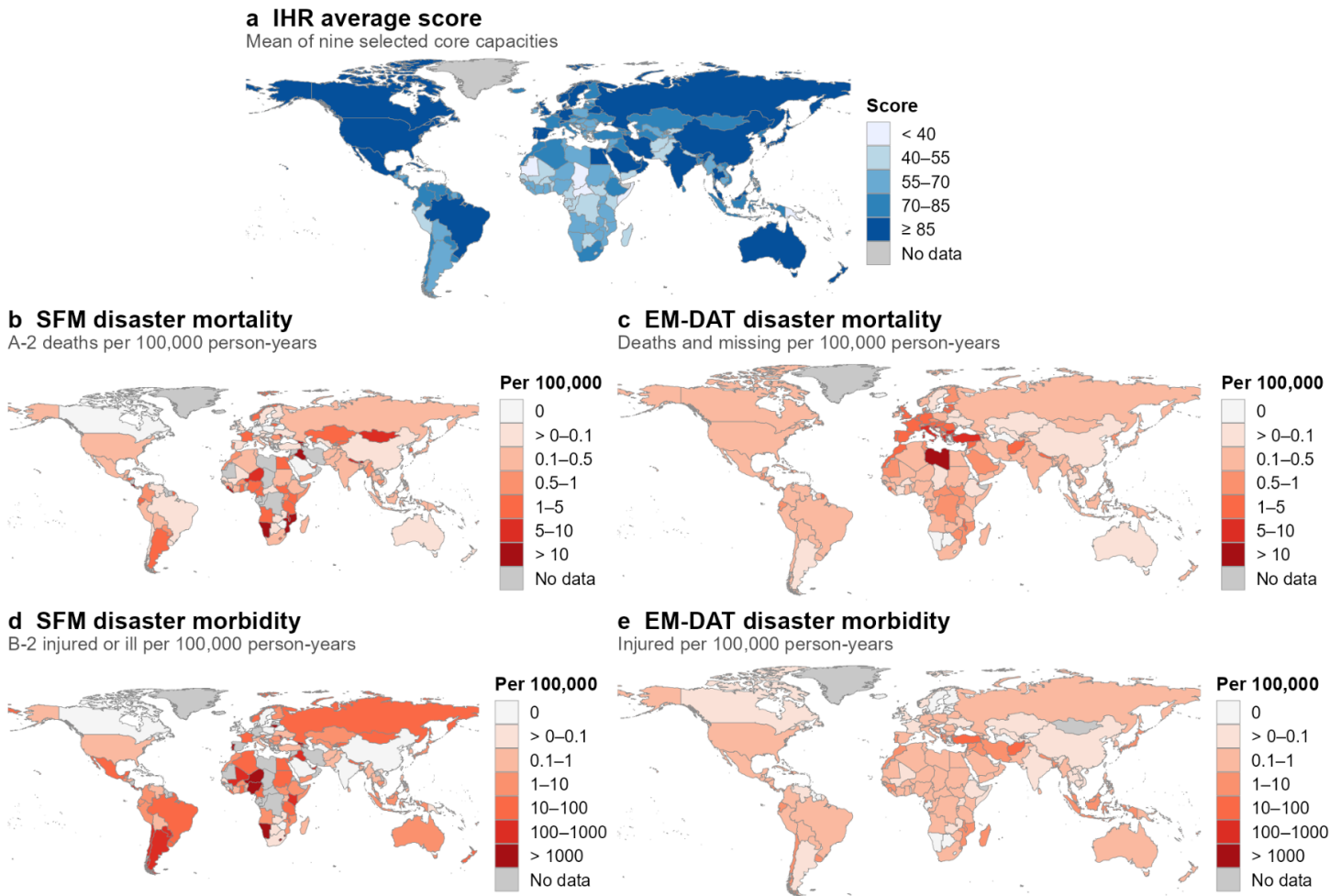


Figure 1

Global distribution of IHR average score and average annual SFM and EM-DAT disaster-attributed mortality and morbidity rates per 100,000 person-years (2015–2023)

Note. Grey indicates countries or territories with no available data or not included in the analytic sample. Class intervals differ between the mortality panels (b, c) and the morbidity panels (d, e). Shading is therefore not comparable between the two groups. Maps were generated by the authors in R; country boundaries derive from Natural Earth (public domain). Map lines delineate study areas and do not necessarily depict accepted national boundaries.

Supplementary Files

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