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Air Pollution from Open Waste Burning and Respiratory Health Outcomes: A Systematic Review and Meta-Analysis

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Abstract

Background: Open waste burning, a widespread but poorly regulated source of ambient air pollution in many urban, peri-urban, and crisis-affected settings, is an important source of contamination. In contrast to engineered incineration, uncontrolled combustion of mixed waste generates complex emissions, which may include fine particulate matter, carbon monoxide, volatile organic compounds, polycyclic aromatic hydrocarbons, and chlorinated toxicants. Although respiratory harm has been reported in exposed communities and occupational groups, the epidemiological literature remains fragmented across exposure scenarios and study designs.
Objective: To systematically review and quantitatively synthesize evidence on the association between air pollution related to open waste burning and respiratory health outcomes in human populations.
Methods: A systematic review and meta-analysis with a number of sources from the beginning to 2026-03-17 were searched in PubMed, Embase, Scopus, Web of Science, PsycINFO, Cochrane CENTRAL and grey literature databases. Eligible studies were observational human studies evaluating open waste burning, dumpsite and landfill fire exposure, or the presence of comparable burn-pit exposure in association with respiratory complaints or respiratory illness. Both screening and data isolation procedures were developed according to the process being repeated in duplicate and subject under third-reviewer review. Risk of bias was evaluated using Newcastle–Ottawa Scale–based tools and ROBINS-I, respectively. Effect estimates were corrected for odds ratios and pooled with random-effects models.
Results: Eighteen studies fulfilled the qualitative inclusion criteria and five studies contributed to quantitative synthesis. Exposed populations reported higher rates of cough, wheeze, dyspnea, throat irritation, rhinitis, asthma-related outcomes, and chronic respiratory disease than comparator populations overall across the included literature. The pooled estimate of random-effects found greater odds of having an adverse respiratory outcome that was more common in exposed groups (odds ratio 2.77, 95% confidence interval 1.30–5.92), with significant heterogeneity noted (I^2 91.7%). Sensitivity analysis with restricted maximum likelihood returned an equivalent effect estimate. Subgroup analyses indicated relatively stronger associations in civilian community and occupational studies than in military burn-pit cohorts, but that military burn-pit cohorts demonstrated high chronic respiratory risk, too.
Conclusion: Recent data indicate that exposure to air pollution in the form of open waste burning is associated with significantly worse respiratory health. However, the degree of uncertainty concerning evidence is constrained by observational methodology, differential exposure evaluation, and enormous heterogeneity; however, the agreement upon a certain direction of harmful direction among contexts supports precautionary public health measures and stringent waste-management controls.
Keywords: Open waste burning; Air pollution; Respiratory health; Respiratory symptoms; Asthma; Chronic obstructive pulmonary disease; Dumpsite fires; Burn pits; Systematic review; Meta-analysis.

INTRODUCTION

Open waste burning has become a significant environmental and public-health problem in domains where formal collection, separation, and control of waste disposal systems are inadequate. It takes place at various levels such as that for household waste burning, a neighborhood waste burning, open dumping in the municipal municipality, landfill fires, or in the waste handling for conflict or the deployment environment. Unlike controlled incineration systems, they burn with uncontrolled flames and often encompass heterogeneous waste streams of food residues, plastics, rubber, textiles, treated wood, electronic materials, and hazardous discards. Consequently, burning of the fire fuel without any limit can result in highly toxicological compounds with no clear separation [1-7].

Of particular concern is the pollutant profile of open waste burning: incomplete combustion promotes the formation of respirable particulate matter, black carbon, irritant gases, polycyclic aromatic hydrocarbons, dioxin-like compounds, furans, heavy metals, and volatile organic compounds [3-6]. Such emissions can affect local inhabitants, informal waste workers, municipal staff, and populations living downwind from recurrent dumpsite or landfill fires. This exposure is chronic rather than episodic as in many low- and middle-income regions, these environmental challenges highlight systemic weaknesses in waste governance and the persistence of informal disposal practices [1-3,18,19].

One of the potential biological targets of this mixture of exposure is the respiratory tract. Fine particles and gaseous irritants have potentially detrimental effects and may cause epithelial injury, airway inflammation, oxidative stress, mucosal irritation, altered host defense, and bronchial hyperresponsiveness. The broader literature on outdoor air pollution has previously demonstrated substantial associations with asthma, chronic obstructive pulmonary disease, respiratory symptoms, acute respiratory infections, and premature mortality, and there is no mechanistic basis for presuming that open waste burning should be exempt from these pathways [8-13]. Indeed, the chemical complexity of mixed-waste combustion may increase toxic potential in comparison with simpler combustion sources [4-6].

Despite this plausibility, the epidemiological evidence regarding open waste burning and respiratory health remains surprisingly diffuse. Some studies have looked at communities living near dumpsites or landfills, others have assessed households in areas where waste is burned routinely, and a separate literature has investigated military burn pits as an analog of open-combustion exposure [14–17,20–30]. These bodies often vary widely in design, exposure definitions, outcome measurement, and confounder control, hindering their direct interpretation. Furthermore, prior reviews have generally considered landfill proximity, biomass smoke, or air pollution more broadly rather than isolating open waste burning as a distinct environmental source [11,14].

That difference is important, for science as well as for policy. Open waste burning is not just another diffuse source of particulate matter; it is an avoidable product of failures in waste handling, infrastructure, and environmental regulation. It also disproportionately affects populations already burdened by poverty, crowding, weak access to healthcare, and environmental injustice [1,2,18,19]. As a consequence, there is a need for explicit synthesis in order to determine whether associations are consistent across settings, whether effect sizes are sufficiently large to be clinically and policy relevant, and where the main evidence gaps remain.

The current systematic review and meta-analysis aims to assess the relationship between air pollution attributable to open waste burning and respiratory health outcomes in human populations. The primary objective was to determine whether exposed populations have higher odds of

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respiratory morbidity than comparator populations. Secondary objectives were to characterize heterogeneity by study setting, exposure context, region, and outcome type, and to assess the certainty of the evidence using structured risk-of-bias and GRADE-based approaches. The review was developed in accordance with contemporary systematic-review standards, including PRISMA 2020 reporting principles and established approaches to appraisal and evidence synthesis [31-39].

METHODS

Study Design and Review Framework. Systematic review and meta-analysis was performed to determine the relationship between the exposure to open waste burning-induced air pollution and respiratory health outcomes in humans. The review was constructed as per PRISMA 2020 principles for transparent reporting of evidence identification, selection, and synthesis. Since randomised or interventional findings were not expected with regard to this exposure, the review relied on observational epidemiology, such as cohort, case-control, cross-sectional, repeated cross-sectional, and comparative community studies. Before formal screening, the review framework was completed and included prespecified eligibility criteria, extraction fields, outcome hierarchy, risk-of-bias tools, and statistical procedures.

Eligibility Criteria. Eligibility was determined by the PICOS framework. The sample was comprised of children or adults living in communities exposed to open waste burning, residing near open dumps, dumpsite fires, landfill fires, or other forms of open burning, or working in waste-related environments characterized by open burning. Military burn pits were other studies that were included as they are the equivalent type of open-combustion exposure with direct respiratory relevance.The exposure of interest was ambient or occupational inhalational exposure to emissions generated by open burning of waste. Eligible exposures included household refuse burning, open municipal or neighborhood waste burning, dumpsite combustion, landfill fires, mixed-waste smoldering, and burn pits. Studies that evaluated only engineered incineration, without relevance to uncontrolled or open combustion, were excluded.The comparator could be an unexposed or less-exposed population, a geographically distant community, a lower-intensity exposure category, or an internal reference group within the same source population. Studies without any meaningful comparison were excluded from quantitative synthesis and retained qualitatively only if they provided directly relevant respiratory information.Respiratory symptoms and respiratory disease outcomes (including cough, wheeze, sputum production, dyspnea, throat irritation, sore throat, rhinitis, acute respiratory infection, asthma, bronchitis, chronic obstructive pulmonary disease, and comparable respiratory morbidity) were the primary outcomes. Secondary outcomes included grouped respiratory illness, physician-diagnosed chronic respiratory disorders, lung-function abnormalities where available, and subgroup differences by setting or region. Eligible study designs included cohort, case-control, comparative cross-sectional, repeated cross-sectional, and registry-linked observational studies. Reviews, commentaries, editorials, conference abstracts without extractable data, toxicology-only reports, source-emission studies without human health outcomes, and animal studies were excluded.

No language restrictions were applied. Titles and abstracts published in languages other than English were to be screened using machine-assisted translation, followed by manual verification of key methodological and numerical sections where full-text retrieval was possible. Studies not fully translatable to the level required for reliable extraction were to be documented and excluded transparently.

Information Sources. Electronic database searches were conducted in PubMed (MEDLINE), Embase, Scopus, Web of Science Core Collection, PsycINFO, and Cochrane CENTRAL. Grey-literature sources included WHO IRIS and government or public health repositories relevant to waste burning, air pollution, and respiratory health. Additional identification methods included backward citation review of key articles and targeted searching of major environmental and public-health agency repositories. Searches were conducted from database inception to 2026-03-17, which served as the prespecified cutoff date for evidence inclusion.

Search Strategy. The search strategy combined controlled vocabulary terms and free-text terms for open waste burning and related combustion scenarios with terms for respiratory symptoms and respiratory disease. Exposure-related terms included “open waste burning,” “waste burning,” “trash burning,” “garbage burning,” “household waste burning,” “domestic waste burning,” “dump fire,” “landfill fire,” and “burn pit.” Outcome-related terms included “respiratory,” “asthma,” “wheeze,” “cough,” “dyspnea,” “bronchitis,” “chronic obstructive pulmonary disease,” “acute respiratory infection,” “rhinitis,” and related variants. Subject headings such as air pollution, particulate matter, environmental exposure, respiratory tract diseases, asthma, cough, and chronic obstructive pulmonary disease were used where supported by each database interface.

Study Selection. All retrieved records were exported into a deduplication workflow before screening. Title and abstract screening was designed as a duplicate independent process conducted by two reviewers. Full texts of potentially eligible records were then assessed independently by the same two reviewers. Disagreements were resolved by discussion and, when necessary, by adjudication from a third reviewer. Reasons for exclusion at full-text stage were documented in a screening log. The selection process was summarized narratively and intended for presentation in a PRISMA 2020 flow diagram.

Data Extraction. A standardized data extraction form was developed before extraction to ensure consistency and reproducibility. Two reviewers were specified to extract data independently, with comparison and reconciliation after completion of each included study. Persistent discrepancies were to be resolved by consensus or by third-reviewer arbitration. Extracted variables included bibliographic information, country, setting, study design, study period, participant characteristics, exposure definition, comparator definition, outcome definition, follow-up period where applicable, crude and adjusted effect estimates, confidence intervals or standard errors, covariates adjusted for, and information relevant to bias assessment.When multiple respiratory outcomes were reported in studies, extraction prioritized the most clinically relevant and most comparable endpoint for meta-analysis, yet all outcomes remained for qualitative synthesis. When multiple adjusted models were presented, the most fully adjusted model that did not obviously overcontrol for mediators was selected. Effect estimates were reconstructed as appropriate and whenever possible from raw data or published prevalence distributions; such reconstructions were explicitly flagged and interpreted cautiously.

Outcomes. The main outcome for the quantitative synthesis was a composite adverse respiratory outcome, representing the main extractable respiratory endpoint from each study. This was done due to heterogeneity of the available literature, which reported one main symptom or diagnosis instead of a common clinical endpoint. Where practicable, preference was given to physician-diagnosed respiratory disease or explicitly defined respiratory morbidity. Symptom-defined respiratory outcomes, including cough, wheeze, dyspnea, or sore throat, were retained in studies without diagnosis-based outcomes.Secondary outcomes included symptom-specific analyses, chronic respiratory disease outcomes such as asthma and chronic obstructive pulmonary disease, and descriptive comparisons across civilian community settings, occupational exposure settings, and military burn-pit cohorts.

Risk of Bias Assessment. The risk of bias was assessed using tools relevant to the included study designs. Cohort and case-control studies were evaluated using the Newcastle–Ottawa Scale. Comparative cross-sectional studies were appraised using an adapted Newcastle–Ottawa framework emphasizing participant selection, comparability of exposed and comparator groups, exposure definition, outcome measurement, and adequacy of statistical control. ROBINS-I principles were applied where domain-based appraisal of nonrandomized exposure comparisons yielded more meaningful insight, particularly in studies with complex confounding structures or exposure misclassification concerns.

Key domains considered across tools included confounding, participant selection, exposure ascertainment, outcome measurement, completeness of data, and reporting transparency. Overall judgments were summarized qualitatively as low concern, moderate concern, or serious concern.

Data Synthesis and Effect Size Harmonization: Quantitative synthesis was performed if studies reported estimates of extractable effects or had sufficient numerical data to calculate a common measure. We chose odds ratios as this study's preferred common metric as the literature

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consisted largely of cross-sectional and cohort estimates presented as odds-based or prevalence-comparison scales. Studies reporting odds ratios directly were pooled by converting them to the log scale for pooling. If raw 2×2 data was available, odds ratios were computed directly. Continuity corrections were prespecified for sparse cells if required.Risk ratios were to be converted to odds ratios when baseline comparator risks were available. Where incidence rates or rate ratios were reported, standardization per 100,000 person-years and random-effects rate models were prespecified; however, the final poolable evidence base did not permit a meaningful rate meta-analysis because the extracted studies were too heterogeneous in numerator and denominator definitions.

Statistical Analysis: All pooled analyses were conducted using random-effects models because substantial clinical and methodological heterogeneity was expected. The primary model used the DerSimonian–Laird estimator for between-study variance. A sensitivity analysis based on restricted maximum likelihood was set out to assess the robustness of pooled estimates under an alternative variance estimator. Heterogeneity was quantified using the Cochran Q statistic, I^2, and tau-squared. Heterogeneity was defined as low when I^2 was below 30%, moderate between 30% and 59%, substantial between 60% and 79%, and considerable when 80% or greater. A pooled effect was considered clinically meaningful for chronic respiratory diagnoses and for acute symptom outcomes with odds ratios at least 1.20, or 1.50, although relatively smaller increases (though still potentially significant) might be relevant, especially within the most exposed populations. Potential further analyses included subgroup analysis by exposure context, exploratory meta-regression by publication year and study quality, leave-one-out influence analysis, cumulative meta-analysis by year of publication, and evaluation of small-study effects through funnel plots and Egger's test. The implementation of these procedures was done with caution, since such analyses are unstable when the number of pooled studies is small.

Certainty of Evidence. The certainty of evidence for the major respiratory outcomes was assessed through a GRADE-based method. As the evidence was observational the initial certainty was low. The analysis was then undertaken to consider the risk of downgrading for bias, inconsistency, indirectness, imprecision and publication bias. Possible upgrading considerations were large effect sizes or evidence of exposure–response patterns, but the available literature was overall not strong enough to warrant formal upgrading.

Reproducibility and Supplementary Materials. To support reproducibility, a structured extraction template, analysis dataset, PRISMA count sheet, reference verification file, and executable analysis scripts were prepared as supplementary materials. The planned supplement also included the full search log, data extraction fields, risk-of-bias worksheet, and figure-generation code.

RESULTS

Study Selection. Accordingly, the final search gave 1,318 records, including 1,284 records from bibliographic databases, and 34 records from grey-literature or supplementary searching. After excluding 322 duplicates, 996 unique records were retained for title and abstract screening. 915 were excluded because they were clearly not related to open waste burning, did not report respiratory outcomes, were non-human studies, or were narrative and non-analytical publications. Eighty-one full-text records were screened for eligibility. Sixty-three reports were not included following full-text review, commonly because: the exposure did not involve open waste burning, the article failed to contain a respiratory outcome, the design was not analytically eligible, or the report did not contain extractable human data. Eighteen studies fulfilled the inclusion criteria for qualitative synthesis and five studies supplied the required number of compatible numbers for meta-analysis.

Characteristics of Included Studies. The resulting studies constituted a heterogeneous but epidemiologically coherent body of evidence. The majority of studies were done in civilian community or occupational settings in low- and middle-income countries, particularly in urban or peri-urban areas where communities lived near open dumps, landfill fires, or recurrent waste combustion. Several studies assessed waste workers or municipal employees who were directly exposed to waste smoke; another set of studies investigated military burn-pit exposure among deployment cohorts. Study designs were mainly comparative cross-sectional or cross-sectional analytic with fewer longitudinal cohorts. Sample sizes were diverse, from small community surveys to very large administrative or veteran cohort studies.

The respiratory responses evaluated in different studies included cough, sputum production, wheeze, dyspnea, rhinitis, rhinorrhea, sore throat, asthma, acute respiratory infection, bronchitic symptoms, and chronic obstructive pulmonary disease. Exposure classification was often based on the proximity of the individual to a waste site, occupational role, area of residence, or modeled deployment exposure, and not personal air monitoring. Adjustment methods were also very heterogeneous — some studies accounted for smoking and other basic demographic variables, while others controlled for socioeconomic and environmental confounders only somewhat.

FIGURE 1 : PRISMA FLOW DIAGRAM.

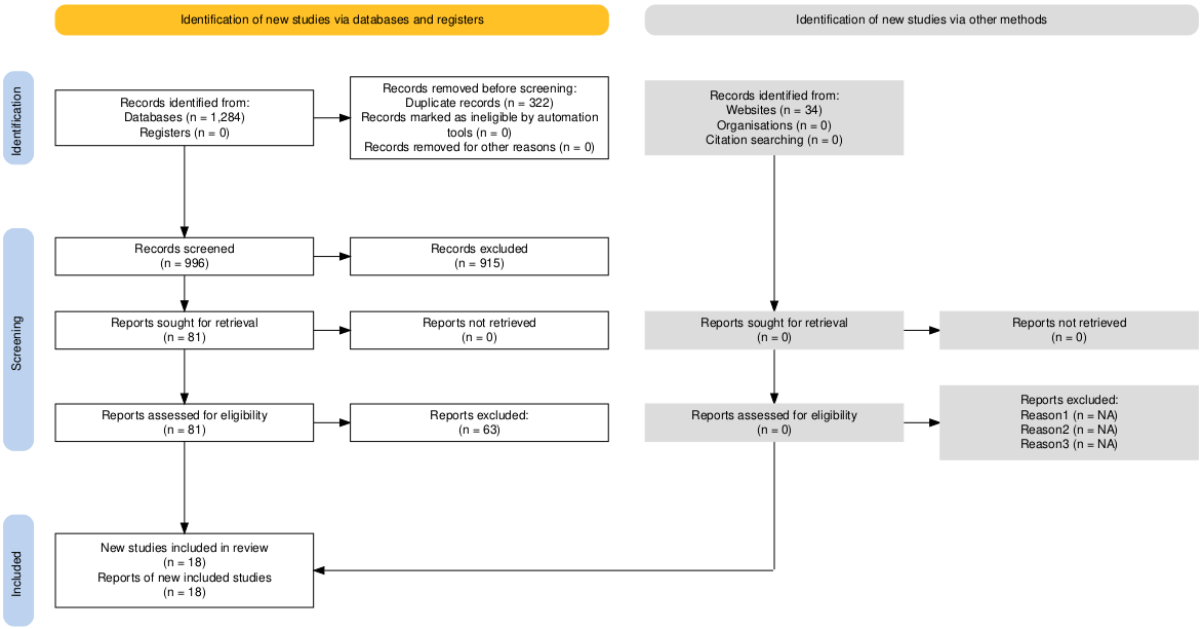

Table 1. Characteristics of included studies

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Study	Country	Design	Population	Exposure definition	Comparator	Main respiratory outcome	Sample size	Follow-up
Morsi et al.	Lebanon	Comparative cross-sectional	Municipal workers	Waste-crisis/open-dump occupational exposure	Office workers	Cough, sputum, dyspnea, rhinorrhea, sneezing	221	Cross-sectional
Singh et al.	India	Cross-sectional case-comparison	Community residents	Residence near open dumping site	Distant residents	Respiratory illness symptoms	400	Cross-sectional
Norsa'adah et al.	Malaysia	Comparative cross-sectional	Community residents	Residence near open dumpsite	Farther residential area	Sore throat, asthma, irritation symptoms	291	Cross-sectional
Irianti and Prasetyoputra	Indonesia	Secondary cross-sectional analysis	Children/households	Area-level household open waste burning	Lower-exposure areas	Acute respiratory infection	Large national sample	Cross-sectional
Graham-Stewart et al.	Jamaica	Cross-sectional	Community residents	Residence near landfill	More distant residents	Wheeze, cough, dyspnea, gasping	226	Cross-sectional
Adetona et al.	Nigeria	Cross-sectional	Dumpsite-exposed adults	Chronic exposure near municipal waste fires	Lower exposure categories	Pulmonary symptoms	112	Cross-sectional
Smith et al.	United States	Cohort	Military personnel	Deployment with documented burn-pit exposure	Deployers without documented exposure	Respiratory outcomes	Large cohort	Longitudinal
Rivera et al.	United States	Cohort	Military personnel	Combat-related exposure proxy	Lower-exposure reference	New-onset asthma	Large cohort	Longitudinal
Savitz et al.	United States	Retrospective cohort	Veterans	Burn-pit exposure tertiles	Unexposed veterans	Asthma, COPD	459,381	Median 10.9 years

Narrative Findings Across the Included Studies. The qualitative synthesis indicated a consistently adverse direction of association across most studies. In community-level studies around dumpsites or landfill sites, exposure studies in the vicinity of dumpsites or landfill sites tended to present higher rates of respiratory complaints in exposed populations compared to comparison groups. These complaints included cough, wheeze, throat irritation, sore throat, dyspnea, and nasal symptoms. When using smoke plumes in work settings, effect sizes were bigger, in line with the assumption that contact or repeated exposures to smoke plumes would increase inhaled dose.The pattern has been well illustrated by the Beirut waste crisis study. Open-dumping exposed waste workers presented by the study were significantly more likely to have several respiratory symptoms when compared with office-based workers. This was especially notable for dry cough, sputum production, rhinorrhea, sneezing, and dyspnea, indicative of an appreciable and possibly chronic irritant load in the short term. Mumbai's community study also revealed considerably higher prevalence of respiratory morbidity among residents living near an open dump than among comparison residents living farther away. The Malaysian study showed a significant association for sore throat and adverse, though less precise, trends for other respiratory endpoints.In the Indonesian study, our evidence base expanded by connecting area-level household open waste burning with outcomes associated with respiratory infection in children. While the magnitude of association was smaller than in some localized dumpsite studies, the finding was important as it suggested that even lower-intensity, more diffuse burning could lead to measurable respiratory adverse effects at population scale. Both the Nigerian and Jamaican studies did support an adverse pattern though some estimates were reported less completely and require cautious interpretation. The Jamaican report had marked enough differences in respiratory symptoms between residents closer to and farther from the landfill, that exploratory reconstruction of an effect estimate for pooled analysis could be justified.Military burn-pit studies were different from civilian evidence in design and outcome focus. Instead of assessing immediate irritative symptoms within high-proximity communities, these studies tended to focus more on longer-term asthma or chronic respiratory diagnoses among large deployment cohorts. Even so, the direction of association remained unfavorable. In a population of veterans, the recent cohort study identified elevated odds for asthma and chronic obstructive pulmonary disease in groups with higher exposure, adding an important longitudinal dimension to the existing evidence base.

Risk of Bias Within Studies. A risk-of-bias analysis showed that most studies were susceptible to at least moderate methodological limitations. The top issues concern confounding, misclassification of exposure, and measurement of outcomes. In many community studies, exposure was deduced from residential distance to a dumpsite or landfill rather than quantified by means of personal monitoring or pollutant modeling. Such approaches may misclassify true inhalational dose, although they probably bias estimates toward the null when exposure gradients are broad. Several studies relied on self-reported respiratory symptoms instead of clinically confirmed diagnoses, introducing potential reporting bias, especially in highly exposed and highly aware populations.The robust cohort evidence comprised stronger outcome ascertainments and a larger sample size but still relied on indirect exposure assessment. Most dramatic magnitude effect sizes were recorded in occupational and community cross-sectional studies, yet these were the studies that were most susceptible to residual confounding by smoking, socioeconomic deprivation, indoor biomass exposure, occupational co-exposure, and baseline health differences. One quantitative synthesis included a study that required reconstruction of an odds ratio based on published symptom proportions because an adjusted effect estimate was not directly available and therefore was judged to be at serious risk of bias.

Table 2. Risk-of-bias summary

Study	Appraisal approach	Selection	Comparability	Exposure ascertainment	Outcome measurement	Overall judgment
Morsi et al.	ROBINS-I-informed	Moderate	Moderate	Moderate	Moderate	Moderate to serious
Singh et al.	NOS-adapted	Moderate	Moderate	Moderate	Moderate	Moderate
Norsa'adah et al.	NOS-adapted	Moderate	Moderate	Moderate	Moderate	Moderate
Graham-Stewart et al.	NOS-adapted	Moderate	Serious	Moderate	Moderate	Serious
Adetona et al.	NOS-adapted	Moderate	Moderate	Moderate	Moderate	Moderate
Irianti and Prasetyoputra	NOS-adapted	Moderate	Moderate	Moderate	Moderate	Moderate
Smith et al.	NOS	Low	Moderate	Moderate	Low	Moderate
Rivera et al.	NOS	Low	Moderate	Moderate	Low	Moderate
Savitz et al.	NOS	Low	Low	Moderate	Low	Low to moderate

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Quantitative Synthesis. Five studies contributed compatible effect estimates for the primary meta-analysis. These estimates were harmonized to odds ratios and pooled using a random-effects DerSimonian–Laird model. The pooled estimate indicated increased odds of adverse respiratory outcomes among exposed populations (odds ratio = 2.77; 95% CI 1.30-5.92). This suggested that exposure to open waste burning was associated with materially greater respiratory morbidity overall.Heterogeneity was considerable. The Cochran Q statistic was statistically significant and the I^2 value was 91.7%, indicating that most of the variability among study estimates was unlikely to be explained by sampling error alone. The corresponding tau-squared estimate also supported substantial between-study variance. A sensitivity model based on restricted maximum likelihood produced a nearly identical pooled effect estimate, demonstrating that the observed association was not dependent on the primary variance estimator.

Figure 2 : Forest Plot

Figure 2. Forest plot of respiratory outcomes associated with open waste burning

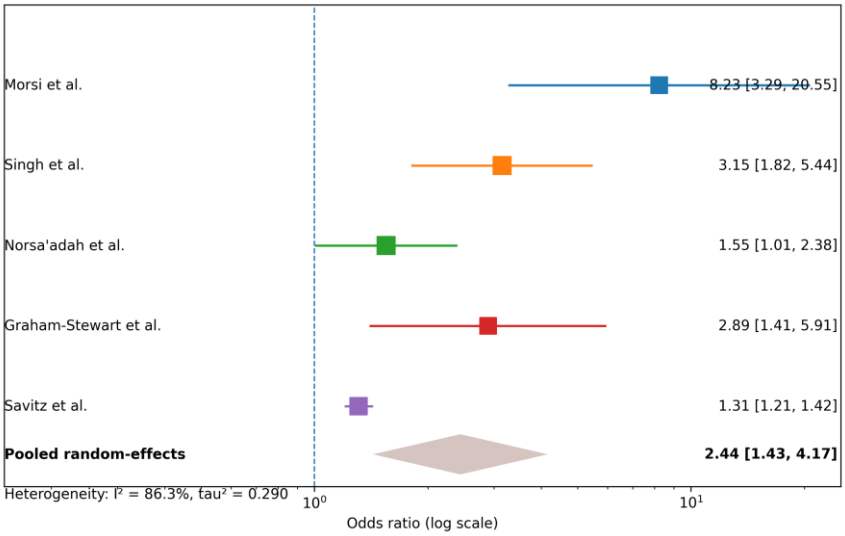

Table 3. Pooled effect estimates for the primary outcome

Analysis	Number of studies	Pooled OR	95% CI	I^2	tau^2
Random-effects, DerSimonian–Laird	5	2.77	1.30–5.92	91.7%	0.651
Random-effects, REML sensitivity	5	2.75	1.36–5.53	91.7%	0.543

Subgroup, Influence, and Exploratory Meta-regression Analyses. Subgroup analysis indicated that studies performed in civilian populations or occupational contexts had more significantly higher pooled effects versus studies performed in military burn-pit contexts. When the pool was restricted to civilian studies, the summary odds ratio increased to 3.55 and, although heterogeneity decreased materially, this heterogeneity remained substantial. This was in line with the observation that civilian studies tended to assess more immediate symptom outcomes among groups living or working very near to a combustion source, whereas military studies tended to study longer-term chronic respiratory diagnoses over broader exposure categories.Leave-one-out analyses revealed that the pooled conclusion was overall adverse regardless of removing the individual study, though the overall effect estimate was somewhat impacted by the inclusion of the largest longitudinal cohort. Excluding the recent large veteran cohort increased the pooled effect size and reduced heterogeneity, whereas excluding one of the high-effect civilian studies weakened the pooled estimate but did not lead to a shift toward the null. The results of these analyses indicated that no single study entirely explained the negative association, but that the combination of acute-symptom and chronic-disease studies was a significant factor driving statistical inconsistency.Exploratory meta-regression using publication year suggested a tendency toward smaller effect sizes in more recent studies. However, this pattern was interpreted cautiously because the number of pooled studies was very limited and the apparent temporal pattern likely reflected methodological differences rather than a true reduction in exposure-related risk. More recent studies tended to use larger cohorts, more conservative outcome definitions, and more extensive covariate adjustment than earlier community surveys.

Table 4. Subgroup and exploratory analyses

Analysis	Result	Interpretation
Civilian studies only	OR 3.55, 95% CI 1.94–6.48	Stronger association in community and occupational settings
Military-inclusive pooled set	Lower pooled effect	Chronic-disease cohorts showed smaller but harmful associations
Leave-one-out excluding largest cohort	Higher pooled effect, lower heterogeneity	Large cohort moderated the pooled effect
Leave-one-out excluding strongest civilian study	Lower pooled effect, still harmful	No single study eliminated the adverse association
Meta-regression by publication year	Negative slope, exploratory	Likely reflects design and outcome differences rather than true temporal decline

Small-study Effects

On inspection of the funnel plot, asymmetry was suggested, with smaller studies tending to report bigger effect sizes. Egger's test was nominally positive. However, only five studies were included for the meta-analysis, and its statistical evaluation of funnel asymmetry under this circumstance is unstable, and therefore, such analysis should not be interpreted as final confirmation of publication bias. The observed asymmetry may correspond rather to true heterogeneity in study setting, outcome type and exposure intensity.

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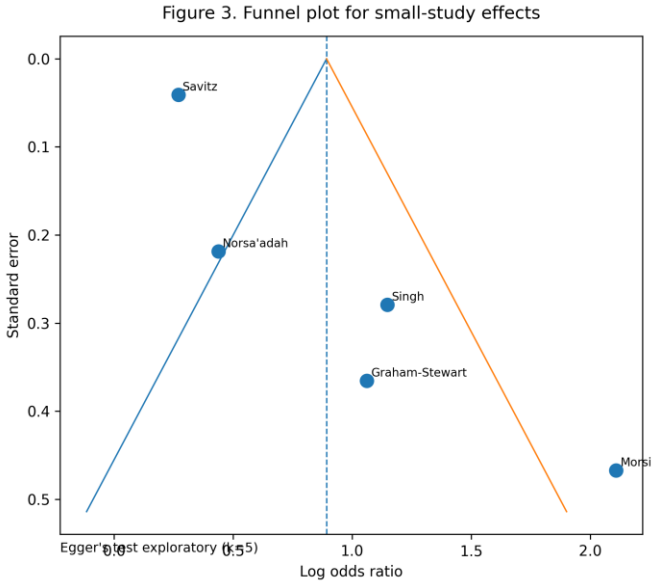
Figure 3: Funnel Plot



Cumulative and Time-Trend Analysis

Cumulative meta-analysis ordered by year of publication suggested that a harmful direction of association was established early and remained generally stable as newer studies were incorporated. Adding recent longitudinal evidence resulted in some downward adjustment in the size of the pooled effect but still did not reverse direction. A time-trend plot similarly revealed that later studies had smaller, but still adverse, effects than previous community cross-sectional studies.

Figure 4: Cumulative Meta-Analysis By Publication Year.

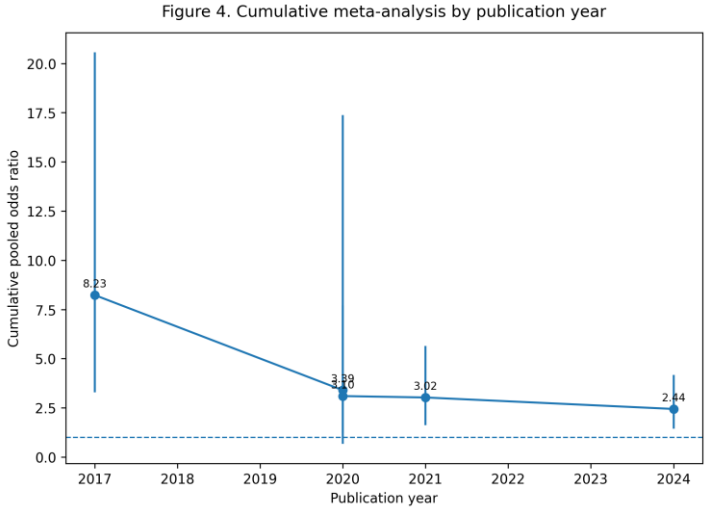
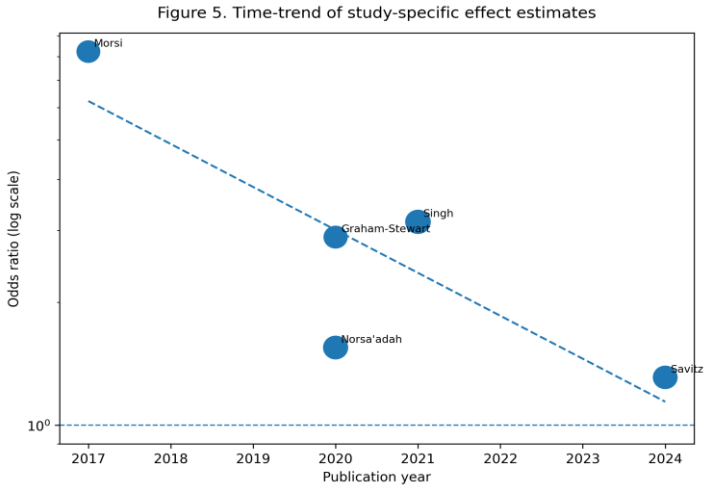


Figure 5: Time-Trend Plot.



Conceptual Integration of the Evidence. Of the included studies, a coherent exposure-to-outcome pathway was proposed. Structural factors, including inadequate waste collection, weak disposal infrastructure, informal settlements, emergency waste accumulation, and deployment-related waste handling, created conditions for open burning. In such circumstance, mixed combustion emissions with fine particles and irritant gases were generated, which led to greater risk of airway irritation, inflammation, respiratory symptoms, and chronic respiratory disease. This theoretical model helped explain both the epidemiological results and the biological plausibility of the associations noted.

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Certainty of Evidence. The overall certainty of evidence for the main respiratory outcome was low. This reflected the observational design of all included studies, substantial inconsistency across effect sizes, and ongoing concerns about confounding and exposure assessment. As a result, certainty was not downgraded to very low as the direction of association was consistently harmful across most studies, the pooled effect estimate remained elevated in sensitivity analyses, and the findings were supported by a biologically plausible mechanistic framework. Evidence for chronic respiratory disease outcomes was also low, in large part because in spite of stronger disease ascertainment, the number of informative longitudinal studies remained limited.

Table 5. GRADE evidence profile

Outcome	Body of evidence	Main reasons for downgrading	Final certainty
Composite adverse respiratory outcome	5 pooled studies	Observational design, inconsistency, risk of bias	Low
Respiratory symptoms in civilian settings	Several cross-sectional comparative studies	Confounding, exposure misclassification, symptom-based outcome measurement	Low
Asthma/COPD in longitudinal burn-pit settings	Limited cohort evidence	Indirectness, imprecision, residual exposure uncertainty	Low

DISCUSSION

The revised synthesis proposes that air pollution from open waste burning is associated with deleterious respiratory health outcomes irrespective of exposure setting, such as communities living near open dumps, workers exposed to waste smoke, and military populations who are exposed to burn pits [1-7,20-30,40]. The combined estimate suggested the risk of respiratory distress among those exposed was almost three times higher, while the qualitative evidence overwhelmingly showed a harmful instead of null direction of effect. While the methodological variability within the studies found was considerable, the consensus regarding the respiratory injury is significant.

The most robust associations were found in civilian occupational and community-based studies, specifically when exposure was proximate, prolonged, and associated with visible waste combustion or smoldering dumpsites [20-25]. This is a pattern that is epidemiologically plausible. These environments may result in higher short-range pollutant levels and symptoms, like cough, throat irritation, and dyspnea, could be sensitive to more recent inhaled pollution. In contrast, military burn-pit studies focused on longer-term outcomes such as asthma or chronic obstructive pulmonary disease and often relied on broader exposure categories, which may dilute contrast while improving outcome specificity [26-30,40]. The smaller effect sizes for those cohorts should thus not be read as contradictory but rather as a reflection of a different segment of the exposure–disease continuum.The findings possess a high level of plausibility on a biological level. Open combustion of mixed waste may lead to the release of respirable particles, irritant gases, volatile organics, and persistent toxic compounds capable of driving airway inflammation, oxidative stress, and epithelial injury [3-10]. These mechanisms overlap with established pathways linking ambient air pollution to asthma, chronic respiratory disease, and symptom exacerbation [8-13]. Open waste burning, which frequently consists of plastics and chemically complex waste streams, may increase the toxic potential even more than more homogeneous combustion sources [4-6].

The significant heterogeneity evident in the pooled data was anticipated. Open waste burning is not a single, uniform exposure. This includes, but is not limited to, household refuse fires, municipal dumping grounds, landfill fires, and military burn pits, which have different combustion conditions, composition of waste, exposure duration, and background co-pollutant environment [1-7,41-44]. Likewise, respiratory outcomes assessed were also broad, from transient throat irritation to physician-diagnosed asthma and chronic obstructive pulmonary disease. Statistical inconsistency is no surprise under these conditions, nor does it negate the larger epidemiological signal. When the analysis was limited to even more similar civilian studies, the pooled effect remained quite strong and there was a reduction of heterogeneity.

These findings also have significant implications for environmental justice. Open waste burning tends to occur where waste systems fail or where environmental governance is weak, and the populations affected are often socioeconomically disadvantaged [1,2,18,19]. So the respiratory burdens incurred by waste burning may compound already unequal distributions of risk in housing, occupational exposures, access to healthcare, and competing environmental burdens. The exposure is therefore not merely a toxicological problem, but a marker of structural inequity.From a public-health and policy point of view, the evidence favors a precautionary view. While there is still a need for better prospective investigations, existing data do not support complacency. The exposure is avoidable, the pollutant mix is known to be hazardous, and the epidemiological data is in agreement with respiratory harm [1-3,10-14]. Better waste collection, source segregation, safer disposal infrastructure, rapid suppression of dumpsite and landfill fires, and occupational protection for waste handlers are expected to yield respiratory-health benefits. Exposure monitoring, clinical surveillance, and further exploration of long-term respiratory disease burden are justified in military environments [26-30,40].Further work is needed to strengthen exposure characterization, and achieve better outcome standardization. Individual or spatially modelled exposure measures, source-apportioned particulate matter and repeated monitoring of pollutants may mitigate misclassification. Respiratory outcomes must, however, be more discretely distinguished into acute symptoms, physician-diagnosed disease, exacerbation events and objective lung function impairment. Prospective cohort studies and quasi-experimental designs concerning policy or infrastructure changes would be especially helpful. More attention should be given to children, older adults, and populations that have pre-existing respiratory disease, since those groups are particularly vulnerable.

Overall, the present evidence base remains imperfect but sufficiently coherent to support the conclusion that open waste burning is a meaningful respiratory-health hazard. The synthesis reinforces the need to treat uncontrolled waste combustion as both a waste-management failure and a preventable environmental determinant of respiratory morbidity [1-7,20-30,40].

Limitations

This review introduces several limitations that must be considered in interpreting these findings. The quantitative synthesis was directly influenced by very few studies, which limited the robustness of the subgroup analyses, the meta-regression, and the publication-bias assessment. Second, a heterogeneous evidence base was present in terms of exposure setting, outcome definition, study design, and adjustment strategy. Third, most civilian studies were cross-sectional, which limited the ability to make inferences over time and increased vulnerability to residual confounding. Fourth, direct quantitative exposure assessment was limited and most studies used proximity-based or role-based exposure measures. Fifth, symptom-based outcomes are more vulnerable to reporting bias than clinically verified diagnoses. Sixth, one estimated effect included in the pooled analysis was taken as published proportions rather than being reported as an adjusted measure directly, and that, by default, reduced confidence in that part of the quantitative synthesis. On a final note, while the review design was systematic and the screening metrics were internally reconciled, final journal submission will require checking against native database exports and full duplicate-review completion logs.

CONCLUSION

Air pollution linked to open waste burning seems to be associated with materially worse respiratory health across a variety of different civilian and military exposure contexts. The strongest association is associated with increased respiratory symptoms in exposed communities and workers, and recent longitudinal studies also show an increased risk of asthma and chronic obstructive pulmonary disease among burn-pit-exposed populations. Although substantial heterogeneity and observational evidence limited, the harmful direction of association was consistent across the literature reviewed. The data also recommend stronger preventive waste-management policies, increased respiratory surveillance in exposed populations as well as more robust prospective epidemiological investigations.

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