Supplementary Information

Rising risk of elephant-caused human casualties in Tropical Asia

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Appendix S1 – Searching protocol

Searches were conducted in English and country-specific languages using online databases (Web of Science, Google Scholar, Scopus) and search engines (Google, Baidu). A set of keywords were designed to return potentially relevant information from the online platforms. Keywords include "*Asian elephants*", "*Elephas maximus*", "*Elephant*", combined with "*attacks*", "*conflict*", "*mortalities*", "*death*", "*injury*", "*trampled*", "*human*", "*people*", and "*killing*". Additional keywords mentioning the target country were also added. Non-English documents were translated with online tools (Google Translate, ChatGPT, or Gemini) and verified by native speakers where necessary. For each case, we recorded details of the incident: (1) location (GPS coordinates when provided, otherwise geocoded from place names), (2) type of casualty (fatality or injury), victim and elephant demographics, and victim activity where reported. Geocoding and digitizing were performed in QGIS 3.40.12. Duplicates were removed by cross-matching date, location, and narrative. Reports lacking sufficient geographic information were excluded (19% of the initial reports).

Appendix S2 – Combining deaths and injuries as a single category

We combined data on human deaths and injuries as casualties to improve predictive power. To test whether deaths and injuries could be pooled, we compare two regression models (one with deaths, one with injuries) to calculate the similarity between the coefficients' estimates and standard errors of the two fitted models using z-test (Clogg *et al.* 1995; Paternoster *et al.,* 1998), expressed as:

$$Z = \frac{\beta 1 - \beta 2}{\sqrt{((SE\beta 1)^2 + (SE\beta 2)^2)}}$$

where β is the model's coefficient, and $SE\beta$ is the coefficient's standard error.

Table S1. Sets of models, arranged in an ascending order based on AIC and ΔAIC.

Model	**Form**	**AIC**	**ΔAIC**
Full model with quadratic terms	att ~ ed + mesh + tri + wetness + popdens + gdp + hfp + dist_forest + dist_fp + dist_cropland + dist_pa + I(dist_forest^2) + I(dist_fp^2) + I(dist_cropland^2) + I(dist_pa^2) + Matern (1|long+lat)	1485.9	0
Full model without quadratic terms	att ~ ed + mesh + tri + wetness + popdens + gdp + hfp + dist_forest + dist_fp + dist_cropland + dist_pa + Matern (1|long+lat)	1519	33.1
Potential HEC with quadratic terms	att ~ dist_forest + dist_fp + dist_cropland + dist_pa + I(dist_forest^2) + I(dist_fp^2) + I(dist_cropland^2) + I(dist_pa^2) + Matern(1|long+lat)	1538.9	53
Potential HEC	att ~ dist_forest + dist_fp + dist_cropland + dist_pa + Matern(1|long+lat)	1572.8	86.9
Habitat and natural resources with quadratic term	att ~ wetness + I(wetness^2) + Matern(1|long+lat)	1615.	129.4
Topography	att ~ tri + Matern(1|long+lat)	1618.2	132.3
Forest fragmentation	att ~ ed + mesh + Matern(1|long+lat)	1627.8	141.9
Human disturbance	att ~ hfp + Matern(1|long+lat)	1644.1	158.2
Habitat and natural resources	att ~ wetness + Matern(1|long+lat)	1645.9	160
Null model	att ~ 1 + Matern(1|long+lat)	1652.2	166.3
Socioeconomic	att ~ popdens + gdp + Matern(1|long+lat)	1653.8	167.9

Abbreviations: att = human casualties; ed = edge density, mesh = effective mesh size, tri = terrain ruggedness index, wetness = tasseled cap wetness index, popdens = human population density, gdp = gross domestic product, dist_forest = distance to forest, dist_fp = distance to forest plantations, dist_cropland = distance to cropland, dist_pa = distance to protected areas, hfp = human footprint

Table S2. Elephant-caused human casualties risk distribution in 2015. Percentages are relative to respective countries; brackets are size in km^2. (*) indicates area at risk relative to the study area.

Country	**Low**	**Moderate**	**High**	**Severe**	***Area at Risk**
Sri Lanka	12.5% (6,836)	41.8% (22,900)	44% (24,071)	1.7% (920)	0.9 % (54,729)
Sabah (Malaysia)	46.3% (26,667)	31.4% (18,045)	18.4% (10,608)	3.9% (2,242)	1% (57,564)
Cambodia	46.4% (96,149)	30.9% (63,938)	21.6% (44,749)	1.2% (2,413)	3.4% (207,250)
Thailand	54.2% (433,247)	29.5% (235,854)	15.8% (126,487)	0.5% (3,583)	13% (799,172)
Vietnam	58.4% (348,357)	26.6% (158,966)	14.4% (86,177)	0.6% (3,488)	9.7% (596,989)
Laos	60.7% (348,365)	25.9% (148,709)	13.1% (75,400)	0.3% (1,498)	9.3% (573,972)
Peninsula Malaysia	66.7% (101,575)	27.1% (41,199)	6% (9,142)	0.2% (346)	2.5% (152,263)
Bangladesh	68.2% (97,818)	25.2% (36,154)	6.5% (9,273)	0.1% (127)	2.3% (143,373)
India	70.9% (1,161,332)	20.3% (332,611)	8.6% (140,901)	0.3% (4,009)	27% (1,638,855)
Sumatra, Indonesia	73.6% (362,933)	22.2% (109,499)	4.1% (20,054)	0.2% (983)	8% (493,471)
Myanmar	73.7% (774,995)	19.1% (200,391)	7.1% (75,149)	0.1% (1,350)	17.1% (1,051,887)
Nepal	76.9% (126,295)	13.2% (21,746)	9.4% (15,460)	0.5% (874)	2.7% (164,376)
Bhutan	82.7% (34,957)	9.3% (3,909)	7.7% (3,260)	0.4% (148)	0.7% (42,275)
Yunnan, China	87.1% (169,820)	11.4% (22,320)	1.5% (2,877)	0.01% (16)	3.2% (195,034)

Table S3. Baseline human population size at risk (2015).

Country	Moderate	High	Severe	Total
India	112,679,776	43,380,284	883,964	156,944,024
Myanmar	24,712,724	10,157,166	197,054	35,066,944
Thailand	19,297,678	9,808,117	177,619	29,283,414
Vietnam	14,559,162	6,585,284	179,459	21,323,905
Nepal	10,327,248	6,733,308	276,392	17,336,948
Bangladesh	19,213,766	4,576,210	43,234	23,833,209
Laos	11,675,124	6,009,674	87,538	17,772,336
Sri Lanka	7,257,112	2,931,549	45,817	10,234,477
Sumatra, Indonesia	14,352,103	2,111,585	65,688	16,529,376
Peninsula Malaysia	7,591,289	1,448,450	50,504	9,090,242
Cambodia	4,611,863	2,324,423	94,781	7,031,067
Bhutan	435,362	993,172	32,185	1,460,719
Sabah, Malaysia	623,308	470,250	128,602	1,222,160
Yunnan, China	2,002,917	477,162	1,454	2,481,533

Table S4. Projected area at risk by 2050. Percentages are relative to respective countries; brackets are the size in km^2. (*) indicates area at risk relative to the study area

Country	Low	Moderate	High	Severe	*Area at Risk
Sri Lanka	6% (3,462)	27% (15,519)	50.5% (29,053)	16.6% (9,557)	0.87% (57,593)
Sabah, Malaysia	66.7% (38,719)	28.6% (16,583)	4.6% (2,672)	0.2% (98)	0.88% (58,074)
Cambodia	40% (89,618)	30% (67,036)	21.5% (48,075)	8.5% (19,116)	3.4% (223,846)
Thailand	53.7% (457,644)	26.4% (225,348)	15.4% (131,686)	4.5% (38,262)	12.9% (852,942)
Vietnam	55.6% (350,547)	25.3% (159,336)	14.5% (91,122)	4.7% (29,366)	9.6% (630,372)
Laos	60.2% (363,524)	24% (144,946)	12.2% (73,863)	3.6% (21,539)	9.1% (603,874)
Peninsula Malaysia	60.3% (93,136)	27.8% (42,873)	11% (16,934)	1% (1554)	2.3% (154,499)
Bangladesh	69% (115,494)	23% (38,303)	7.2% (12,087)	1% (1467)	2.5% (167,352)
India	70% (1,261,225)	18.9% (341,803)	9.2% (165,213)	2.1% (38,315)	27.3% (1,806,558)
Sumatra, Indonesia	66.8% (332,339)	26% (129,353)	6.8% (33,856)	0.6% (2,224)	8% (493,471)
Myanmar	71,7% (807,579)	18.9% (212,466)	7.9% (88,810)	1.5% (17,340)	17% (1,126,196)
Nepal	78.3% (151,119)	12.7% (24,583)	6.5% (12,522)	2.4% (4,703)	2.9% (192,928)
Bhutan	73.2% (31,225)	15.3% (6,544)	7.4% (3,152)	4% (1,726)	0.7% (42,648)
Yunnan, China	85.4% (166,957)	12.4% (24,310)	1.9% (3,683)	0.26% (511)	3% (195,463)

Table S5. Projected human population size at risk by 2050.

Country	Moderate	High	Severe	Total
India	136,519,504	62,069,136	12,518,925	211,107,565
Myanmar	24,766,404	11,528,165	2,522,746	38,817,315
Thailand	17,594,938	9,837,038	2,891,100	30,323,076
Vietnam	15,389,817	7,304,384	1,879,302	24,573,503
Nepal	13,758,316	7,235,163	2,379,862	23,373,341
Bangladesh	26,034,340	8,284,714	914,709	35,233,763
Laos	10,812,401	5,404,986	1,444,630	17,662,016
Sri Lanka	5,908,302	8,416,694	1,203,520	15,528,516
Sumatra, Indonesia	20,226,230	8,229,399	940,104	29,395,732
Peninsula Malaysia	9,079,643	5,169,395	865,122	15,114,160
Cambodia	5,834,804	2,340,035	817,595	8,992,434
Bhutan	409,150	850,541	800,912	2,060,603
Sabah, Malaysia	697,685	390,541	76,648	1,164,874
Yunnan, China	1,577,841	652,339	114,759	2,344,939

Table S6. Z-statistics between death and injury model. P-values beyond significance (>0.001) indicate no significant differences between coefficients' estimates and standard errors of the two fitted model.

Coefficient	Z-statistics	P-value
Edge Density	0.4	0.69
Effective Mesh Size	-0.54	0.59
Terrain Ruggedness Index	2.8	0.005
Tasselled Cap Wetness Index	1.26	0.2
Human Footprint	0.9	0.38
Human Population Density	-0.47	0.64
Gross Domestic Product	0.39	0.69
Distance to Forest	0.32	0.75
Distance to Cropland	-0.91	0.36
Distance to Forest Plantations	1.21	0.23
Distance to Protected Areas	0.4	0.69

Table S7. Definitions and sources for the predictor variables. *** indicates used in the regression analysis. We omitted some variables due to multicollinearity.

Variable	Description	Source Dataset	Usage
Fragmentation			
Edge density (ed)	The amount of edge habitat (forest), representing the number of human–elephant interfaces in a landscape	Xu et al. (2024)	***
Landscape shape index (lsi)	Complexity of landscape shapes in relation to how irregular or fragmented the patches are	Xu et al. (2024)	
Largest patch index (lpi)	Proportion of the landscape occupied by the largest habitat patch, identifying how dominant a habitat is in certain areas	Xu et al. (2024)	
Effective mesh size (mesh)	Measures the connection between patches, representing the connectivity in the area	Xu et al. (2024)	***
Patch density (pd)	Habitat patches per unit area in relation of fragmentation levels	Xu et al. (2024)	
Habitat and Natural Resources			
Tasseled cap wetness index (wetness)	A proxy for forest quality. Used to also detect changes in forest structure	Landsat 8 Collection 2 (GEE)	***
Socioeconomic			
Human population density (popdens)	Count of people per unit area	Tatem (2017)	***
Gross domestic product (gdp)	Measures the economic output of a certain area	Wang and Sun (2022)	***
Nightlights (vnl)	Nighttime lights as seen from satellite data, proxy for economic development	Elvidge et al. (2021)	
Potential human–elephant conflict			
Distance to forest (dist_forest)	Euclidean distance to naturally regenerated manage or unmanaged forests	Xu et al. (2024)	***

Distance to cropland (dist_cropland)	Euclidean distance to cropland	Potapov et al. (2021)	***
Distance to forest plantations (dist_fp)	Euclidean distance to forest plantations including agroforestry	Xu et al. (2024)	***
Distance to protected areas (dist_pa)	Euclidean distance to protected areas	IUCN and UNEP-WCMC	***
Human Disturbance			
Human footprint (hfp)	Index of human pressure on the landscape	Venter et al. (2016)	***
Topography			
Terrain ruggedness index (tri)	Variability in ground terrain elevation, measures the ruggedness of the land	Danielson and Gesch (2011)	***

Table S8. List of *a priori* hypotheses of each driver and their references.

Drivers	Model	Hypotheses	References
Potential Human-Elephant Conflict (distance to forest, distance to forest plantations, distance to cropland, and distance to protected areas), with and without quadratic terms	Human Casualties (HC) ~ Potential HEC + Spatial Autocorrelation Term (SAC)	Human casualties will be higher nearer to forests, forest plantations, croplands, and protected areas due to elephant habitat preferences.	Natarajan *et al.,* 2023
Habitat and Natural Resources (wetness)	HC ~ Habitat and natural resources + SAC	Elephants prefer disturbed forests due to abundant food resources – wetness characterized forest structure. Human casualties will be higher where food resources are abundant for elephants.	de la Torre *et al.,* 2021, 2022
Topography (terrain ruggedness index)	HC ~ Topography + SAC	Elephants prefer flat surfaces; hence encounters are much more likely in less rugged environment.	de la Torre *et al.,* 2021
Forest Fragmentation (edge density, landscape shape index, largest patch index, effective mesh size, and patch density	HC ~ Fragmentation + SAC	Elephants prefer the periphery of forest. Fragmentation indicates higher human-elephant interfaces. Human casualties will be higher where forests are more fragmented.	Acharya *et al.,* 2017
Human Disturbance (human footprint)	HC ~ Human Disturbance + SAC	Higher human disturbance (built-up area and linear infrastructure) increases the chance of encounter. Human casualties will be	Natarajan *et al.,* 2023

		higher where there is higher rate of human disturbance.	
Socioeconomic (Human population density, gross domestic product, nightlights)	HC ~ Socioeconomic + SAC	Human casualties will be higher in densely populated settlements and among people with low economic background.	Ram *et al.*, 2021
Full Model, with and without quadratic terms	HC ~ Potential HEC + Habitat and Natural Resources + Topography + Fragmentation + Human Disturbance + Socioeconomic + SAC		

Table S9. Sources for country-level patterns of wild elephant-caused human casualties across Tropical Asia for the period 2020-2024.

No	Country	Period covered	Total casualties	Source
1	*India*	2000, 2009-2024	1,581	Centre for Science and Environment (2025); Lok Sabha Unstarred Questions No. 3194: Elephant-Human Conflict (2023); Pandey *et al.* (2024)
2	*Sri Lanka*	2010-2024	358	Gunawansa *et al.* (2023)
3	*Nepal*	2000-2020	412	Ram *et al.* (2021)
4	*Myanmar*	2010-2022	171	Forest Department, Myanmar
5	*Bangladesh*	2001-2004, 2005-2009, 2012	242	Hossen (2013)
6	*China*	2000-2004, 2013-2019	105	Chen *et al.* (2012); Hu *et al.* (2021)
7	*Malaysia*	2006-2021	42	Department of Wildlife and National Parks Peninsula Malaysia
8	*Laos*	2000-2020	22	Ministry of Agriculture and Forestry (2022)
9	*Cambodia*	2009, 2011, 2012, 2014	4	*Pers. Communication*
10	*Sabah (Malaysia)*	2011, 2015, 2016, 2023	4	*Pers. communication*

Table S10. Province-level data used to compare predicted risks and actual data.

No	Country	Period covered	Source
1	*Bangladesh*	2012	Hossen, A. (2013)
2	*Myanmar*	2010-2022	Department of Forestry, Myanmar
3	*India*	2019-2021	"Lok Sabha Unstarred Questions No. 3194: Elephant-Human Conflict (2023)"

4	*Sri Lanka*	2019-2021	Gunawansa *et al.* (2023)
5	*China*	2000-2004	Chen *et al.* (2012); Hu *et al.* (2021)
6	*Malaysia*	2006-2021	Department of Wildlife and National Parks of Peninsular Malaysia
7	*Laos*	2000-2020	Ministry of Agriculture and Forestry (2022)
8	*Indonesia*	2015-2020	Leuser International Foundation (2021)

Figure S1. Risk change across all scenarios compared to the baseline scenario (2015).

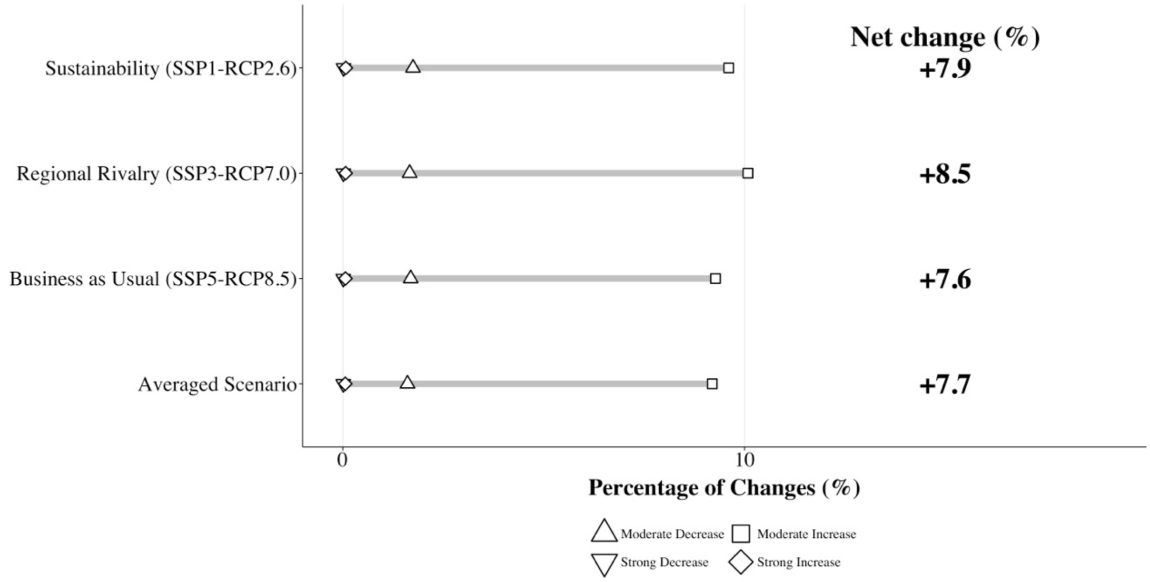


Figure S2. Simulated residuals diagnostics of the chosen model.

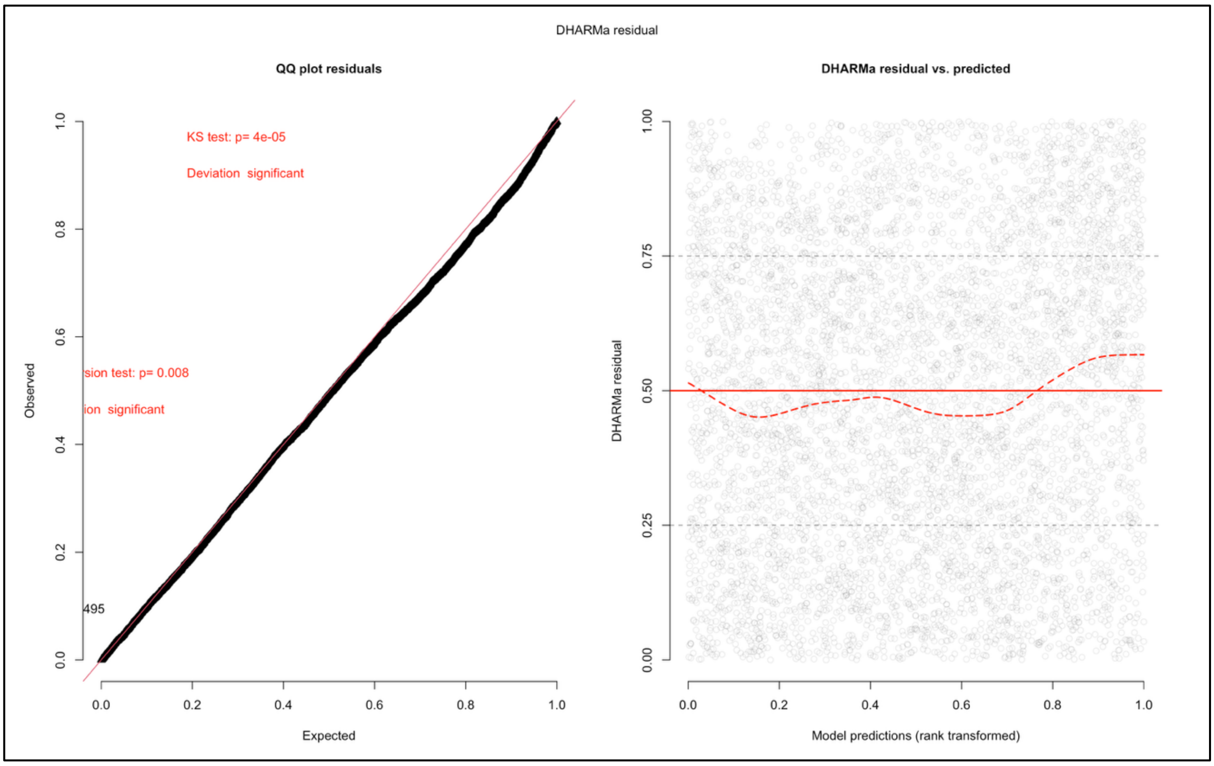


Figure S3. Spatial (fitted with Matérn covariance) and non-spatial model correlogram.

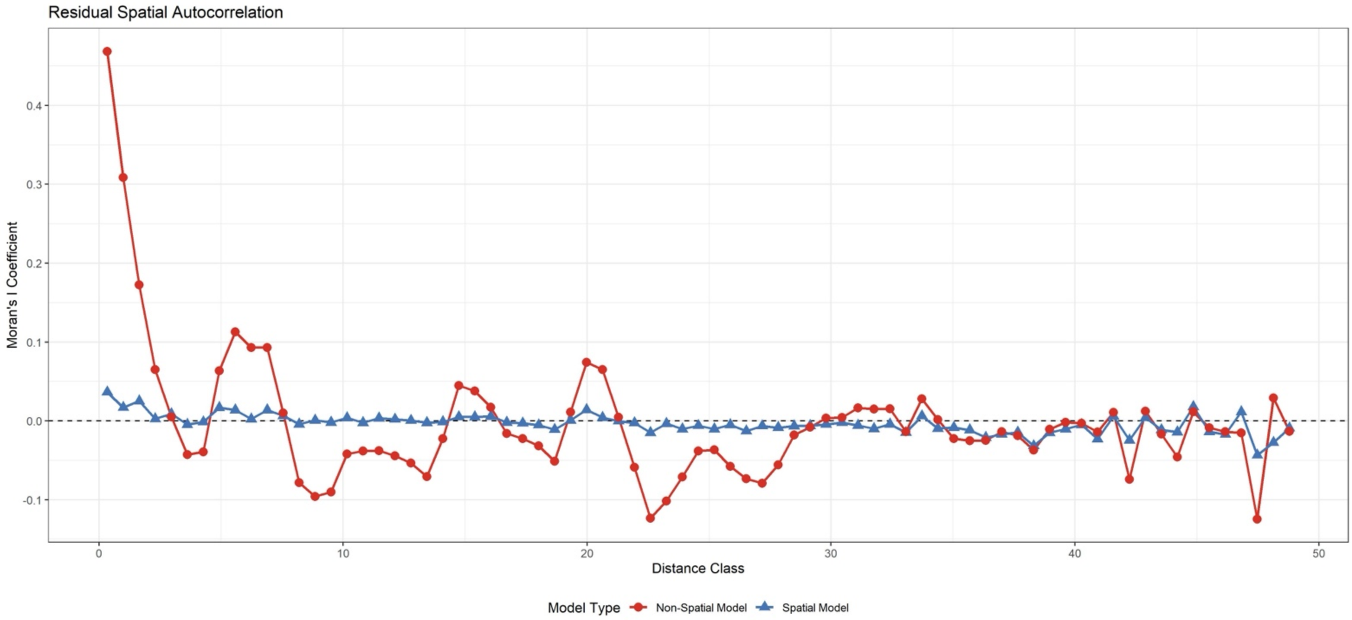
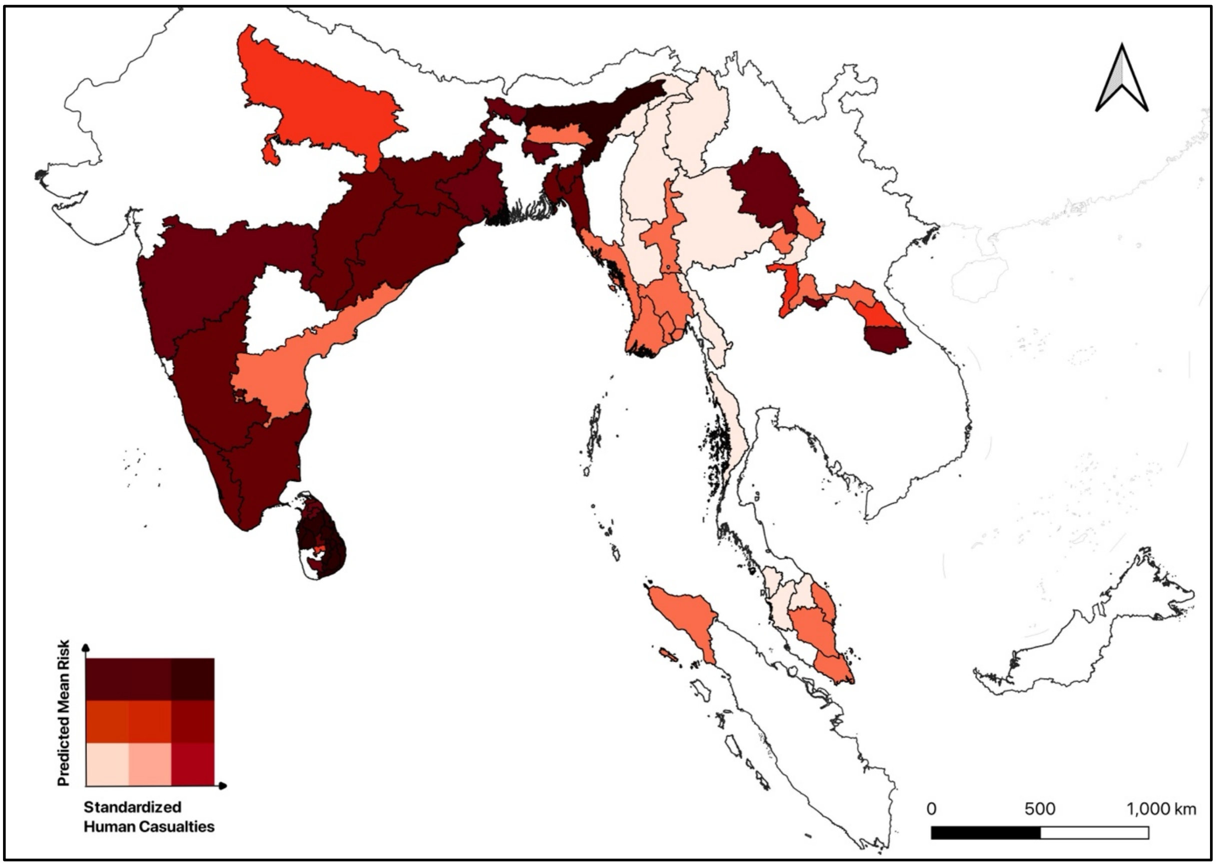


Figure S4. Standardized human casualties against the area-weighted predicted mean risk. We validated our predictions to actual data at province-level. Official reports were compiled from 64 provinces across 8 countries (Table S10).



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