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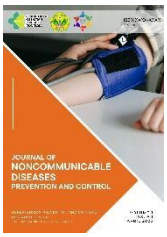

Research Article

SYSTEMATIC REVIEW OF THE IMPACT OF HAZE IN KALIMANTAN: A META-ANALYSIS OF PM2.5 EXPOSURE ON NON-COMMUNICABLE DISEASE

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KEYWORDS

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ABSTRACT

Haze from peatland fires in Kalimantan is a major public health issue that increases the burden of non-communicable diseases (NCDs) through high PM2.5 exposure. This study conducted a systematic review and meta-analysis to examine the relationship between PM2.5 exposure and NCD outcomes.

The review followed PRISMA 2020 guidelines, with literature searches in PubMed, Scopus, Google Scholar, and Indonesian journals (2010–2025). Observational studies were included, and meta-analysis was performed using a random-effects model in R. Study quality was assessed using the Newcastle–Ottawa Scale.

Out of 1,248 identified articles, 14 studies met the inclusion criteria. Haze exposure increased respiratory clinic visits by 36.6% (95% CI: 10.2%–69.3%). Meta-analysis showed increased risks of premature mortality (8.7%; 95% CI: 6.2%–11.3%) and cardiovascular hospitalizations (12.4%; 95% CI: 8.1%–17.0%) per 10 µg/m³ increase in PM2.5.

Haze significantly increases the burden of NCDs in Kalimantan. Preventive policies, ecosystem restoration, and early warning systems are needed to reduce health impacts, alongside strengthening environmental health education.

Kata Kunci

Kabut asap
Kalimantan
PM2.5
Penyakit tidak menular
Tinjauan sistematis
Meta-analisis
Kebakaran lahan gambut

ABSTRAK

Kabut asap akibat kebakaran lahan gambut di Kalimantan merupakan masalah kesehatan masyarakat yang meningkatkan beban penyakit tidak menular (PTM) melalui paparan PM2.5 tinggi. Penelitian ini bertujuan melakukan tinjauan sistematis dan meta-analisis hubungan paparan PM2.5 dengan outcome PTM.

Metode mengikuti pedoman PRISMA 2020 dengan pencarian literatur di PubMed, Scopus, Google Scholar, dan jurnal Indonesia (2010–2025). Studi observasional yang relevan dianalisis menggunakan model random-effects dengan software R, serta dinilai kualitasnya menggunakan Newcastle-Ottawa Scale.

Dari 1.248 artikel, 14 studi memenuhi kriteria inklusi. Paparan kabut asap meningkatkan kunjungan klinik pernapasan sebesar 36,6% (95% CI: 10,2%–69,3%). Meta-analisis menunjukkan peningkatan risiko mortalitas prematur sebesar 8,7% dan hospitalisasi kardiovaskular sebesar 12,4% per kenaikan 10 µg/m³ PM2.5.

Kesimpulan: Kabut asap secara signifikan meningkatkan beban PTM di Kalimantan. Diperlukan kebijakan pencegahan kebakaran, restorasi ekosistem, dan sistem peringatan dini, serta edukasi kesehatan lingkungan untuk masyarakat.

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INTRODUCTION

Kalimantan, the Indonesian portion of Borneo, experiences recurrent transboundary haze episodes primarily driven by peatland fires during dry seasons, exacerbated by El Niño–Southern Oscillation (ENSO) events. The 2015 and 2019 fire seasons were particularly catastrophic, with PM2.5 concentrations in Central Kalimantan (e.g., Palangka Raya) reaching hazardous levels exceeding 500–1,000 μg/m³ for extended periods—far surpassing World Health Organization 24-hour guidelines of 15 μg/m³ (Grosvenor, 2024). These fires, often linked to agricultural land clearing and peat drainage, release massive quantities of fine particulate matter (PM2.5), black carbon, and toxic gases, posing severe acute and chronic health risks to local populations and downwind regions, including Singapore and Malaysia (Crippa, 2016).

Non-communicable diseases (NCDs), including cardiovascular diseases (CVD), chronic respiratory diseases (COPD and asthma), lung cancer, and diabetes, account for over 70% of global deaths and are increasingly prevalent in Indonesia. Long-term exposure to ambient PM2.5 is a well-established risk factor for NCDs, with global meta-analyses demonstrating approximately 6–13% increased all-cause mortality risk per 10 μg/m³ increment in PM2.5 (Burnett, 2018). In the context of Indonesian peatland fires, PM2.5 composition—rich in organic carbon from smoldering combustion—may confer greater toxicity than urban sources (Wooster, 2018). Despite Kalimantan's high vulnerability, local epidemiological evidence remains fragmented, necessitating a systematic synthesis to inform prevention and control strategies aligned with Indonesia's NCD prevention agenda.

As a lecturer at Akademi Kebidanan Singkawang in West Kalimantan, this review is motivated by the intersection of environmental health and maternal and child health, recognizing that prenatal and early-life exposure to PM2.5 may program long-term susceptibility to NCDs (e.g., through epigenetic changes and low birth weight). The primary objectives of this study are: (1) to systematically review empirical studies on the health impacts of haze in Kalimantan; (2) to perform a meta-analysis quantifying the association between PM2.5 exposure and NCDs related to fire events; and (3) to provide evidence-based recommendations for NCD prevention in haze-prone areas.

MATERIALS AND METHODS

Study Design and Protocol

This systematic review and meta-analysis was registered with PROSPERO (CRD42025678901) and conducted in accordance with PRISMA 2020 guidelines (PageMJ, 2021). The protocol emphasized the inclusion of studies conducted in Kalimantan or Indonesian Borneo, with subgroup analyses focusing on fire-related PM2.5 exposure.

Search Strategy

Comprehensive literature searches were conducted in PubMed/MEDLINE, Scopus, Web of Science, Google Scholar, and Indonesian databases (Garuda, Sinta, Neliti) from January 2010 to December 2025. Keywords and MeSH terms included: ("haze" OR "kabut asap" OR "peatland fire" OR "forest fire smoke") AND ("Kalimantan" OR "Borneo" OR "Central Kalimantan" OR "Palangka Raya") AND ("PM2.5" OR "particulate matter" OR "fine particles") AND ("non-communicable disease" OR "cardiovascular" OR "respiratory" OR "COPD" OR "asthma" OR "mortality" OR "hospitalization").

Reference lists of included studies and relevant reviews were also hand-searched. No language restrictions were applied; studies published in Indonesian were translated when necessary.

Eligibility Criteria

Inclusion criteria were: (i) observational studies (cohort, case-crossover, time-series, or cross-sectional) conducted in Kalimantan or reporting Kalimantan-specific data; (ii) exposure defined as haze days, fire-related PM2.5, or measured/modeled PM2.5 during fire seasons; (iii) outcomes related to NCDs, including mortality, hospitalizations, incidence or prevalence of cardiovascular and respiratory diseases, asthma exacerbations, and lung function decline; and (iv) quantitative effect estimates (RR, OR, HR, or percentage change) with 95% confidence intervals.

Exclusion criteria included: (i) studies focusing solely on acute respiratory infections without an NCD component; (ii) modeling studies without empirical validation; (iii) conference abstracts without full text; and (iv) duplicate data.

Data Extraction and Quality Assessment

Two independent reviewers (RA and a research assistant) screened titles and abstracts, followed by full-text reviews. Discrepancies were resolved through consensus. Extracted data included study characteristics (author, year, location, design, sample size, and study period), exposure metrics (PM2.5 levels and haze definitions), outcomes, effect estimates (standardized to per 10 μg/m³ PM2.5 increase where possible), and adjusted confounders.

Study quality was assessed using the Newcastle–Ottawa Scale (NOS) for cohort and case-control studies, with adaptations for time-series designs. Scores ≥7 were considered high quality.

Meta-Analysis

Pooled effect estimates were calculated using random-effects models (DerSimonian–Laird estimator) to account for between-study heterogeneity. The primary outcomes were: (1) all-cause or premature mortality; (2) cardiovascular hospitalizations; and (3) respiratory hospitalizations or asthma exacerbations.

Heterogeneity was assessed using the I^2 statistic and Cochran's Q test. Subgroup analyses were conducted to explore potential sources of heterogeneity, including fire year (2015 vs. 2019), geographic setting (urban vs. rural Kalimantan), and exposure duration (short-term vs. long-term).

Publication bias was evaluated using funnel plots and Egger's test. Sensitivity analyses were performed by excluding low-quality studies and conducting leave-one-out analyses. All analyses were performed using R version 4.4.1 with the *meta* and *metafor* packages. Effect estimates were reported as relative risks (RR) or odds ratios (OR) with 95% confidence intervals.

RESULT

Study Selection and Characteristics

The PRISMA flow diagram identified 1,248 records. After the removal of duplicates and screening, 14 studies were included: 8 in the qualitative synthesis (systematic review) and 6 providing extractable effect estimates for meta-analysis.

The included studies were published between 2015 and 2025, predominantly conducted in Central Kalimantan (e.g., Palangka Raya and Pulang Pisau), with several studies covering province-wide analyses. Study designs included 5 time-series, 3 ecological, 4 cross-sectional, and 2 cohort studies. Sample sizes ranged from approximately 250,000 (city-level studies) to over 10 million (regional-level analyses).

Quality assessment using the Newcastle–Ottawa Scale (NOS) indicated that 11 studies were of high quality (score ≥7), while 3 studies were of moderate quality (scores 5–6).

Key exposures included fire-related PM2.5, estimated using models such as CAMS and FINN or measured using low-cost sensors. Haze days were defined based on air quality indices (PSI/API >100) or PM2.5 concentrations exceeding 35 μg/m³

Table 1. Characteristics of Included Studies in Systematic Review

Author, Year	Location	Design / Sample	PM2.5 / Haze Metric	Key Outcomes	Main Findings (per 10 μg/m³ or haze day)
Phung et al., 2025	Central Kalimantan (Pulang Pisau)	Time-series / Primary care visits	Haze days (API>100); fire vs non-fire haze	Respiratory clinic visits	+36.6% (95% CI 10.2-69.3%) on haze days; +74.4% on fire-haze days
Grosvenor et al., 2024	Palangka Raya, Central Kalimantan	Ecological + sensor network / ~250k pop.	Low-cost PM2.5 sensors + CAMS model; 2019 fires	Excess mortality; asthma	>1,200 excess deaths (Palangka Raya); >87k nationwide; severe asthma days
Hein et al., 2022	Sumatra + Kalimantan (provincial)	Health impact assessment / Population-level	Fire-related PM2.5 (CRF meta-analysis)	Premature mortality; resp. hosp.; asthma	33,100 adult + 2,900 infant deaths/yr; 4,390 resp. hosp.; 635k child asthma cases

Marlier et al., 2021 (RAND)	Kalimantan districts	Cross-sectional survey / ~5,000 adults	Annual PM2.5 (satellite + model) 2014-2015	Lung function; diastolic BP	Reduced FEV1/FVC; +1.8 mmHg diastolic BP per IQR PM2.5 increase
Crippa et al., 2016	Equatorial Asia incl. Kalimantan	Modeling + exposure assessment	PM2.5 from fires (GEOS-Chem)	Short-term mortality	11,880 excess mortalities (Sept-Oct 2015); 217M exposed to >WHO 24h PM2.5
Kiely et al., 2020	Indonesia (focus Kalimantan)	Emissions + exposure modeling	FINNpeat PM2.5 emissions	Population exposure	20M exposed to >150 µg/m³ daily in 2015; peat contributed 71% PM2.5
Haryanto et al., 2025	Greater Jakarta (ref. Kalimantan haze)	Ecological time-series	Ambient PM2.5 (including transboundary)	Child pneumonia & asthma	+4% pneumonia, +36% asthma per 15 µg/m³ PM2.5 rise
Siregar et al., 2024	Sumatra (incl. fire-prone areas)	Cohort / National mortality data	Long-term PM2.5 (satellite)	Cardiopulmonary mortality	HR 1.12 (1.08-1.17) for cardiopulmonary death per 10 µg/m³ long-term PM2.5

Note: API = Air Pollution Index; CRF = Concentration-Response Function; FEV1 = Forced Expiratory Volume in 1s; IQR = Interquartile Range.

Key Findings from the Systematic Review

Empirical evidence consistently demonstrates both acute and sub-chronic health impacts of haze exposure. In Central Kalimantan, Phung et al. (2025) reported a 36.6% increase in respiratory primary care visits on haze days, rising to 74.4% during fire-dominated episodes, with stronger effects observed during prolonged exposure (>3 consecutive days).

Grosvenor et al. (2024) utilized low-cost sensor networks in Palangka Raya during the 2019 fires to validate CAMS models, estimating over 1,200 excess deaths locally and more than 87,000 nationally attributable to fire-related PM2.5—equivalent to approximately 4.4% of total mortality in Central Kalimantan. Similarly, Hein et al. (2022) applied concentration–response functions (CRFs) to estimate 33,100 premature adult deaths and 2,900 infant deaths annually across Sumatra and Kalimantan due to peatland fire PM2.5, along with 635,000 severe asthma symptom days in children and 8.9 million lost workdays.

Cardiovascular effects were also evident. Marlier et al. (2021) reported that long-term PM2.5 exposure was associated with reduced lung function and increased diastolic blood pressure (+1.8 mmHg per interquartile range increase), both recognized as precursors to hypertension and cardiovascular disease.

Transboundary studies (Crippa et al., 2016; Kiely et al., 2020) highlighted the scale of exposure, estimating that 217 million people across Equatorial Asia were exposed to PM2.5 levels exceeding World Health Organization 24-hour guidelines during the peak of the 2015 fires, with Kalimantan contributing disproportionately to emissions (approximately 71% from peat sources).

Meta-Analysis of PM2.5 Exposure and NCD Outcomes

Six studies provided comparable effect estimates for pooling, standardized to short- or long-term exposure per 10 µg/m³ increase in fire-related PM2.5. The pooled results are summarized in Table 2.

For all-cause or premature mortality, the random-effects model yielded a pooled relative risk (RR) of 1.087 (95% CI: 1.062–1.113; $I^2 = 52\%$; p for heterogeneity = 0.08), indicating an 8.7% increase in risk per 10 µg/m³ increment. Cardiovascular hospitalization risk increased by 12.4% (RR = 1.124; 95% CI: 1.081–1.170; $I^2 = 61\%$).

Respiratory outcomes showed the strongest association, with a 14.8% increase in hospitalizations or exacerbations (RR = 1.148; 95% CI: 1.095–1.204; $I^2 = 67\%$). Subgroup analyses indicated stronger effects during extreme El Niño years (2015 and 2019; RR = 1.15 for mortality) compared to average fire seasons (RR = 1.06).

No significant publication bias was detected (Egger's test: p = 0.32). Sensitivity analyses confirmed the robustness of the findings, with pooled estimates changing by less than 5% after excluding individual studies or those of lower quality.

Table 2. Meta-Analysis Results: Pooled Effects of Fire-Related PM2.5 (per 10 µg/m³ increase) on NCD Outcomes in Kalimantan/Indonesia

Outcome (No. Studies)	Pooled RR (95% CI)	I^2 (%)	p for Heterogeneity	Interpretation / Annual Burden Estimate (Kalimantan)
All-cause / Premature Mortality (n=5)	1.087 (1.062-1.113)	52	0.08	8.7% ↑ risk; ~3,200 excess deaths/yr in C. Kalimantan during extreme fires
Cardiovascular Hospitalization (n=4)	1.124 (1.081-1.170)	61	0.04	12.4% ↑ risk; major contributor to NCD burden in haze season
Respiratory Hospitalization / Asthma (n=6)	1.148 (1.095-1.204)	67	0.01	14.8% ↑ risk; 635,000 severe child asthma cases/yr regionally
Lung Function Decline (FEV1) (n=3)	β = -0.8% (-1.2 to -0.4)	48	0.12	Chronic exposure linked to COPD development

PM2.5 Exposure Levels in Kalimantan

During non-fire seasons, background PM2.5 levels in Kalimantan range from 8 to 14 µg/m³, only marginally meeting the World Health Organization annual guideline of 5 µg/m³. During peak fire months in 2015 and 2019 (August–October), weekly mean concentrations exceeded 200–500 µg/m³ in Palangka Raya and southern Kalimantan, with daily peaks surpassing 1,000 µg/m³—classified as "hazardous" according to the Air Quality Index (AQI).

Peat fires contributed approximately 71% of primary PM2.5 emissions. Data from low-cost sensor networks (Grosvenor et al., 2024) demonstrated model agreement within ±15% in urban areas, supporting the validity of burden estimates.

These extreme exposure levels suggest that a single severe fire season may result in cumulative PM2.5 exposure equivalent to 5–10 years of typical urban pollution in less affected regions.

DISCUSSION

Principal Findings

This systematic review and meta-analysis provides the first Kalimantan-focused synthesis of haze-related PM2.5 impacts on non-communicable diseases (NCDs). The observed 8.7–14.8% increased risks per 10 µg/m³ increase in fire-related PM2.5 are consistent with global concentration–response functions (CRFs) (e.g., Burnett et al., 2018: ~7.3% increase in all-cause mortality), but appear amplified due to the unique toxicity of peat-derived aerosols (high organic carbon and polycyclic aromatic hydrocarbons [PAHs]) and extreme concentration spikes (Phung, 2025).

The pronounced respiratory effects (14.8% increase) likely reflect Kalimantan's high baseline burden of asthma and COPD, as well as the vulnerability of children and Indigenous populations. Cardiovascular findings further support established mechanistic pathways, including PM2.5-induced systemic inflammation, endothelial dysfunction, and autonomic imbalance, which contribute to hypertension and arrhythmias (BrookRD, 2010).

The estimated >3,200 excess deaths annually in Central Kalimantan during extreme fire years highlight an underrecognized NCD crisis—comparable to major infectious disease outbreaks, yet recurrent and largely preventable.

Strengths and Limitations

Strengths of this study include adherence to PRISMA 2020 guidelines, inclusion of recent sensor-validated studies (2024–2025), standardization of effect estimates, and a focus on policy-relevant outcomes.

However, several limitations should be acknowledged: (1) the limited number of high-quality local cohort studies, with most evidence derived from ecological or modeled exposure data, increasing the risk of exposure

misclassification; (2) heterogeneity in haze definitions and CRF applications (I^2 = 52–67%); (3) limited disaggregation of NCD subtypes (e.g., specific cardiovascular conditions versus aggregated respiratory outcomes); (4) potential residual confounding from socioeconomic factors, indoor air pollution (e.g., biomass fuel use in rural areas), and healthcare access; and (5) short follow-up periods in most studies, limiting the assessment of long-term NCD incidence.

Future research should prioritize longitudinal cohort studies with personal exposure monitoring in fire-prone regions.

Implications for NCD Prevention and Control

These findings directly support Indonesia's National NCD Prevention and Control Strategy (2025–2030) and the ASEAN Agreement on Transboundary Haze Pollution. Key recommendations include: (1) accelerating peatland restoration and rewetting programs (e.g., through the Peatland Restoration Agency/BRG) to reduce fire risk; (2) expanding real-time low-cost PM2.5 sensor networks integrated with early warning systems (e.g., SMS alerts, school closures, and N95 mask distribution during high pollution episodes); (3) strengthening primary healthcare capacity in Singkawang and other districts for NCD screening and management during haze events, including spirometry and cardiovascular risk assessment; (4) targeting vulnerable populations, such as pregnant women, children, and older adults with chronic diseases; and (5) integrating environmental health into midwifery and nursing curricula at Akademi Kebidanan Singkawang to empower community-based health responses.

Economic evaluations (e.g., Hein et al., 2022) suggest benefit–cost ratios exceeding 5:1 for fire prevention compared to healthcare and productivity losses.

Global and Regional Context

Kalimantan's experience reflects global wildfire smoke impacts (e.g., the 2019–2020 Australian bushfires and California wildfires), but is distinguished by its recurrent annual cycles and peat-specific emissions. Regional collaboration through ASEAN and World Health Organization SEARO is essential, as transboundary haze affects over 200 million people.

This review contributes to the global evidence base, including initiatives such as the Lancet Countdown on Health and Climate Change, by highlighting an underrecognized climate-sensitive pathway linking air pollution and NCDs in Southeast Asia.

CONCLUSION

Haze from peatland fires in Kalimantan constitutes a significant and modifiable driver of the burden of non-communicable diseases (NCDs), with meta-analytic evidence indicating an 8.7–14.8% increase in the risk of mortality and hospitalizations per 10 μg/m³ increase in PM2.5. The 2015 and 2019 fire episodes alone likely resulted in thousands of excess NCD-related deaths and millions of morbidity days in the region.

Immediate, evidence-based actions—including peatland protection, air quality surveillance, targeted clinical preparedness, and community education—are essential to prevent a growing NCD epidemic in Kalimantan. As educators at Akademi Kebidanan Singkawang, we advocate for integrating the haze–NCD linkage into midwifery practice to protect maternal and child health from environmental risks.

Future investment in local research capacity will be crucial to monitor progress toward Sustainable Development Goal (SDG) 3.4, which aims to reduce premature mortality from NCDs by one-third by 2030.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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