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Narrative Review

Open Waste Burning in Indonesia: Pulmonary Toxicity, Injury Mechanisms, and Clinical Challenges

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Abstract: Open waste burning is a widespread but underrecognized source of air pollution, particularly where waste services are inadequate. This narrative review aimed to synthesize evidence on the scale and drivers of open waste burning, emission toxicology, mechanisms of lung injury, respiratory effects, clinical management, and public-health implications, with relevance to Indonesia. PubMed/MEDLINE, Scopus, ScienceDirect, Google Scholar, and relevant institutional sources were searched. Evidence was classified into three tiers: direct waste-burning evidence, analogous combustion-exposure evidence, and broader air-pollution evidence. Open waste burning releases particulate matter, black carbon, polycyclic aromatic hydrocarbons, volatile organic compounds, metals, dioxins, and furans, which may promote oxidative stress, epithelial barrier dysfunction, impaired mucociliary defense, immune activation, and airway remodeling. Available evidence indicates potential acute respiratory symptoms and exacerbation of existing respiratory disease, although direct epidemiological evidence remains limited. No exposure-specific biomarker or treatment protocol has been established. Clinical management should therefore emphasize exposure history, syndrome-based care, and exposure reduction, while public-health measures should prioritize improved waste services and source control. The review is limited by heterogeneous evidence and the scarcity of exposure-linked human studies. Prospective studies are needed to quantify respiratory burden and evaluate intervention benefits.

Keywords: Air pollution; Lung injury; Indonesia; Respiratory health; Particulate matter; Open waste burning.

Introduction

Rapid urbanization, population growth, and changing consumption patterns have increased the challenge of municipal solid waste management, particularly in low- and middle-income countries with inadequate collection and treatment infrastructure. In Indonesia, persistent limitations in waste-management systems have prompted efforts to improve collection, treatment, and disposal services (World Bank, 2019). Under these conditions, open waste burning—the uncontrolled combustion of household or municipal waste—may become a practical disposal practice where formal systems are insufficient. The World Health Organization (WHO) recognizes open waste burning as an important source of air pollution with adverse health and environmental consequences (World Health Organization, 2025). Ambient air pollution remains a major global health problem, causing an estimated 4.2 million premature deaths worldwide in 2019 (World Health Organization, 2024b). In Indonesia, open burning remains common; Riskesdas 2013 reported that approximately one in two households practiced open burning of solid waste (Irianti & Prasetyoputra, 2019). Evidence from Semarang also indicates its persistence despite formal collection services, with 88.6% of uncollected waste estimated to be openly burned (Ramadan et al., 2023). These findings suggest that open waste burning

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may represent a recurrent source of localized air-pollution exposure.

Unlike the episodic regional haze associated with vegetation and peatland fires, open waste burning commonly occurs at household, community, and informal-disposal-site levels, producing localized exposure in residential and peri-urban areas (Phung et al., 2022; World Health Organization, 2025; Ramadan et al., 2023). Waste contains heterogeneous materials, including plastics, metals, paper, and organic matter, which can generate complex emissions during uncontrolled combustion (World Health Organization, 2025). Potential pollutants include particulate matter, black carbon, polycyclic aromatic hydrocarbons (PAHs), volatile organic compounds (VOCs), metals, dioxins, and furans. Plastic waste is of particular concern because its uncontrolled combustion may release hazardous combustion products (Pathak et al., 2023). Thus, open waste burning represents a heterogeneous multipollutant exposure rather than exposure to a single pollutant.

The respiratory tract is a major target of these emissions. Fine particulate matter can penetrate deeply into the lungs and is associated with respiratory morbidity and mortality (World Health Organization, 2024a, 2024b). Particulate matter may promote oxidative stress, inflammation, and airway epithelial dysfunction (Cooper & Loxham, 2019), while air pollutants can disrupt the epithelial barrier and contribute to respiratory disease development or exacerbation (Aghapour et al., 2022). PAHs and other combustion-derived compounds may further affect respiratory function through multiple toxicological pathways (Låg et al., 2020). These mechanisms provide biological plausibility for respiratory symptoms and exacerbation of pre-existing disease, although the extent to which such effects are specifically attributable to open waste burning remains uncertain.

Despite its potential health significance, evidence linking quantified open waste-burning exposure with specific respiratory outcomes remains limited, particularly in Indonesia. Existing research is fragmented across waste management, exposure assessment, toxicology, and broader air-pollution epidemiology, while clinical evidence is largely derived from general particulate pollution or other combustion exposures. Consequently, an evidence gap remains between the characterization of waste-burning emissions and their interpretation in respiratory health and clinical care. No widely established clinical guideline or exposure-specific biomarker is currently available for respiratory disease specifically associated with open waste burning. This review therefore distinguishes direct waste-burning evidence from analogous combustion and broader air-pollution evidence.

This narrative review integrates evidence on the scale and drivers of open waste burning, emission composition and toxicology, molecular and cellular mechanisms of respiratory injury, epidemiological and clinical effects, and implications for clinical management and prevention. Unlike reviews focused primarily on environmental or waste-management aspects, this review connects waste combustion with pollutant generation, biological mechanisms, respiratory outcomes, and clinical response. Evidence is categorized into three tiers—direct waste-burning evidence, analogous combustion-exposure evidence, and broader air-pollution evidence—to clarify its strength and applicability. The review aims to characterize the respiratory implications of open waste burning, evaluate current clinical and preventive approaches, and identify priorities for future exposure-linked research in Indonesia.

Methods

Review Design

This study was conducted as a narrative review using a structured and reproducible literature search to synthesize evidence on open waste burning, waste-burning-derived air pollution, emission toxicology, mechanisms of lung injury, respiratory health outcomes, and clinical management. A narrative review approach was selected because the available evidence is heterogeneous in terms of disciplines, exposure definitions, study designs, and health outcomes, encompassing environmental science, exposure assessment, toxicology, epidemiology, and clinical research. The search strategy was designed to improve transparency and reduce selective identification of evidence by using predefined databases, search concepts, eligibility considerations, and an evidence-classification framework. Sources were identified from

PubMed/MEDLINE, Scopus, ScienceDirect, Google Scholar, and relevant institutional sources, with search concepts combining terms related to open waste burning, waste combustion, air pollution, respiratory health, toxic emissions, lung injury, and clinical management. Retrieved evidence was screened for relevance to the review objectives and synthesized narratively rather than statistically.

As a quality-assurance measure, evidence was explicitly classified into three tiers according to its directness to the review question: (1) direct evidence derived from open waste-burning exposure or waste-burning emissions; (2) analogous combustion-exposure evidence from chemically or environmentally related combustion sources; and (3) broader air-pollution evidence used to support biological mechanisms or general respiratory effects. Conclusions were based preferentially on direct evidence, while findings from the second and third tiers were identified as extrapolated evidence rather than presented as direct evidence of health effects from open waste burning.

The review does not claim to provide a systematic review, formal risk-of-bias assessment, pooled effect estimates, or causal effect estimates. Its conclusions are therefore limited by the heterogeneous nature of the underlying literature, the scarcity of exposure-specific human studies, differences in exposure characterization and outcome measurement, and the need to extrapolate from related combustion and air-pollution evidence where direct data are unavailable. The review is intended to provide an evidence-integrating clinical and public-health framework and to identify priorities for future exposure-linked research rather than to establish definitive causal or quantitative estimates of respiratory risk.

Information Sources and Search Strategy

A literature search was conducted using PubMed/MEDLINE, Scopus, ScienceDirect, and Google Scholar. Grey literature and relevant institutional reports were additionally identified from international and national organizations, including the World Health Organization (WHO), United Nations Environment Programme (UNEP), World Bank, and the Indonesian Ministry of Environment and Forestry.

The search strategy combined terms related to exposure, respiratory outcomes, toxicology, geographic context, and biological mechanisms. Core search terms included “open waste burning”, “municipal solid waste burning”, “backyard burning”, “informal waste burning”, “dumpsite fire”, and “landfill fire”. These terms were combined with respiratory terms including “lung”, “pulmonary”, “respiratory”, “asthma”, and “COPD”; toxicological terms including “particulate matter”, “dioxin”, “furan”, “polycyclic aromatic hydrocarbon”, “volatile organic compound”, and “toxicology”; and geographic terms including “Indonesia” and “Southeast Asia”.

Additional searches incorporated related combustion exposures, including biomass smoke, wildfire smoke, and combustion-derived particulate matter, together with mechanistic terms such as “oxidative stress”, “airway epithelial injury”, “barrier dysfunction”, “airway inflammation”, and “NLRP3 inflammasome”. These supplementary searches were used to identify mechanistic, epidemiological, and clinical evidence when direct evidence specific to open waste burning was limited.

Eligibility Criteria

No lower publication-date limit was applied. The final literature search was conducted in July 2026. Publications in English or Indonesian were included. Recent evidence was prioritized where available, while older studies were retained when they provided seminal or directly relevant evidence. Eligible sources comprised original toxicological studies, exposure-assessment studies, epidemiological studies, clinical studies, systematic reviews, narrative reviews, and reports from governmental or internationally recognized organizations.

Studies were eligible if they directly investigated open waste burning, municipal or household waste combustion, dumpsite or landfill fires, or the respiratory effects of emissions generated by these sources. Studies examining related combustion exposures were also considered when they provided relevant evidence regarding pollutant toxicity, biological mechanisms of lung injury, respiratory health effects, or clinical management.

Studies were excluded if they were unrelated to waste-burning emissions or the respiratory objectives of the review, lacked sufficient relevance to the review questions, or did not provide meaningful information regarding exposure, toxicology, mechanisms, clinical outcomes, or management. Sources for which the origin or relevant information could

not be adequately verified were also excluded.

Evidence Selection and Synthesis

Given the heterogeneity of the available literature and the limited number of studies directly examining the clinical consequences of open waste burning, a tiered evidence approach was used. Evidence was classified into three levels according to its proximity to the primary exposure of interest.

The first tier comprised direct evidence from studies specifically investigating open waste burning, household or municipal waste combustion, dumpsite or landfill fires, and related waste-burning emissions. The second tier included evidence from analogous combustion exposures, such as biomass smoke, wildfire smoke, and other sources of combustion-derived air pollution, when used to support mechanistic, epidemiological, or clinical interpretation. The third tier consisted of evidence extrapolated from the broader air-pollution literature and established clinical guidance when waste-burning-specific evidence was unavailable.

Throughout the synthesis, direct evidence was distinguished from analogous and extrapolated evidence to avoid overstating the certainty or exposure specificity of the available findings. The evidence was synthesized narratively across environmental, toxicological, mechanistic, epidemiological, and clinical domains, with particular attention to areas supported by direct waste-burning evidence and those that remained dependent on extrapolation from related combustion exposures.

Results and Discussion

The Scale and Drivers of Open Waste Burning in Indonesia

Open waste burning in Indonesia is best understood not merely as an isolated household behavior, but as a manifestation of persistent gaps in solid-waste management. The practice can occur at multiple scales, ranging from the burning of household refuse to the combustion of accumulated waste in streets, informal dumpsites, and landfills (World Health Organization, 2025). Recent nationwide evidence suggests that its magnitude may be substantial. A machine-learning-based national inventory estimated that approximately 26.6 million tonnes of municipal waste are openly burned annually in Indonesia, with residential burning accounting for approximately 70% of the total waste burned (Ramadan et al., 2026). These estimates indicate that open waste burning represents a potentially important and geographically widespread source of air pollution rather than a marginal waste-disposal practice.

The persistence of open waste burning is closely linked to limitations in formal waste collection and disposal systems. Where regular, affordable, and accessible waste services are unavailable or inadequate, burning may become a practical means of reducing accumulated waste at the household or community level. Open burning may also be motivated by convenience and by the desire to reduce waste volume, odors, and pest problems associated with accumulated refuse (AQMx, 2025). Consequently, the practice should be viewed partly as a downstream consequence of structural deficiencies in waste management rather than solely as an individual behavioral choice. This interpretation is supported by evidence from Semarang, where open burning remained the second most common household waste-disposal practice even after formal waste-collection services had been introduced, and an estimated 88.6% of uncollected waste was openly burned (Ramadan et al., 2023). These findings suggest that the presence of a collection system alone may be insufficient if service coverage, accessibility, reliability, or household participation remains inadequate.

The spatial distribution of open waste burning is also unlikely to be uniform across Indonesia. The recent nationwide inventory identified substantial geographic clustering, with a considerable burden concentrated in densely populated provinces, particularly on Java (Ramadan et al., 2026). At a more local scale, the Semarang study found higher open-burning intensity in rural and outer urban areas, illustrating how inadequate service coverage and local waste-management practices can produce important variation even within a single metropolitan region (Ramadan et al., 2023). Open waste burning should therefore not be considered exclusively a rural or urban phenomenon. Instead, it may occur across the urban–peri-urban–rural continuum, with the magnitude and characteristics of exposure determined by population density, waste generation, access to formal collection, and local disposal practices.

The temporal characteristics of this exposure remain less well defined. Unlike major

landscape-fire events, which often occur episodically and are strongly influenced by climatic conditions, household and community waste burning can occur repeatedly as waste accumulates. However, the frequency and seasonality of open waste burning may vary according to local waste-generation patterns, collection schedules, weather conditions, and community practices, and a consistent nationwide temporal pattern has not yet been established (AQMx, 2025). This evidence gap is important because recurrent local burning may create intermittent or repeated near-source exposure that is not adequately captured by monitoring systems designed primarily to identify large regional air-pollution episodes.

This exposure pattern distinguishes open waste burning from the peatland and forest-fire haze that has traditionally dominated discussion of haze-related health effects in Indonesia. Tropical peatland-fire haze can affect extensive geographic areas, with severe episodes strongly associated with drought and El Niño conditions (Kuwata, 2024). Open waste burning, by contrast, commonly originates from numerous smaller sources at the household, neighborhood, dumpsite, or landfill level (World Health Organization, 2025). Its emissions may therefore produce more localized and recurrent exposure, particularly among individuals living or working close to burning sites. The distinction is clinically and epidemiologically important: large-scale peatland-fire haze may produce identifiable episodes of population-wide exposure, whereas waste-burning exposure may be less visible, more spatially heterogeneous, and potentially overlooked during routine assessment of patients with respiratory symptoms.

Composition and Toxicology of Waste-Burning Emissions

Open waste burning produces a chemically heterogeneous emission mixture because household waste typically contains plastics, metals, cardboard, paper, polystyrene, organic matter, and sometimes demolition waste, household chemicals, or tyres (World Health Organization, 2025). WHO states that the emissions from open waste burning include a variety of air pollutants that can harm both health and climate, while uncontrolled waste incineration and open burning are recognized sources of toxic by-products such as dioxins and furans (World Health Organization, 2025; World Health Organization, 2023). In practice, this means that waste-burning smoke should be understood not as a single-pollutant exposure, but as a complex multipollutant mixture whose composition varies according to waste type and combustion conditions (World Health Organization, 2025; Pathak et al., 2023).

The major pollutant classes associated with open waste burning include particulate matter ($PM_{2.5}$, PM_{10}, and ultrafine particles), black carbon, volatile organic compounds (VOCs), polycyclic aromatic hydrocarbons (PAHs), heavy metals, dioxins, furans, and dioxin-like PCBs (Ramadan et al., 2023; Kumari et al., 2019; World Health Organization, 2023; Pathak et al., 2023). In a study of household waste burning in Semarang, plastic burning contributed the highest emission share among waste components, and open waste burning was associated with PM, black carbon, PAHs, and metal-related contaminants (Ramadan et al., 2023). A study of open burning of municipal solid waste in India likewise reported emissions of major pollutants including dioxins, furans, particulate matter, and other hazardous compounds, reinforcing the view that waste burning is a substantial source of toxic air pollution rather than a benign disposal strategy (Kumari et al., 2019). Open burning of solid waste has also been shown to release VOCs and heavy metals into surrounding communities, further expanding the toxicological burden of exposure (Popoola et al., 2023).

Waste-type-specific emission profiles matter because the toxic output changes with what is being burned. Plastic-containing waste is especially concerning because it can yield higher levels of toxic organic by-products, including PAHs and dioxin-related compounds, while mixed municipal waste can emit a broader combination of PM, black carbon, VOCs, and metal-bound particulates (Ramadan et al., 2023; Pathak et al., 2023). WHO also notes that uncontrolled waste incineration is a major route for dioxin release, and that dioxins are highly toxic persistent organic pollutants with long biological half-lives and broad systemic effects (World Health Organization, 2023). Because household waste streams are usually mixed and uncontrolled, real-world open burning is likely to generate variable and often unpredictable pollutant profiles rather than a single reproducible chemical signature (World Health Organization, 2025).

From a respiratory toxicology perspective, PM is one of the most important harmful

components because it can penetrate deeply into the airway and interact directly with the airway epithelium (Cooper and Loxham, 2019). Air pollutants can disrupt epithelial barrier function, promote oxidative stress, and trigger inflammatory signaling in asthma and chronic obstructive lung disease (Aghapour et al., 2022). PAHs are also relevant because exposure has been linked to impaired respiratory function, asthma exacerbation, and increased morbidity and mortality of obstructive lung disease, especially in more vulnerable populations (Låg et al., 2020). Dioxins add a separate toxicological dimension because they are persistent environmental pollutants with recognized effects on the immune system, endocrine system, reproductive function, development, and carcinogenesis (World Health Organization, 2023). Together, these pathways provide a biologically plausible basis for acute and chronic respiratory injury from repeated exposure to waste-burning smoke.

Direct biomonitoring evidence specific to open waste burning remains limited, so current interpretation relies heavily on emission measurements, toxicological plausibility, and mechanistic evidence from related combustion exposures. This is an important limitation because the biological impact of the smoke likely depends on both the pollutant mix and the intensity and frequency of exposure, which can vary across communities and waste streams (Ramadan et al., 2023; Pathak et al., 2023). For this reason, the toxicology of waste burning should be interpreted as a source-dependent exposure problem rather than a uniform disease entity.

Table 1. Major pollutant classes in open waste burning and their toxicological relevance

Pollutant class	Typical relevance in open waste burning	Key toxicological significance
Particulate matter ($PM_{2.5}$, PM_{10}, and ultrafine particles)	Major products of incomplete combustion and among the principal pollutants generated during open waste burning (World Health Organization [WHO], 2025; Ramadan et al., 2023).	Fine and ultrafine particles can penetrate deeply into the respiratory tract and interact with the airway epithelium, contributing to oxidative stress, inflammation, and impaired epithelial function (Cooper & Loxham, 2019).
Black carbon (BC)	A carbonaceous component of combustion-derived particulate matter generated under incomplete-combustion conditions; BC has been reported in emissions associated with household waste burning (Ramadan et al., 2023).	BC is a component of fine particulate matter and an indicator of combustion-related air pollution. Epidemiological and toxicological evidence links exposure to BC-containing particulate pollution with cardiopulmonary morbidity and mortality, although some health effects may reflect the broader PM mixture rather than BC alone (WHO, 2012, 2024).
Volatile organic compounds (VOCs)	Released during incomplete combustion of mixed municipal waste and plastic-containing materials; the specific compounds and concentrations vary with waste composition and combustion conditions (Popoola et al., 2023).	Toxicological effects are compound-specific and may include airway irritation, oxidative stress, inflammation, and systemic toxicity. Therefore, the health significance of VOC exposure should not be generalized across all VOCs.
Polycyclic aromatic hydrocarbons (PAHs)	Produced during incomplete combustion of organic and plastic-containing waste and reported among combustion-derived pollutants (Ramadan et al., 2023; Låg et al., 2020).	Several PAHs are associated with oxidative stress and adverse respiratory effects. Certain PAHs also possess mutagenic and carcinogenic properties, although respiratory risk depends on the specific compounds, exposure concentration, and duration (Låg et al., 2020).
Heavy metals	Metals may be released in particulate form during combustion or remain concentrated in ash and combustion residues. Their occurrence depends strongly on the composition of the waste stream (Popoola et al., 2023; Ramadan et al., 2023).	Toxicological effects are metal-specific and may include respiratory, neurological, renal, developmental, or systemic toxicity depending on the metal and exposure level.

Pollutant class	Typical relevance in open waste burning	Key toxicological significance
Dioxins and furans (PCDDs/PCDFs)	Polychlorinated dibenzo-p-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs) may form during uncontrolled combustion of waste, particularly when combustion conditions are unfavorable and chlorine-containing materials are present (WHO, 2025; WHO, 2019).	Dioxins are persistent organic pollutants (POPs) with high toxic potential. Human exposure has been associated with immunotoxicity, developmental and reproductive effects, endocrine effects, and cancer (WHO, 2019, 2026).
Dioxin-like polychlorinated biphenyls (dl-PCBs)	Certain PCB congeners have toxicological properties similar to dioxins and may occur in contaminated waste streams or be released during combustion of PCB-containing materials. Their occurrence in a particular waste-burning plume should not be assumed without source-specific measurements (WHO, 2019; WHO, 2024).	Dioxin-like PCBs can activate the aryl hydrocarbon receptor and are included in the WHO toxic-equivalency framework for dioxin-like compounds. Exposure has been associated with immunotoxic, developmental, reproductive, endocrine, and carcinogenic effects (WHO, 2019, 2024; IARC, 2015).

Molecular and Cellular Mechanisms of Lung Injury

Direct mechanistic studies of open waste-burning smoke remain limited; therefore, current understanding is largely derived from research on particulate matter (PM), polycyclic aromatic hydrocarbons (PAHs), and other combustion-related pollutants. These pollutants may activate interconnected pathways involving oxidative stress, airway epithelial injury, immune activation, and tissue remodeling (Cooper & Loxham, 2019; Låg et al., 2020; Aghapour et al., 2022). Accordingly, the mechanisms described below represent a biologically plausible framework based partly on analogous air-pollution and combustion evidence, rather than established waste-burning-specific pathways.

Oxidative stress is a key mechanism of pollutant-induced lung injury. Combustion-derived PM can increase reactive oxygen species (ROS), disrupt redox homeostasis, and overwhelm antioxidant defenses, while PAHs may generate reactive intermediates that amplify oxidative and inflammatory responses (Cooper & Loxham, 2019; Låg et al., 2020). Persistent oxidative stress can activate redox-sensitive signaling and promote inflammatory mediator production, particularly in the airway epithelium (Aghapour et al., 2022).

Airway epithelial injury may subsequently impair the respiratory tract's barrier and clearance functions. Air pollutants can disrupt intercellular junctions, increase epithelial permeability, impair mucociliary clearance, and interfere with epithelial repair (Cooper & Loxham, 2019; Aghapour et al., 2022; Kayalar et al., 2024). Repeated injury and abnormal repair may contribute to mucus dysregulation, epithelial plasticity, and airway remodeling. These processes provide a plausible link between recurrent pollutant exposure and chronic respiratory disease, although direct evidence for open waste burning remains insufficient.

Epithelial injury is accompanied by activation of innate immune responses. Particulate exposure can stimulate inflammatory signaling and activate the NLRP3 inflammasome, promoting the maturation and release of interleukin-1β and interleukin-18 (Leszczyńska et al., 2022). Experimental studies have demonstrated particulate-matter-induced activation of NLRP3-related pathways and airway inflammation (Dai et al., 2020; Brugge et al., 2023). Alveolar macrophages also contribute to particle clearance and immune regulation; exposure to particulate pollution may alter their cytokine responses and phagocytic function, potentially resulting in persistent inflammation and impaired pulmonary host defense (Sawyer et al., 2010; Li et al., 2022).

Adaptive immune responses may further amplify airway inflammation, particularly in susceptible individuals. Disruption of the epithelial barrier and pollutant-induced inflammatory signaling may enhance airway hyperresponsiveness and type 2 inflammation, mechanisms relevant to asthma exacerbation (Aghapour et al., 2022; Kayalar et al., 2024). Children and individuals with pre-existing respiratory disease may be more susceptible to

these effects because of developmental or underlying airway factors (Aithal et al., 2023). However, these mechanisms are primarily supported by broader air-pollution evidence and should not be interpreted as direct evidence of a specific effect of open waste-burning exposure.

With recurrent or prolonged exposure, the combined effects of oxidative stress, epithelial injury, inflammatory activation, and abnormal repair may contribute to airway remodeling and impaired pulmonary function (Aghapour et al., 2022; Kayalar et al., 2024). PAHs may further contribute to respiratory morbidity through multiple toxicological pathways (Låg et al., 2020). Nevertheless, long-term pulmonary effects specifically attributable to open waste burning remain poorly quantified. Overall, the available evidence supports a coherent biological pathway from combustion-derived pollutants to oxidative stress, epithelial dysfunction, immune activation, and potential chronic airway injury, but the causal relevance of this pathway to real-world open waste-burning exposure requires further direct investigation.

Clinical and Epidemiological Evidence

Despite the biological plausibility of respiratory injury from open waste burning, direct clinical and epidemiological evidence remains limited and heterogeneous. Available studies include household waste burning, recurrent dumpsite fires, populations near waste-management facilities, and broader combustion-related air pollution. These settings are not directly interchangeable because uncontrolled burning differs from engineered incineration in waste composition, combustion conditions, emission control, and exposure intensity. Therefore, evidence from landfills, incinerators, and broader particulate-pollution studies should be interpreted as supportive or analogous rather than direct evidence of open waste-burning effects.

In Indonesia, Irianti and Prasetyoputra (2019) examined household solid-waste burning and acute respiratory infection (ARI) among children younger than five years using data from the 2013 Indonesian Basic Health Research survey. This study provides important population-level evidence because household waste burning was common and the exposure was directly related to household waste disposal. However, its observational design, potential exposure misclassification, and residual confounding limit causal interpretation. Similarly, Adetona et al. (2020) investigated residents living near the Olusosun dumpsite in Lagos, Nigeria, where recurrent municipal solid-waste fires occurred. Greater potential exposure was associated with more frequent adverse health symptoms, including respiratory symptoms. Its relevance to uncontrolled waste combustion is high, but cross-sectional design, residential proximity as an exposure surrogate, self-reported outcomes, and possible co-exposures limit causal inference.

Broader evidence also indicates potential respiratory effects, although attribution to open burning remains uncertain. Vinti et al. (2021), in a systematic review of health outcomes associated with municipal solid-waste management, identified respiratory conditions among the outcomes reported across exposed populations but highlighted substantial heterogeneity in exposure definitions, study designs, and outcomes. Earlier evidence from populations near waste facilities similarly reported possible adverse health effects but emphasized limitations in exposure assessment and confounding (Porta et al., 2009). More recently, Bottini et al. (2025) found heterogeneous and generally uncertain evidence of respiratory morbidity among populations living near municipal solid-waste incinerators. Because modern incinerators use controlled combustion and emission-control technologies, these findings cannot be directly extrapolated to uncontrolled household or dumpsite burning (Bottini et al., 2025; World Health Organization, 2025).

The most plausible clinical effects are acute respiratory symptoms, including cough, airway irritation, wheezing, and dyspnoea, as well as exacerbation of pre-existing respiratory disease. Children may be particularly susceptible to air-pollution exposure because of developmental and physiological factors (Aithal et al., 2023). Individuals with asthma or COPD may also be vulnerable because particulate and combustion-related pollutants can aggravate airway inflammation (Aghapour et al., 2022; Låg et al., 2020). However, direct estimates of these risks specifically attributable to open waste burning remain scarce. Evidence for chronic outcomes such as accelerated lung-function decline, incident COPD, or persistent airway remodelling is even more limited and is currently supported mainly by indirect mechanistic and environmental evidence (Vinti et al., 2021; Bottini et al., 2025).

Table 2. Summary of clinical and epidemiological evidence relevant to open waste burning and respiratory health

Evidence source	Study design and population (n)	Exposure metric/setting	Respiratory outcome	Effect estimate (95% CI)	Relevance to open waste burning	Major limitations
Irianti & Prasetyoputra (2019)	Population-based cross-sectional analysis using Indonesia Basic Health Research (Riskesdas 2013); children aged <5 years; n = 82,359	Household open burning of solid waste and area-level proportion of households practicing open burning; exposure assessed from survey data	Acute respiratory infection (ARI) in children	In the final multivariable model, higher area-level prevalence of household open burning was associated with ARI (OR = 1.06); household-level open burning was not statistically significant after adjustment	Direct evidence from household open waste burning in Indonesia	Cross-sectional design; exposure and ARI were survey-based; no direct measurement of pollutant concentrations or individual inhaled dose; potential residual confounding and ecological component of the area-level exposure
Adetona et al. (2020)	Cross-sectional community study of residents living near the Olusosun dumpsite, Lagos, Nigeria; sample size based on community survey	Residential proximity/duration of residence near a dumpsite with recurrent municipal solid-waste fires; exposure primarily characterized by residence duration rather than personal pollutant monitoring	Respiratory and other self-reported symptoms; respiratory effects were among the outcomes assessed	Longer residence (≥11 years) was associated with several adverse symptoms; reported ORs included 2.614–3.033 for selected neurological symptoms. A source-specific quantitative estimate for respiratory symptoms was not consistently reported in the abstract	Directly relevant evidence from recurrent open municipal solid-waste combustion	Cross-sectional design; proximity/duration used as exposure surrogate; self-reported outcomes; limited exposure characterization; possible co-exposure to other urban pollutants
Waleed et al. (2023)	Community-based cross-sectional study; n = 844 participants from Khartoum State, Sudan	Self-reported household waste burning; 74.5% (619/831) reported household/neighborhood waste burning	Self-reported asthma and respiratory manifestations	Respiratory manifestations were reported by 38.0% and asthma by 57.0% among respondents reporting health conditions related to waste burning; regression estimates in the study primarily addressed determinants of waste-burning practice rather than respiratory disease risk	Direct evidence from household waste burning	Online questionnaire; cross-sectional design; health outcomes self-reported; no direct pollutant measurements; possible reporting and selection bias; effect estimates for respiratory outcomes were limited
Kret et al. (2018)	Two-stage cluster cross-sectional household health survey; n = 343 completed household interviews (170 landfill, 173 comparison)	Residence near a subsurface smoldering municipal landfill versus comparison areas; exposure based principally on residential proximity	Asthma, COPD, other respiratory conditions, and attacks of shortness of breath	Asthma: 26.7% vs 24.7%; COPD: 13.7% vs 12.5%; other respiratory conditions: 17.6% vs 9.5%; shortness-of-breath attacks: 33.9% vs 17.9% in landfill versus comparison households, respectively	Analogous/directly relevant combustion evidence; landfill smoldering differs from routine household open burning but represents uncontrolled waste combustion	Cross-sectional design; residential proximity rather than individual exposure measurements; self-reported outcomes; potential selection and recall bias; landfill smoldering is not equivalent to household open burning
Vinti et al. (2021)	Systematic review of 29 epidemiological studies covering residents near MSW facilities	Landfills, dumpsites/open-burning sites, incinerators, and other MSW-management facilities; heterogeneous exposure definitions, mainly residential proximity	Respiratory diseases and other health outcomes	No single pooled respiratory effect estimate; the review reported some evidence of increased respiratory disease risk near landfills but emphasized that evidence was inadequate in many cases to establish strong exposure–outcome relationships	Indirect/secondary evidence; useful for contextualizing the broader epidemiological evidence base rather than estimating the risk of open burning specifically	Heterogeneous exposures, facilities, populations, outcomes, and study designs; limited comparability; many studies did not directly measure combustion-related exposure
Bottini et al. (2025)	Systematic review and meta-analysis of epidemiological studies of residential exposure to municipal solid-waste incinerators	Residential exposure to MSW incinerator emissions; exposure categories varied across included studies and included pollutant/proximity-based metrics	Hospitalization for respiratory diseases, COPD, and asthma	Respiratory disease hospitalization: HR 1.02 (95% CI 0.94–1.11); COPD: HR 1.08 (95% CI 0.82–1.41); asthma: HR 1.02 (95% CI 1.00–1.05)	Analogous evidence only; controlled MSW incineration differs substantially from uncontrolled open waste burning	Low exposure levels relative to uncontrolled burning; heterogeneous exposure definitions and combustion technologies; moderate heterogeneity for several outcomes; evidence does not directly quantify risk from open burning

Exposure and susceptibility may also vary among population groups. Residents near recurrent burning sites and informal waste workers may experience repeated or occupational exposure, while children, older adults, and individuals with pre-existing respiratory disease may be more susceptible to air-pollution effects (Adetona et al., 2020; World Health Organization, 2025; Aithal et al., 2023; Aghapour et al., 2022). Nevertheless, the magnitude of risk in these groups remains poorly quantified because few studies combine individual-level exposure measurements with objective respiratory outcomes. In Indonesia, attribution is further complicated by co-exposure to cigarette smoke, biomass fuel, traffic pollution, landscape-fire haze, and occupational pollutants (Schikowski et al., 2008). Overall, current evidence supports concern regarding respiratory effects of open waste burning but does not yet allow a reliable quantification of its attributable respiratory burden or establishment of exposure-specific risk thresholds.

Interpretation of the current evidence is constrained by several recurring methodological limitations. Exposure is often classified using self-reported burning behavior or residential proximity rather than personal monitoring or source-specific biomarkers. Definitions of "waste burning" vary substantially between studies and may encompass household refuse burning, dumpsite fires, landfill fires, or controlled incineration, despite major differences in their emission profiles. Cross-sectional designs are common, limiting temporal and causal inference, while respiratory outcomes are frequently self-reported rather than confirmed through spirometry, medical records, or longitudinal follow-up. Confounding by smoking, socioeconomic status, occupational exposure, household air pollution, traffic emissions, and other combustion sources further complicates interpretation (Vinti et al., 2021; Bottini et al., 2025).

Overall, the clinical and epidemiological literature supports concern but does not yet provide a precise estimate of the respiratory disease burden attributable specifically to open waste burning. The strongest relevance comes from direct household-burning and dumpsite-fire studies, while evidence from landfills, incinerators, and broader air-pollution research provides progressively more indirect support. This pattern reinforces the tiered evidence framework used in this review: direct evidence should be prioritized, analogous evidence should be clearly identified, and clinical extrapolation should not be presented as waste-burning-specific proof. The current evidence is sufficient to justify clinical awareness and further investigation, but not to define a unique waste-burning-associated respiratory syndrome or establish exposure-specific diagnostic criteria.

Clinical Approach and Management

At present, no clinical guideline specifically addresses respiratory disease associated with open waste-burning exposure. Therefore, the recommendations in this review should be considered a pragmatic, evidence-informed framework, rather than a validated waste-burning-specific clinical guideline. Management should emphasize recognition of relevant exposure, assessment of respiratory manifestations, treatment according to the established clinical syndrome, and reduction of further exposure. Because waste-burning smoke is a heterogeneous multipollutant mixture without a specific diagnostic biomarker or pathognomonic clinical presentation, exposure history should be interpreted as a potential contributing environmental factor rather than sufficient evidence of causation (World Health Organization, 2025).

Clinical recognition should begin with an environmental and occupational exposure history, including household or neighborhood burning, residence near recurrently burning dumpsites or landfills, and occupational contact with burning waste. Clinicians should document the type of source, materials burned when known, proximity, frequency and duration of exposure, and temporal relationships between exposure and symptoms. Important co-exposures, including cigarette smoke, biomass fuel, traffic pollution, occupational dust or fumes, and regional haze, should also be considered. Clinical assessment should be based primarily on the presenting syndrome, including symptom severity, respiratory rate, oxygen saturation, work of breathing, and relevant physical findings. Severe dyspnoea, hypoxaemia, altered mental status, haemodynamic instability, or rapidly worsening symptoms require urgent evaluation. Spirometry may be considered for persistent or recurrent symptoms, particularly when asthma or chronic obstructive pulmonary disease (COPD) is suspected, in accordance with established disease-specific guidelines (Global Initiative for Asthma, 2026; Global Initiative for Chronic

Obstructive Lung Disease, 2026). Chest imaging should be guided by clinical indications rather than exposure history alone.

No specific pharmacological treatment or antidote has been established for open waste-burning exposure. Respiratory manifestations should therefore be managed according to the underlying diagnosis and disease severity. Asthma and COPD exacerbations should follow current GINA and GOLD recommendations, respectively (Global Initiative for Asthma, 2026; Global Initiative for Chronic Obstructive Lung Disease, 2026). Bronchodilators, systemic corticosteroids, antibiotics, and supplemental oxygen should not be administered solely because of waste-burning exposure but according to established clinical indications. Long-term care should similarly focus on guideline-directed management of established respiratory disease, assessment of disease control, inhaler technique, follow-up, and reduction of recurrent exposure. Routine biomarker testing, imaging, or pulmonary-function testing solely because of exposure is not currently supported by waste-burning-specific evidence.

Exposure reduction is the principal preventive measure. Patients should be advised to avoid burning waste, minimize proximity and duration of exposure, and reduce indoor infiltration of smoke when burning occurs nearby. WHO emphasizes source reduction and improved waste management as key approaches, while personal interventions may provide additional exposure reduction but cannot replace source control (World Health Organization, 2025; World Health Organization, 2024a). Air-cleaning devices may reduce indoor particulate exposure during smoke episodes, although much of the supporting evidence comes from wildfire and ambient-pollution settings and should therefore be regarded as analogous rather than waste-burning-specific evidence (World Health Organization, 2024a). Similarly, well-fitted particulate respirators may reduce particle inhalation but do not remove all gaseous pollutants and should be considered a supplementary measure, particularly for unavoidable high-exposure activities (World Health Organization, 2024a, 2025). This consideration is particularly relevant to informal waste workers who may experience repeated occupational exposure.

Air-quality information can support exposure counselling, particularly for patients with asthma or COPD, but conventional regional monitoring may not capture highly localized emissions from nearby waste burning (World Health Organization, 2025; Ramadan et al., 2023). Clinicians should therefore combine available air-quality information with the patient's proximity to burning, activity pattern, duration of exposure, and temporal relationship between exposure and symptoms. Overall, the clinical approach proposed here integrates direct evidence on open waste burning, disease-specific guidance from GINA and GOLD, and analogous exposure-reduction evidence from WHO and broader combustion-smoke literature. Given the absence of validated waste-burning-specific diagnostic or treatment protocols, these recommendations should be interpreted as a pragmatic framework for exposure recognition, syndrome-based management, and prevention rather than as a dedicated clinical guideline.

Public Health and Policy Implications

The persistence of open waste burning in Indonesia indicates that its respiratory health consequences cannot be addressed through clinical management or individual behavior change alone. Because burning frequently occurs where waste collection and disposal services are inadequate, the most relevant public-health response is to reduce exposure at its source. Four complementary priorities are particularly relevant to respiratory health: upstream source control, adequate service coverage, exposure and health surveillance, and multisectoral action.

Upstream source control. Preventing open waste burning should be prioritized over managing its downstream health consequences. WHO identifies the reduction and elimination of open waste burning as an important intervention for reducing air pollution and associated health risks, with additional environmental and climate benefits (World Health Organization, 2025). In practice, source control requires feasible alternatives to burning, including waste reduction, separation, collection, treatment, and safe disposal. Regulatory restrictions on open burning are therefore more likely to be effective when accompanied by accessible disposal alternatives and locally appropriate waste-management systems. Evidence from Indonesia indicates that burning may persist even where formal collection services exist, emphasizing that source control depends not only on service availability but also on accessibility, reliability, affordability, and community participation (Ramadan et al., 2023).

Service coverage. Expansion of reliable waste services is an upstream intervention with potential respiratory-health benefits because it can reduce the need for households and communities to dispose of residual waste through uncontrolled combustion. World Bank assessments have identified gaps in waste collection and management in many low- and middle-income settings, including Indonesia (World Bank, 2021). However, improvements in infrastructure should not be assumed to automatically reduce exposure. Waste-service programmes should incorporate measurable indicators of collection coverage, residual waste disposal, and open-burning frequency so that reductions in burning and associated exposure can be evaluated rather than inferred. Community-based collection, waste separation, and recycling initiatives may complement municipal services, but should not substitute for adequately funded collection, treatment, and final-disposal systems.

Surveillance. Environmental and respiratory surveillance should be strengthened to identify populations and locations in which recurrent waste-burning exposure may be clinically relevant. Current epidemiological evidence is limited by heterogeneous exposure assessment and difficulty distinguishing waste-burning exposure from other sources of air pollution (Vinti et al., 2021). Integrating questions on household, neighborhood, and occupational waste-burning exposure into selected respiratory health surveys could improve exposure characterization. Where feasible, health surveillance can be linked with air-quality measurements, waste-service coverage, and spatial information on burning activity to identify geographic or occupational patterns. Such surveillance should be considered primarily a tool for exposure characterization, burden assessment, and intervention evaluation, rather than evidence that waste burning is the sole cause of individual respiratory disease.

Multisectoral action. Open waste burning involves interacting waste-management, environmental, public-health, and social determinants and therefore requires coordination across sectors. Local governments and waste-service authorities have primary roles in collection and disposal; environmental agencies contribute emission and air-quality monitoring; and the health sector can identify respiratory morbidity, strengthen exposure history-taking, and contribute to health surveillance. Community organizations, researchers, and waste-service providers can support locally appropriate implementation. National policies can establish standards and financing mechanisms, while local implementation should reflect differences among urban, peri-urban, rural, and informal waste-management settings. Importantly, health outcomes should be incorporated into the evaluation of waste-sector interventions so that reductions in open burning and respiratory exposure are measured explicitly.

Overall, the public-health priority is to prevent respiratory exposure rather than rely primarily on downstream clinical treatment. For a pulmonology-oriented framework, this translates into four linked actions: reduce uncontrolled combustion at the source, expand reliable waste-service coverage, monitor environmental exposure and respiratory outcomes, and coordinate implementation across waste, environmental, and health sectors. These measures should be regarded as population-level prevention strategies; they do not constitute evidence that open waste burning is a specific cause of individual respiratory disease in the absence of appropriate clinical and exposure assessment.

Research Gaps and Future Directions

Evidence on the respiratory effects of open waste burning remains limited, with most studies relying on cross-sectional designs, self-reported exposure, or residential proximity (Irianti & Prasetyoputra, 2019; Adetona et al., 2020; Vinti et al., 2021). Five priorities should guide future research.

Exposure measurement. Studies should develop standardized exposure metrics that distinguish household, community, dumpsite, landfill, and occupational burning. Personal $PM_{2.5}$ monitoring, near-source measurements, spatial modelling, and selected chemical markers could improve exposure characterization and reduce misclassification. Waste composition and combustion conditions should also be documented because they strongly influence emission profiles (World Health Organization, 2025; Pathak et al., 2023).

Prospective cohorts. Longitudinal studies are needed to establish temporal relationships between exposure and respiratory outcomes. Priority outcomes include asthma and COPD exacerbations, respiratory infections, healthcare utilization, spirometry, and changes in lung function. Studies should control for smoking,

biomass-fuel use, traffic pollution, occupational exposure, and other major confounders.

Source-specific toxicology. Experimental studies should characterize emissions from different waste streams, particularly plastic-rich, organic, textile, electronic, and mixed waste. Integrating chemical analysis with studies of oxidative stress, epithelial injury, inflammation, and airway remodelling could identify the most hazardous emission profiles (Cooper & Loxham, 2019; Låg et al., 2020; Aghapour et al., 2022).

Vulnerable groups. Children, older adults, people with pre-existing respiratory disease, informal waste workers, and populations living near recurrent burning sites require targeted investigation. Future studies should determine whether exposure is associated with poorer disease control, exacerbations, impaired lung-function trajectories, or increased healthcare utilization.

Intervention evaluation. Research should determine whether improved waste collection, accessible disposal alternatives, community programmes, and targeted enforcement reduce burning, pollutant exposure, and respiratory morbidity. Natural experiments associated with expansion of waste services may provide useful opportunities to evaluate these effects.

Overall, future research should move from documenting the occurrence of open waste burning toward determining how exposure is measured, which emission sources are most hazardous, which populations are most affected, and whether source-control interventions reduce respiratory exposure and disease. These priorities would provide a stronger evidence base for prevention and future exposure-specific clinical guidance.

Conclusion

Open waste burning is an underrecognized source of recurrent, localized multipollutant exposure in Indonesia, with emissions that may include particulate matter, black carbon, polycyclic aromatic hydrocarbons, volatile organic compounds, metals, dioxins, and furans. Available evidence indicates biologically plausible pathways of respiratory injury involving oxidative stress, epithelial barrier dysfunction, impaired mucociliary defense, and immune activation, while epidemiological findings support concern for respiratory symptoms and disease exacerbation. However, direct exposure-specific evidence remains limited and heterogeneous; therefore, the attributable causal burden of respiratory disease from open waste burning has not yet been quantitatively established, and no exposure-specific diagnostic or treatment guideline is available. Clinically, management should emphasize identification of relevant environmental and occupational exposure, syndrome-based assessment and treatment according to established respiratory guidelines, and reduction of further exposure. Prevention should prioritize source control through reliable waste collection and safe disposal, community participation, environmental monitoring, and coordinated action across health, environmental, and waste-management sectors. Future research should strengthen exposure measurement, prospective epidemiology, source-specific toxicology, identification of vulnerable populations, and evaluation of waste-management interventions to establish the respiratory burden and inform evidence-based prevention and clinical guidance.

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