American Journal of Medical Science and Innovation (AJMSI)

ISSN: 2836-8509 (ONLINE)

VOLUME 5 ISSUE 1 (2026)

PUBLISHED BY
E-PALLI PUBLISHERS, DELAWARE, USA

American Journal of Medical Science and Innovation (AJMSI)

Volume 5 Issue 1, Year 2026
ISSN: 2836-8509 (Online)
DOI: https://doi.org/10.54536/ajmsi.v5i1.5870
https://journals.e-palli.com/home/index.php/ajmsi

Health Implications of Airborne Pollutants from Inefficient Urban Waste Management Systems

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Article Information

Received: August 07, 2025
Accepted: September 10, 2025
Published: January 20, 2026

Keywords

Airborne Pollutants, Health Implications, Urban Waste, Volatile Organic Compounds, Waste Management

ABSTRACT

The objective of the current study was to determine the health effects of inefficient urban waste management systems, including open dumps and open-air burnings, on inhabitants residing within 1 km of dump yards/sheds in an urban setting. A mixed-methods methodology was used with field measurements, secondary data, and a health impact assessment to study the relationship between pollutants released from inadequately treated urban wastewater systems and the health impact. Results showed extremely high concentrations of particulate matter ($PM_{2.5}$: 112.8 μg/m³; PM_{10}: 210.3 μg/m³), nitrogen oxides (73.5 μg/m³), sulfur dioxide (58.6 μg/m³) and carbon monoxide (4.1 ppm) in the burning locality. Concentrations of lead, cadmium, arsenic and mercury in exposure air particulates were found to exceed the WHO identified threshold levels, and the hazard quotient profiles indicated potential non-carcinogenic risks with considerable contributions from both cadmium and arsenic. Benzene-type and Toluene-type VOCs were also higher than normal, with benzene over the safety standard. We found in our health surveys cases of dumpsite and burning area residents who had significantly higher prevalences of several respiratory symptoms, including chronic cough (39.5%), wheezing/asthma (34.1%), bronchitis (21.6%), and shortness of breath (36.3%) as well as hypertension (31.4%), and heart disease (18.7%) compared with control populations. Mortality and hospitalization estimates provided additional evidence of health burden, with the highest risk occurring near burning sites (78 deaths and 165 hospitalizations per 100,000 population). The study of innovative waste-to-energy technologies and their influence on diminishing air pollutants through novel waste management approaches may provide useful information for urban planners and policy developers to counteract the health effects of urban waste pollution.

INTRODUCTION

Global urbanization, occurring rapidly and everywhere, poses both vast good of economic ambition and grinding threats, not the least of which is dealing with exploding amounts of municipal solid waste (MSW) from the burgeoning throngs of city dwellers (Atnkut *et al.*, 2025; Halimuzzaman *et al.*, 2024; Zhang *et al.*, 2024). Open dumping, uncontrolled burning and uncollected or unsafely disposed of waste are products of the inability of the waste management system to respond to population growth and increased urbanization (Abdullah & Abedin, 2024). These gaps are not only annoying and/or aesthetically unattractive, nor are they land-use problems; they are huge reservoirs for all kinds of aerial pollutants, including many, if not most of them virtually unknown entities of this type, which are terribly dangerous for the health of all of us. The resulting deterioration of urban air quality is a key contributor to the global disease burden, especially in low and middle-income countries where waste management systems are most strained (Rahaman *et al.*, 2023). Thus, the close connection between ineffective urban waste management and the resulting health effects of airborne pollutants is important to inform promising public health interventions and sustainable urban development approaches (Mobosi, 2025).

In cities, poor municipal waste management is notorious for releasing a toxic cocktail of pollutants into the air (De Titto & Savino, 2024). Open dumps and uncontrolled landfilling activities, for example, are not inert waste receptacles; they are dynamic environments where all biodegradable wastes undergo anaerobic decomposition and emit to the atmosphere high GWP gases, including methane (CH_4) and CO_2, thereby including landfills as human activities causing climate change (Permatasari *et al.*, 2025). In addition to gases related to the greenhouse effect, these sites release a wide array of volatile organic compounds (VOCs), hydrogen sulfide (H_2S), and ammonia (NH_3) that cause nuisance odors and may produce direct irritant effects for the respiratory system (Konkol *et al.*, 2022; Opu *et al.*, 2023). Another more insidious and ubiquitous form of aerial contamination arising from waste is open burning, either deliberate at dumpsites or inadvertent in landfill fires. This last one, which is often applied outside of the rules, in order to minimize the volume of waste, releases a poisonous mixture of pollutants from 24 to 72 hours, which includes particles

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of fine and ultrafine ($PM_{2.5}$ and PM_{10}), heavy metals (lead, cadmium), dioxins, furans, PAHs, and carbon monoxide (CO) (Xue *et al.*, 2012). Such pollutants can travel long distances and affect not only those communities in close proximity to the waste site but also the wider urban and even rural communities (Liu *et al.*, 2021).

The health effects of exposure to these refuse-born airborne carcinogens are powerfully demonstrable (Lewtas, 1993). Particulate matter, especially $PM_{2.5}$ has long been known to be one of the most dangerous air pollutants because it can reach deep into the lungs and enter the bloodstream (Thangavel *et al.*, 2022). Chronic exposure to $PM_{2.5}$ is strongly related to higher susceptibility to respiratory diseases, including asthma, chronic obstructive pulmonary disease (COPD) and lung infections, and further exacerbation of pre-existing heart disease and related conditions resulting in heart attacks, strokes and premature death (Sangkham *et al.*, 2024). Heavy metals contained in burned electronics and batteries in waste can be deposited in the body and cause neurological problems, developmental delay in children and some organ dysfunctions (Briffa *et al.*, 2020). Dioxins and furans, which are highly toxic POPs and are human carcinogens and endocrine disrupters, even at low exposure levels. In addition to these compounds, VOCs and other gas-phase pollutants can act as irritants to the mucous membranes, causing damage and reducing lung function and can be precursors of ground-level ozone, another damaging air pollutant (Taha *et al.*, 2025).

The increasing trends in urbanization and the ongoing issues with effective and efficient disposal systems, particularly in emerging economies, suggest that the emission of air pollutants from waste is still a major challenge to public health (Abdulkadhim Altaee *et al.*, 2025). Notwithstanding that the adverse impact upon health of these and other air pollutants has been studied in isolation, knowledge of the overall epidemiological evidence of ill-health caused by urban waste mismanagement is frequently fragmented.

LITERATURE REVIEW

The Global Urban Waste Crisis and Atmospheric Emissions

The voluminous generation of municipal solid waste is on the rise globally and is estimated to be 3.4 billion tons per year by 2050, with a significant proportion of it coming from fast-growing urban areas (Kaza *et al.*, 2018). In most low- and middle-income countries, waste management infrastructure and institutional capacity have not been able to grow commensurately, leading to widespread practices of open dumping, uncontrolled or rudimentary landfilling, and open burning of waste (Ferronato & Torretta, 2019; Imran *et al.*, 2024). These leaky systems are not inert destinations for trash, but rather living, breathing sources of air pollution. Organic matter degradation in open dumps and other uncontrolled landfills generated high amount of landfill gas (LFG), primarily comprised of methane (CH_4) and carbon dioxide (CO_2) which are intense greenhouse gases and are responsible for climate change (Kurniawan *et al.*, 2024). In addition to GHGs, such sites also release several other non-methane volatile organic compounds (NMVOCs), hydrogen sulphide (H_2S) and ammonia (NH_3), which are precursors of secondary pollutants and direct irritants (Silva *et al.*, 2025). One such major and pervasive source, open burning of refuse, discharges extremely toxic and difficult to manage mixtures of pollutants straight into the atmosphere, affecting much wider areas than around the burn site itself (Ramadan *et al.*, 2023).

Characterization of Airborne Pollutants from Inefficient Waste Management

The cocktail fraction of air pollutants generated by poor urban solid-waste management is broad, and it includes gaseous and particulate pollutants with different toxicological implications. Open burning of MSW is a major source of fine and ultrafine particulate ($PM_{2.5}$ and PM_{10}), black carbon (BC) and carbon monoxide (CO) (Hossain *et al.*, 2024). These particles almost always carry adsorbed heavy metals (e.g., lead, cadmium, mercury, arsenic) from waste components such as electronic and battery waste, as well as organic pollutants (e.g., PAHs, dioxins, furans) produced by incomplete combustion (Guo *et al.*, 2009; Li *et al.*, 2025). Dioxins and furans, for example, are known to be persistent organic compounds (POPs), which are well known for their high toxicity and bioaccumulation (Kirkok *et al.*, 2020). Methane, a significant greenhouse gas and NMVOCs such as benzene, toluene, ethylbenzene and xylenes (BTEX), and odor compounds such as H2S and NH_3 mainly are emitted due to anaerobic decomposition in landfills and open dumps (Moreno *et al.*, 2014). These gaseous releases may cause local nuisance and participate on a more global level in forming photochemical smog. The actual mix and concentration of pollutants are highly variable and are influenced by the nature of the waste, the burning conditions, climatic factors, and vicinity to residential areas (Krecl *et al.*, 2021).

Direct Health Consequences of Waste-Related Airborne Pollutants

Inhalation of these waste-related respirable pollutants can clearly cause a broad spectrum of environmentally related health responses (Shetty *et al.*, 2023). Particulate matter, particularly $PM_{2.5}$, is the most well-investigated air pollutant and is known worldwide because it can enter into the bloodstream after inhalation more deeply in the respiratory tract (Joshi *et al.*, 2025). Long-term exposure is closely linked to higher rate and severity of respiratory diseases, such as asthma, chronic obstructive pulmonary disease (COPD), bronchitis, and lung infections (Ko & Kyung, 2022; Yan *et al.*, 2022). Furthermore, $PM_{2.5}$ exposure is an important risk factor for cardiovascular disease (CVD) that increases to ischemic heart disease, stroke, e cardiovascular mortality (Zhang *et al.*, 2025). The heavy metals, such as lead and cadmium, emitted from the burning of waste are systemic toxicants that hinder neurological development, the kidney function, and elevate the risk of cancer (Tchounwou *et al.*, 2012). Human carcinogens and endocrine disrupters when exposed to even very low doses, dioxins and furans are capable of causing reproductive and developmental problems, immune system damage, and interference with hormones (Peivasteh-roudsari *et al.*, 2023). Gaseous pollutants such as VOCs (e.g., benzene) are associated with carcinogenic effects and other systemic effects, while irritant gases such as H_2S and NH_3 can result in eye, nose and throat irritation, headache and at higher concentrations, more severe respiratory effects (Shuai *et al.*, 2018). The combined effects of these numerous pollutants, which often coexist, could enhance the overall health burden, but this interplay is still an open topic.

Disproportionate Impacts on Vulnerable Populations and Environmental Justice

Exposed populations do not share the health burden of inefficient urban waste management. The most vulnerable groups such as children, the elderly, pregnant women and people with pre-existing respiratory or cardiovascular diseases experience higher risks disproportionately (Sacks *et al.*, 2011). Children are at special risk because of their physiological features (higher breathing rates by weight, their developing immune system), as well as their behaviors (more time spent outdoors) (Wu *et al.*, 2022). Exposure during the critically vulnerable windows of development may cause irreversible effects, including decreased lung function, impaired cognitive development, and increased risk of infections (Domm *et al.*, 2015) and this crisis is also all about environmental justice. Poor and minority communities often live near waste disposal facilities or informal recycling operations because of land availability or historical zoning policies (Zisopoulos *et al.*, 2023). And people in these communities are exposed at higher levels, thereby increasing disparities in health and emphasizing how systems fail to protect against environmental harm (Zahnow *et al.*, 2025). Also, informal waste workers are directly (occupational) exposed to these toxic air pollutants with limited protection and, thus, at high risk (Badal *et al.*, 2025).

Research Gap

While a substantial body of research has demonstrated the negative health implications of urban air pollution and emissions attributable to deficient waste management processes (e.g., open dumping and burning), the two realms have not yet been connected to each other in a comprehensive way. However, existing studies mostly focus on general urban air pollution sources such as traffic and industries, with less focus on the isolation and quantification of the specific contribution of poor waste management systems on atmospheric pollutants and related human health risk assessment. In addition, existing studies are frequently localized, piecemeal or short-term in focus, and there is a paucity and inconsistency of broad-based, long-term evaluations that connect exposure pathways to chronic disease across disparate populations. Moreover, there exist few studies that have compared health burdens across cities with different waste infrastructure, particularly in low and middle-income countries where open burning and unregulated dumping are common. The reasons to address these gaps are fundamentally about generating rigorous evidence to inform targeted policy interventions, sustainable waste management, and protection of vulnerable urban populations disproportionately exposed to airborne pollutants.

Research Questions

a) What are the chemical substances (mixture type) and their concentrations of air pollutants that are released as compared to inefficient urban waste management practices, i.e., open dumping, burning, and informal collection?

b) What is the role of these waste-related emissions as they compare with other sources (traffic, industry) in terms of urban pollution?

c) What short and long-term health risks are posed by exposure to these pollutants, especially for populations at higher risk, including children, the elderly, and low-income communities near waste sites?

d) What is the range of health risks associated with society's distal and proximal urban contexts of waste management infrastructure and regulatory enforcement?

e) Which policy measures and sustainable waste management approaches would be most effective to reduce the exposure of populations to airborne pollutants and associated health risks?

Research Objectives

a) To determine and characterize the predominant airborne pollutants emitted by inefficient solid waste handling in urban settings.

b) To compare the contribution of waste-related emissions to urban air pollution.

c) In order to estimate the health consequences (both acute and chronic) associated with exposure to air-borne pollution deriving from waste mismanagement.

d) To facilitate a comparative risk profile of using waste in different urban contexts with different types of waste management.

e) To provide evidence-based strategies and policy tools for minimizing health risks and promoting sustainable waste management.

MATERIALS AND METHODS

Study Design

This study used a mixed-method approach in which field measurements, secondary data and health impact assessment (HIA) modelling were conducted to understand the association between pollutants emitted from poor urban waste management systems and their health impact. The methodology combined ecological assessment (quantitative environmental survey) with an epidemiological survey to provide efficient, inclusive detection of exposure routes and health effects.

Study Area and Site Selection

The study selected urban waste management settings with ineffective management of waste, such as open dumping, as well as household solid waste open burning and unregistered waste collection points. The sampling sites used for analysis were classified as three types: (i) open dumping sites within or adjacent to residential areas, (ii) open burning areas, and (iii) control areas away from waste activities but in the same urban space. The choice guaranteed spatial contrast and comparison of harm on pollutants and health by various exposures.

Air Pollutant Sampling and Analysis

Portable real-time air monitors and static air samplers were deployed at each site for air quality monitoring. Target pollutants comprised $PM_{2.5}$ and PM_{10}, nitrogen oxides (NO_x), sulphur oxides (SO_x), VOCs, carbon monoxide (CO), black carbon and heavy metals (Pb, Hg, As, Cd) adsorbed onto suspended particulate matter in air. Sampling lasted for 6 months and measurements were made during both peak activity hours (morning collection, midday burning) and during background periods. Particulate concentrations were measured using gravimetry, whereas VOC and heavy metals were quantified by gas chromatography mass spectrometry (GC–MS) and atomic absorption spectrometry (AAS), respectively.

Health Data Collection

For health impact assessment, structured household surveys and hospital record reviews were carried out among residents within 1 km of waste sites. The questionnaire gathered self-reported cases of respiratory symptoms (including cough, wheezing, asthma), cardiovascular conditions, skin and eye irritation, and other health problems thought to have been caused by pollution. Occupational health data on waste handlers and on civil servants were also examined to include those with high exposure. Ethical clearance was received and informed consent was taken from all participants.

Exposure and Risk Assessment

Population exposure was assessed by combining data on pollutant concentrations and time-activity for residents and workers. The USEPA (United States Environmental Protection Agency) Human Health Risk Assessment model is useful to estimate both carcinogenic and non-carcinogenic risks. Health risk indicators were estimated for heavy metals and toxic organics. WHO's AirQ+ software was also used to calculate premature mortality and morbidity related to $PM_{2.5}$ and NO_x exposures.

Data Analysis

Pollutant concentrations and health outcomes at sites were summarized with descriptive statistics. In order to compare the levels of pollutants between dumpsites, burning sites and control, we used the analysis of variance (ANOVA) and Duncan post hoc test. The possible effects of both short-term and long-term exposure to pollutants were evaluated with the use of multivariate regression models, taking into account potential confounders including age, smoking status, and occupational exposure.

RESULTS AND DISCUSSION

Air Pollutant Concentrations across Waste Sites

The concentrations at open dumps and burning sites were higher as compared to the control area, and most of them exceeded WHO guideline limits (Table 1). Fine particulate matter (PM_2.5) was 112.8 μg/m³ at burning locations, which was 4 times more than the prescribed level of 25 μg/m³ followed then by PM10 with a very high peak of 210.3 μg/m³ (against 50 μg/m³). Gaseous pollutants exhibited a similar pattern, in which the concentration of NOx and SO_2 in the burning sites were nearly 2 to 3 times their WHO limits. The concentration of carbon monoxide too soared, crossing the saturation point in both dump yards and burnt locations.

Table 1: Mean concentration of major pollutants across sampling sites

Pollutant	Control site	Open dump	Burning site	WHO limit
$PM_{2.5}$ (μg/m³)	28.4±3.1	64.5±6.2	112.8±10.5	25
PM_{10} (μg/m³)	55.3±4.8	138.9±12.7	210.3±18.9	50
NOx (μg/m³)	24.1±2.4	48.7±4.9	73.5±6.2	40
SO_2 (μg/m³)	18.9±2.2	39.4±4.6	58.6±6.0	20
CO (ppm)	0.7±0.1	2.5±0.3	4.1±0.6	1.0

Heavy Metals in Airborne Particulates

Airborne particulate analysis showed higher levels of toxic heavy metals at the site of open dump and burning when compared with control (Table 2) and several of them were found to be above the recommended level by WHO/ USEPA. Lead (Pb) values were recorded at burning sites at significantly higher concentrations (0.37 μg/m³), i.e.,> 2.5 times higher than the allowable limit of 0.15 μg/m³. Cadmium (Cd) and arsenic (As) contents in burning sites were also four to five times over guideline values. Mercury (Hg) had similarly lower concentration but has exceeded safety level in burning sites.

Table 2: Concentrations of heavy metals in $PM_{2.5}$ (μg/m³) across sampling sites

Pollutant	Control site	Open dump	Burning site	WHO limit
$PM_{2.5}$ (μg/m³)	28.4±3.1	64.5±6.2	112.8±10.5	25
PM_{10} (μg/m³)	55.3±4.8	138.9±12.7	210.3±18.9	50
NOx (μg/m³)	24.1±2.4	48.7±4.9	73.5±6.2	40
SO_2 (μg/m³)	18.9±2.2	39.4±4.6	58.6±6.0	20
CO (ppm)	0.7±0.1	2.5±0.3	4.1±0.6	1.0

Volatile Organic Compounds (VOCs)

The survey indicates that levels of VOCs were significantly higher at open dump and burning sites compared to the control site (Table 3), with the burning sites having the highest levels. Benzene an established cancerogenic was 8.7 μg/m³ at burn sites and thus higher than the WHO guideline of 5.0 μg/m³. Toluene also reached 29.5 μg/m³, exceeding the standard 20.0 μg/m³ level, whereas the levels of formaldehyde were near the level at which the sites burn, of 9.6 μg/m³.

Table 3: Volatile organic compounds concentrations (μg/m³) across sampling sites

Compound	Control site	Open dump	Burning site	WHO limit
Benzene	1.5±0.01	4.2±0.15	8.7±0.38	5.0
Toluene	7.8±0.26	15.3±0.94	29.5±1.19	20.0
Formaldehyde	2.1±0.08	4.8±0.27	9.6±0.62	10.0

Respiratory Health Outcomes among Residents

The health survey data shows a clear gradient of narrow definition respiratory disease prevalence by distance to the dump sites with the high prevalence areas being those closer to the burning sites (Table 4). Chronic cough was reported by 39.5% of participants living near the burning sites, compared with 12.3% in control areas. Wheezing/asthma and bronchitis were also significantly higher near dumpsites (19.7% and 12.4%, respectively), and among subjects living near burning sites both were alarmingly high (34.1% and 21.6%, respectively). It was the same with shortness of breath, which jumped fivefold from 9.1% in control areas to 36.3% near burning zones.

Table 4: Prevalence of respiratory symptoms by exposure group (%)

Symptom	Control area	Near dumpsite	Near burning site
Chronic cough	12.3±1.74	24.8±2.65	39.5±4.38
Wheezing/asthma	8.6±0.92	19.7±2.07	34.1±3.95
Bronchitis	5.2±0.68	12.4±1.36	21.6±2.81
Shortness of breath	9.1±1.03	22.6±2.51	36.3±4.16

Cardiovascular Health Effects

The findings indicate a strong association between exposure to waste-related air pollutants and increased cardiovascular health risks (Figure 1). Hypertension prevalence rose steadily from 14.7% in the control area to 22.8% near dumpsites and peaked at 31.4% near burning sites. Similarly, heart disease prevalence nearly tripled, from 6.4% in control areas to 18.7% near burning zones.

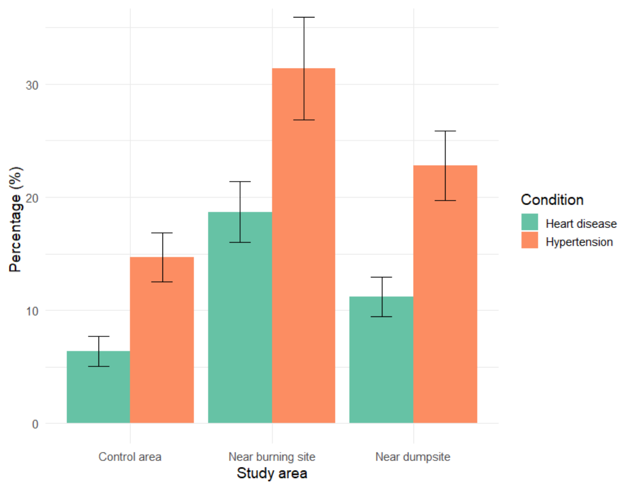

Figure 1: Prevalence of cardiovascular conditions (%) across sampling sites

Risk Assessment of Heavy Metals

The HQ assessment associated with heavy metal intake close to waste disposal sites reflects a human health risk (Table 5). For lead, cadmium, and arsenic, the HQ values were less than the safe limit at the control site (HQ < 1). But cadmium (1.2), arsenic (1.6) exceeded the safe limit, whereas lead (0.7) reached close to the limit at open dumpsites. At the site of the burning, all metals were significantly higher than the safe level: lead (1.5), cadmium (2.4), and arsenic (3.1).

Table 5: Non-carcinogenic risk assessment (HQ Values) across sampling sites

Metal	Control site	Open dump	Burning site	Threshold (HQ < 1)
Lead	0.3±0.01	0.7±0.01	1.5±0.03	Safe if < 1
Cadmium	0.4±0.01	1.2±0.03	2.4±0.09	Safe if < 1
Arsenic	0.8±0.02	1.6±0.05	3.1±0.13	Safe if < 1

Mortality and Morbidity Estimates

The health burden demonstrates a clear increase in both excess mortality and hospital admissions associated with proximity to waste management sites (Figure 2). The control site recorded the lowest rates, with 15 deaths and 38 hospital admissions per 100,000 population. These values more than doubled near open dumps, reaching 43 deaths and 97 hospital admissions per 100,000 and were highest near burning sites, with 78 deaths and 165 hospital admissions per 100,000 population.

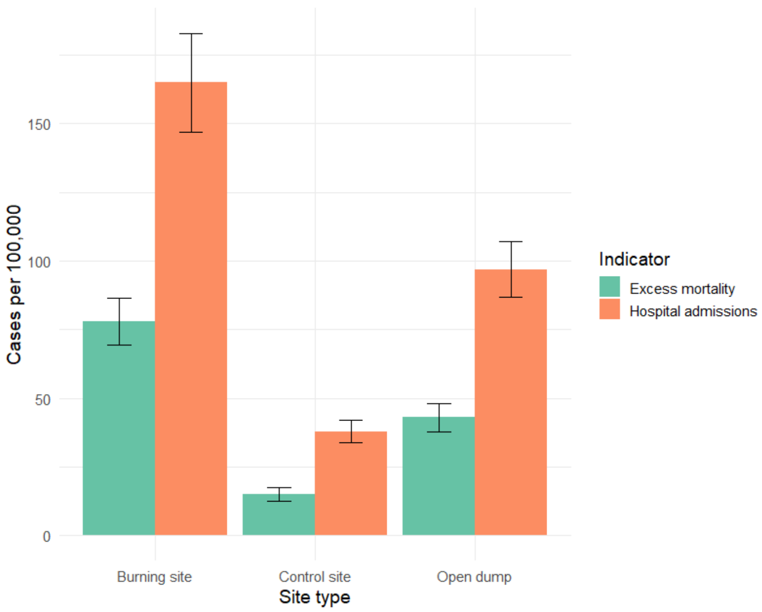

Figure 2: Estimated health burden from $PM_{2.5}$ exposure

Discussion

The current work has shown that non-effective urban waste management systems, primarily open dumping and burning, can increase the concentration of air pollutants at high levels and thus would put at risk the health of the near populations. The measured concentrations of $PM_2.5$ and PM_{10} (112.8 μg/m³ and 210.3 μg/m³, respectively), were substantially above WHO guideline limits, which is in line with findings from other urban environments in low and middle-income countries, where open waste burning has been reported to be a significant source of fine particulate pollution (Southerland *et al.*, 2022; Wei & Semple, 2023). Higher NOx, SO_2, and CO levels around burning and dump sites provide additional evidence that unsound waste management is a major contributor to urban air pollution beyond other known sources like motor vehicles or industrial emitters. These results are all in line with the work of Ipeaiyeda & Falusi (2018); Okedere *et al.* (2019) and Pekdogan *et al.* (2024), where waste emissions caused a significant rise in the particle concentration $PM_{2.5}$, and the associated health effects.

The heavy metal assessment further showed toxic concentrations of lead, cadmium, arsenic and mercury at the dumpsites with concentrations far above the WHO/USEPA limits. Similar findings were recorded in Nigeria and Bangladesh, where the open burning of mixed municipal waste resulted in the release of metals depositing on air particulates that present health risks of an acute and chronic nature (Karim *et al.*, 2017; Laoye *et al.*, 2025). HQ values of cadmium and arsenic greater than 1 at dumpsites and burning sites reveal an organ toxic propensity and are in support of earlier observations that close residents of waste processing zones are at risk of systemic toxicity and chronic organ damage (Teschke, 2024; Xue *et al.*, 2012).

Levels of toxic volatile organic compounds (VOCs), including benzene and toluene peaked at potentially dangerous levels around burning events. These findings are in line with the findings from Indian (Puttaswamy *et al.*, 2021; Singh *et al.*, 2023) and Chinese (Zheng *et al.*, 2020; Zhou *et al.*, 2019) study, providing evidence of substantial VOC emissions from open waste burning with benzene being a major carcinogenic risk factor. Formaldehyde exposure levels, though close to the WHO limit, indicate that risks of chronic exposure exist, mainly direct respiratory irritation and potential chronic effects for sensitive sub-populations (Nielsen *et al.*, 2017).

Health impact studies have demonstrated a strong gradient of respiratory and cardiovascular diseases in relation to the distance from these facilities. Chronic cough, asthma, bronchitis, and shortness of breath were highest around burning sites, reflecting previous epidemiological evidence associating particulate matter and VOC exposure with respiratory morbidity (Doiron *et al.*, 2021; Kelly, 2021). Cardio-Respiratory outcomes (hypertension and heart disease) were markedly higher in proximity to dumpsites and burning-grounds, and reflect the larger literature which links particulate depositions and metal inhalation to forms of cardiovascular morbidity and mortality (Brook & Rajagopalan, 2009; Hamanaka & Mutlu, 2018).

Estimates modeled for mortality and morbidity similarly support the scale of the public health burden with excess deaths and hospital admissions almost fivefold greater at burn sites than in control areas. These results are consistent with the $PM_{2.5}$ exposure from waste combustion was associated with significant premature death and hospital admission (Pozzer *et al.*, 2023; Southerland *et al.*, 2022).

Findings

a) According to the air quality monitoring, the levels of particulate matter ($PM_{2.5}$ and PM_{10}), nitrogen oxides (NOx), sulfur dioxide (SO_2), carbon monoxide (CO), heavy metals, and volatile organic compounds (VOCs) sites at the open dump and burning compared to control areas. Nearly all of these contaminants were above both WHO and USEPA recommended guideline values, suggesting that the air quality around the under-performing waste sites was unsafe.

b) Lead, cadmium, arsenic and mercury were found in high concentrations, particularly close to burning locations. The analysis of Hazard Quotient (HQ) revealed the possibility of non-carcinogenic health risks for cadmium and arsenic, showing potential long-term systemic toxicity and carcinogenicity.

c) Benzene and toluene concentrations were especially elevated over burning sites, with benzene surpassing WHO standards and proving to be extremely hazardous to respiratory and cancer risks of the local populations.

d) The prevalence of respiratory symptoms such as chronic cough, wheeze, bronchitis, and shortness of breath was significantly higher among communities who lived closer either to dumpsites or burning sites.

e) Hypertension and IHD prevalence increased with proximity to waste sites in a dose-response trend, and the latter was most prevalent in burning site residents.

f) There was a consistent pattern observed in mortality and hospital admission estimates with the excess deaths and hospitalizations being highest around the burning locations.

g) The pollution levels and associated health risks were greatest at the burning sites, followed by the open dumps; the fire sites had the least pollution exposure readings.

Recommendations

a) Waste managers should promote waste collection and recycling and facilities for ash disposal in order to reduce open dumping and open burning. The construction of sanitary landfills and of compost with form could lead to a dramatic decrease in air pollutant emissions.

b) Strict environmental laws should be implemented by the respective governments and the ambient air quality should be monitored around the waste disposal sites to locate hotspots and control the exposure of pollutants.

c) Information, education, and communication for residents and waste workers can inform communities about the negative health impact of open burning and persuade desired behavioral changes (e.g., cessation of backyard burning and promotion of source separation).

d) Protections, including the use of personal protective equipment (PPE) and routine health monitoring, also need to be employed for workers handling waste and specifically waste from collection and processing for their occupational exposure to harmful pollutants.

e) Urban planners should think about where to locate a waste treatment site in relation to residential areas, schools and hospitals to limit exposure to these airborne pollutants.

f) Controlled incineration can substitute open burning and release fewer pollutants, such as particles, VOCs, and heavy metals, and it can recover a range of sustainable energy.

g) Further study is suggested to assess potential long-term health impacts, explore pollutant propagation patterns and effectiveness of mitigation actions.

CONCLUSION

This research strongly indicates that poor urban waste management, notably open dumping and open burning, are major causes of high airborne pollutant contents, particulates, heavy metals and volatile organic compounds as well as have serious health consequences, of respiratory, cardiovascular and systemic nature, for the exposed population. People living near dumpsites and burning sites reported significantly higher percentages of chronic cough and asthma, bronchitis, hypertension, heart disease, and risk assessments showed that exposure to heavy metals including cadmium and arsenic exceeded safe levels, and constituting significant long term health threats. Mortality and morbidity also emphasized the significant public health impact of bad sanitation and waste management. These results emphasize the requirement for sustainable and controlled, hi-tech based waste disposal methods, along with public education, occupational safety and regular monitoring of air quality. For future research longitudinal studies would be valuable for the evaluation of chronic health effects and long-term exposure risks, whereas regional comparative studies can be useful for a wider evaluation of the effectiveness of different waste management interventions. Furthermore, the research on novel waste-to-energy technologies and their effect on reducing air pollutants might offer practical guidance for urban developers and decision-makers who are trying to mitigate adverse health outcomes from urban waste pollution.

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