Supplementary information

for CREA's analysis, "Choking on inaction: Indonesia's fires led to 1,700 deaths in August — but regular air pollution even more"

Methodology

What is estimated

This brief estimates the number of deaths brought about by **short-term exposure** to ambient fine particulate matter (PM2.5) in Indonesia during August 2026, separated into a fire and a non-fire component, by province.

These are **acute** deaths: the selected short-term concentration–response functions capture mortality occurring within a two- to three-day lag of exposure. The basis is non-accidental deaths, i.e. excluding deaths caused by accidents and violence.

These figures should not be mistaken for the chronic burden of fire smoke, which repeated seasonal exposure is estimated to cause at 33,000–44,000 deaths per year (Hein et al. 2022; Kiely et al. 2020). This means that over the long term, the exposure to air pollution in August will result in a much larger number of deaths as a delayed effect.

The distinction follows the convention set by Johnston et al. (2012): short-term functions for episodic exposure, long-term functions for chronic exposure.

Exposure

We use the Daily surface PM2.5 from the Tracking Air Pollution (TAP) global product at 0.1° (~11 km) resolution, a fusion of ground monitoring, satellite aerosol optical depth and chemical transport modelling (Geng et al. 2021). TAP publishes total PM2.5 and a landscape-fire channel from the same analysis on the same grid.

Validated against Indonesian ground monitors, TAP under-predicts PM2.5 by roughly half across the fire provinces (median −53%). SILAM, an independent chemistry-transport model built on a different fire-emissions inventory, errs in the same direction by a similar margin (−61%).

We correct the published maps using a multiplicative factor fitted by geographically weighted regression on 139 reference-grade monitors across 97 cities, with an adaptive bandwidth spanning the five nearest instruments — and a taper that returns the published field beyond 250 km of any monitor. The fire and non-fire channels are fitted separately, so the fire/non-fire ratio is measured rather than inherited from TAP.

The corrected surface is weighted by the Gridded Population of the World v4.11 grid (2020, 1 km), with each province scaled to match Statistics Indonesia's (BPS) mid-2025 estimate, 284 million nationally.

Concentration–response functions

Fire and non-fire particles are not assumed to be equally toxic. Two coefficients are used, each applied to the exposure metric on which it was estimated.

Applied to	Outcome	RR per 10 µg/m³	Exposure metric	Source
Fire	All-cause	1.017 (1.013–1.020)	3-day mean, lag 0–2	Chen et al. (2021) *South-East Asia figures*
	Cardiovascular	1.011 (1.005–1.017)	3-day mean, lag 0–2	Chen et al. (2021) *South-East Asia figures*
	Respiratory	1.016 (1.008–1.023)	3-day mean, lag 0–2	Chen et al. (2021) *South-East Asia figures*
Non-fire	Natural	1.0068 (1.0059–1.0077)	2-day mean, lag 0–1	WHO HRAPIE-2 (2025) / Liu et al. (2019)
	Cardiovascular	1.0055 (1.0045–1.0066)	2-day mean, lag 0–1	Liu et al. (2019)
	Respiratory	1.0074 (1.0053–1.0095)	2-day mean, lag 0–1	Liu et al. (2019)

Calculation

For each grid cell g and day d:

- $E(g,d) = β\_fire \cdot MA_3(C\_fire) + β\_nonfire \cdot MA_2(C\_nonfire)$
- $β = \ln(RR)/10$
- $AF(g,d) = 1 − \exp(−E(g,d))$

The attributable fraction is population-weighted to the province and multiplied by that province's absolute annual baseline death count:

- $Deaths(prov,d) = AF\_prov(d) \cdot BaselineDeaths(prov) / 365$

Baseline mortality

Provincial deaths are taken from the Global Burden of Disease Study 2023 (GBD 2025): number of deaths, all ages, both sexes, Indonesia subnational. The headline outcome is natural (non-external) mortality, calculated as all causes minus injuries, which corresponds to what the concentration–response functions measure. Respiratory mortality is the composite of chronic respiratory disease and lower respiratory infections.

Comparison with previous studies

Crippa et al. (2016) estimated 11,880 excess deaths across Indonesia, Malaysia and Singapore over September–October 2015 — about 195 a day — using the same short-term method. This study gives about 120 a day for Indonesia alone. Crippa covers the September–October peak of the burning season, where this study covers August, with the 2026 season still building.

Data acknowledgements

Exposure data from the Tracking Air Pollution (TAP) global product, Tsinghua University, used under its non-commercial research licence. Mortality data from the Institute for Health Metrics and Evaluation (GBD 2023). Ground measurements from the CREA Indonesia air quality tracker, drawing on 171 Indonesia's ground monitors from the Ministry of Environment's national network (133), the Agency for Meteorology, Climatology and Geophysics (26), and Provincial Environmental Agency’s reference sites (12).

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Appendix

Province	Deaths	— fire	— non-fire	Fire share	Per 100k	Fire per 100k
West Java	518	38	480	7%	1.01	0.07
Central Java	421	41	380	10%	1.07	0.10
East Java	352	64	287	18%	0.82	0.15
West Kalimantan	334	331	4	99%	5.69	5.63
South Sumatra	266	167	99	63%	3.02	1.90
Central Kalimantan	172	169	3	98%	6.00	5.90
Riau	154	121	34	78%	2.33	1.83
North Sumatra	151	41	110	27%	0.96	0.26
Jakarta	144	9	135	6%	1.29	0.08
Banten	139	9	130	7%	1.11	0.07
South Kalimantan	137	128	10	93%	3.31	3.07
Lampung	132	47	85	36%	1.37	0.49
West Sumatra	112	93	19	83%	1.88	1.56
Jambi	92	67	26	72%	2.50	1.80
South Sulawesi	81	16	65	20%	0.83	0.16
East Kalimantan	60	51	10	84%	1.48	1.25
West Nusa Tenggara	60	49	10	83%	1.07	0.89

Papua	56	47	8	85%	1.04	0.89
Yogyakarta	45	5	41	10%	1.17	0.12
Bali	43	36	7	85%	0.92	0.78
Aceh	41	6	35	15%	0.75	0.11
Bengkulu	39	15	25	37%	1.85	0.69
East Nusa Tenggara	36	20	16	56%	0.64	0.35
Riau Islands	24	16	8	65%	0.99	0.65
Central Sulawesi	21	12	9	58%	0.67	0.39
Bangka-Belitung Islands	19	11	8	57%	1.24	0.70
Maluku	16	13	2	85%	0.77	0.65
Southeast Sulawesi	14	5	9	35%	0.51	0.18
North Sulawesi	14	8	5	62%	0.48	0.30
West Sulawesi	10	5	5	47%	0.68	0.32
North Kalimantan	10	7	2	74%	1.27	0.95
West Papua	9	8	2	84%	0.71	0.60
North Maluku	8	6	1	85%	0.55	0.46
Gorontalo	5	2	3	43%	0.43	0.18
INDONESIA	**3,735**	1,662	2,073	45%	1.30	0.58