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Airborne pollutants from landfills and their health effects on scavengers and nearby communities: A scoping review

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Abstract: Landfills are major sources of airborne pollutants such as H_2S, NH_3, volatile organic compounds (VOCs), particulate matter, and bioaerosols, which threaten both environmental and human health. This scoping review aimed to map landfill-related airborne pollutants, assess their health impacts, and identify research gaps for future directions. A comprehensive search was conducted in Scopus, PubMed, Web of Science, and ScienceDirect for studies published between 2020 and August 2025. Studies were screened and charted, resulting in 18 articles included. Data were synthesized thematically into four domains: types of airborne pollutants, health effects, methodological innovations, and research gaps. The review identified diverse pollutants, with H_2S, NH_3, VOCs, PM, and microbial bioaerosols most frequently reported. These were associated with respiratory dysfunction, cardiovascular risks, infectious diseases, and possible carcinogenic effects. Scavengers and marginalized communities consistently experienced higher exposures due to socioeconomic disadvantages and the absence of occupational safety measures. While methodological advances such as environmental monitoring and spatial modeling have improved understanding of pollutant dispersion, most studies relied on cross-sectional designs, lacked biomonitoring, and underrepresented vulnerable groups. Airborne pollutants from landfills represent a significant but under-researched environmental health challenge. Strengthening evidence requires longitudinal and biomarker-based studies focusing on vulnerable populations.

Keywords: *Airborne pollutants, Community, Health effects, Landfill, Scavengers.*

1. Introduction

The generation of urban waste is experiencing a record increase globally, presenting significant universal challenges for waste management systems. Current projections showed that population expansion, swift urbanization, and economic advancement will contribute significantly to the estimated 3.40 billion tons of waste produced worldwide by 2050, an increase from 2.01 billion tons in 2016 [1]. The management of waste and its associated health risks is now a significant concern for environmental integrity and public health due to this troubling trend.

Landfills are recognized as a major source of environmental pollutants due to their complex interactions with ecological systems. They generate both gaseous and liquid byproducts that can contaminate air, soil, and water, posing substantial risks to human health and the environment. Leachate, formed as water percolates through waste materials, contains organic and inorganic compounds, heavy metals, and nutrients that threaten groundwater quality and surrounding ecosystems

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[2-4]. Heavy metals such as cadmium, chromium, lead, and nickel are of particular concern due to their persistence and toxicity, necessitating ongoing monitoring and management [4, 5].

In addition, landfill gas emissions, especially methane (CH_4) and carbon dioxide (CO_2), contribute to local air pollution and climate change, with methane having a global warming potential far exceeding carbon dioxide [6, 7]. Poorly managed landfills further exacerbate risks through foul odors, the spread of vectors, and uncontrolled pollutant release, demonstrating the importance of stricter management, advanced treatment technologies, and effective regulatory frameworks [8-11].

Within this environmental context, waste scavenging emerges as a multifaceted phenomenon that intertwines health, socio-economic, and ecological dimensions. In many developing countries where formal waste management systems are inadequate, scavengers play an essential role in retrieving recyclable materials and reducing urban waste volumes [12-14]. Nevertheless, this contribution comes at a significant human cost. Scavengers are routinely exposed to hazardous substances without protective equipment, making them vulnerable to respiratory illnesses, injuries, infections, and toxic exposures [15-19].

These adverse exposures translate into well-documented health outcomes, including impaired lung function and increased susceptibility to infectious diseases, reflecting broader neglect of occupational health protections in the informal labor sector [20, 21]. While scavenging provides critical economic support for marginalized households, these workers often face social stigma, policy exclusion, and gender-based vulnerabilities that compound their health and economic risks [22, 23].

Importantly, the risks associated with landfill pollutants extend beyond scavengers themselves. Communities living near dumpsites are also directly exposed to airborne contaminants, which are strongly associated with severe respiratory illnesses and other chronic health conditions. Children and marginalized populations are disproportionately affected, underscoring how landfill-related pollution not only undermines public health but also reinforces existing socio-economic inequities and constitutes a pressing environmental justice concern [24, 25].

Despite the increasing number of studies, important research gaps persist. Most investigations focus on general air quality, while specific impacts on Scavengers and nearby communities remain underexplored. Few studies integrate biomonitoring, employ longitudinal designs, or address vulnerable groups, limiting our understanding of dose–response relationships and the cumulative health burden of landfill-related pollutants.

Against this background, the present scoping review has three objectives: (1) to map the existing literature on airborne pollutants from landfills, (2) to identify their health impacts on Scavengers and surrounding communities, and (3) to highlight research gaps to propose future research priorities and inform public health policy.

2. Materials and Methods

This scoping review was conducted following the methodological framework outlined in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR). The review aimed to systematically map the existing evidence on airborne pollutants originating from landfills and their health impacts on Scavengers and nearby communities.

2.1. Eligibility Criteria

We included original research, laboratory study, and clinical study that investigated the presence of airborne pollutants in landfill areas and their potential or reported health outcomes. Only studies published in English were considered. The eligibility of studies was defined using the Population–Concept–Context (PCC) framework.

Table 1.
Description of Inclusion Criteria.

Criteria	Inclusion
Population	Studies involving Scavengers (informal recyclers or scavengers) and residents living near landfill sites
Concept	Exposure to airborne pollutants, including gases (H_2S, NH_3, CH_4, CO_2, volatile organic compounds), particulate matter ($PM_{2.5}$, PM_{10}), bioaerosols (bacteria, fungi, endotoxins), and volatile heavy metals
Context	Studies conducted in or around landfill environments, regardless of geographical region

2.2. Information Source and Search Strategy

A comprehensive search was performed across several electronic databases, including Scopus, PubMed, Web of Science, and ScienceDirect, covering the year 2020 to the last search date in August 2025. The search strategy using keywords include (("health risk*" OR "health hazard" OR "health danger" OR "health threat*" OR "health impact*" OR "health effect*") AND ("solid waste" OR "Municipal Solid Waste" OR "waste" OR "garbage" OR "rubbish" OR "trash") AND ("landfill*" OR "waste disposal site" OR "final disposal site" OR "garbage dump") AND ("public" OR "resident" OR "society" OR "community*")).

2.3. Selection Process

A comprehensive search was conducted in three major databases: Scopus (n = 427), PubMed (n = 95), and ScienceDirect (n = 86), resulting in a total of 608 records. After removing duplicates (n = 5), all remaining articles underwent a multi-stage screening process.

During the initial screening, non-original research articles (n = 224), non-English language publications (n = 5), and studies not relevant to the subject of interest (n = 163) were excluded, leaving 216 articles eligible for further assessment. Titles and abstracts of these records were reviewed against the inclusion and exclusion criteria.

From this stage, 161 records were excluded due to irrelevance or insufficient alignment with the predefined criteria, resulting in 55 studies retrieved for full-text assessment. These articles were then subjected to quality appraisal, in which 37 studies were excluded due to methodological limitations or unacceptable quality. Finally, a total of 18 studies met all eligibility and quality requirements and were included in the qualitative synthesis for this scoping review.

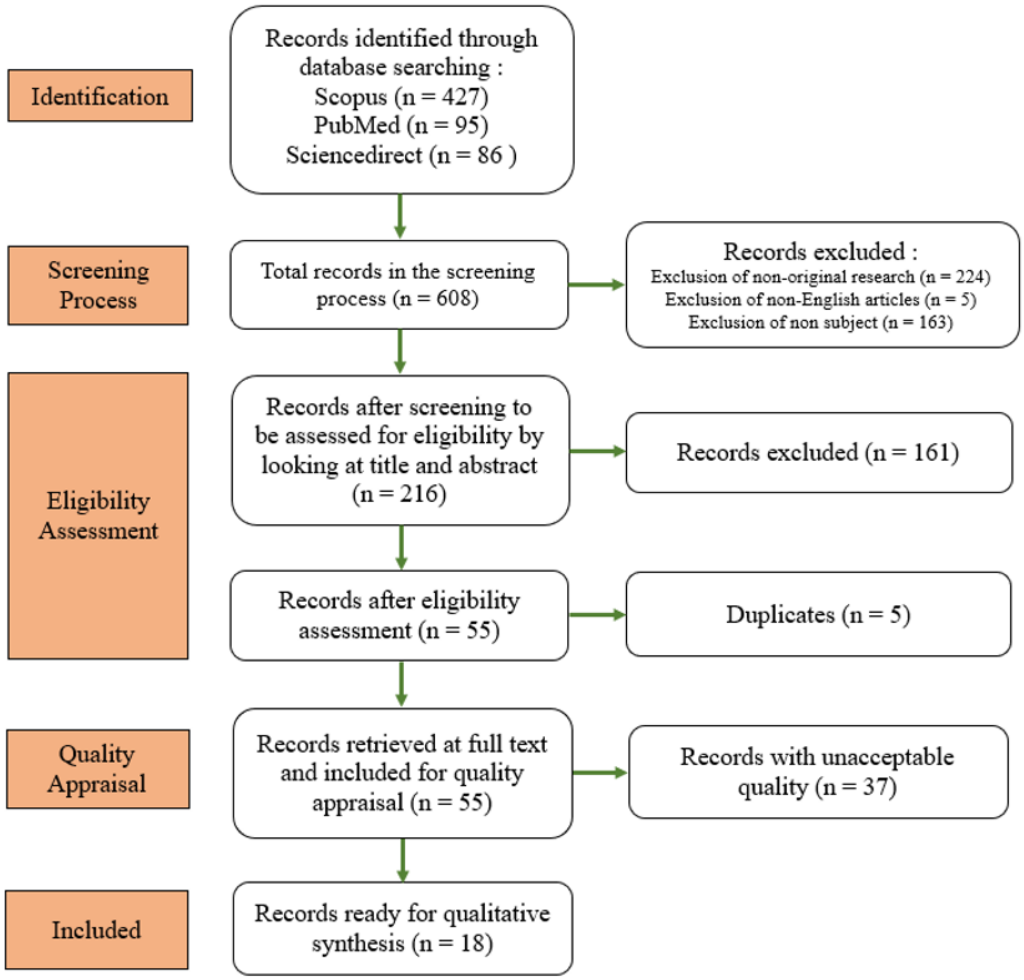

Figure 1.
PRISMA flowchart selection of studies.

2.4. Data Charting Process

A standardized data-charting form was developed to systematically extract relevant information from the included studies. Extracted data included:

1. The extracted data included bibliographic details such as author, year, and country.
2. The study also included characteristics such as the design, population, and sample size.
3. The study assessed the types of airborne pollutants.
4. The study also included methods for measuring or estimating airborne pollutants.
5. The study also examined the health outcomes reported by Scavengers or nearby residents.
6. The study yielded key findings and recommendations.

2.5. Synthesis of Results

The data were synthesized descriptively using a narrative and thematic approach. Studies were grouped according to Types of Airborne Pollutants from Landfills, Health Impacts of Landfill-Related Airborne Pollutants, Methodological Advances and Innovations and Gaps and Research Priorities.

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3. Results

This review included a total of 18 studies published between 2020 and 2025, encompassing diverse settings across Asia, Africa, Europe, and North America (Table 2). The methodological approaches varied from environmental monitoring and cross-sectional surveys to biomarker analyses and probabilistic risk modeling. This heterogeneity reflects the complexity of landfill-related exposures and suggests that it's important to integrate both environmental and human-centered perspectives in assessing health risks.

The pollutants most frequently reported included volatile organic compounds (VOCs), landfill gases such as methane, ammonia, and hydrogen sulfide, particulate matter ($PM_{2.5}$ and PM_{10}), as well as bioaerosols containing pathogenic and antibiotic-resistant microorganisms. Inhalation was the primary exposure pathway, occasionally supplemented by dermal contact. Populations studied ranged from informal Scavengers and landfill workers to residents living near waste sites, with evidence showing exposures frequently exceeded international health-based standards.

Health outcomes associated with these exposures included respiratory illnesses, allergies, skin and eye problems, gastrointestinal disturbances, and, in long-term contexts, risks of cardiovascular, neurological, and carcinogenic effects. Biomarker studies further demonstrated significant elevations in inflammatory and hematological indicators among exposed workers. While limitations such as reliance on cross-sectional designs and self-reported outcomes were noted, methodological strengths included innovative monitoring technologies, molecular microbial analyses, and advanced risk assessment models. Collectively, the evidence demonstrates a consistent pattern of elevated health risks for Scavengers and surrounding communities, which points to the need for more rigorous longitudinal research and policy interventions.

The geographical distribution of the studies shows representation from 12 countries. The largest contribution came from China (4 articles), followed by India (3 articles) and Iran (2 articles). Meanwhile, other countries such as Taiwan, the United States, Russia, Serbia, Bangladesh, Malaysia, Palestine, Ghana, and Nigeria each contributed one article. This pattern indicates that the majority of evidence comes from Asia, particularly countries with high population densities and complex waste management issues. However, representation from Africa (Ghana, Nigeria), Eastern Europe (Russia, Serbia), the Middle East (Palestine, Iran), and North America (USA) enriches the global perspective, although the number remains limited. Figure 2 presents a map of the number of articles by country.

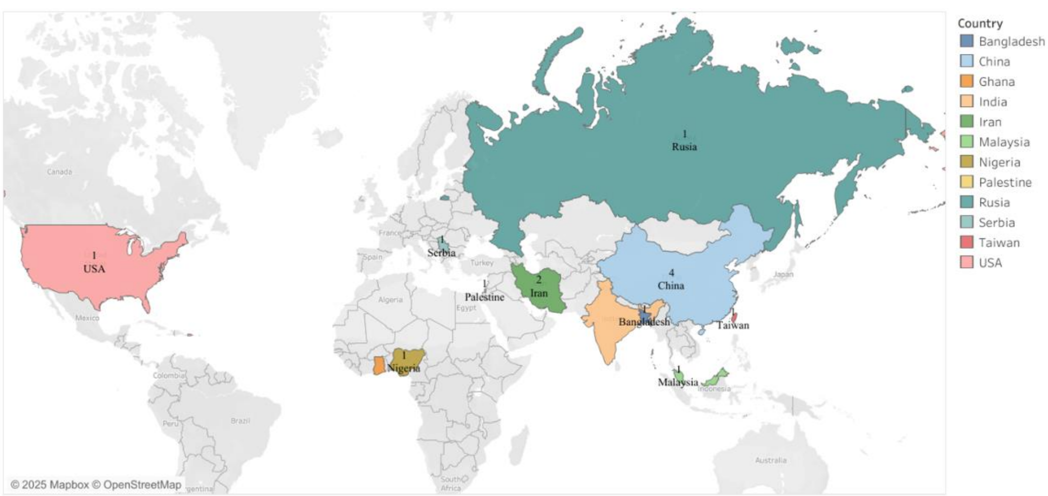

Figure 2.
Number of Articles by Country.

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Table 2.
Characteristics of Included Studies.

No	References	Title/Location/ Year	Design/ Method	Population	Polluttant	Exposure Pathway	Health Effects	Main findings	Limitations	Strengths
1	Chang, et al. [26]	A study of VOCs in waste incinerator plumes and landfill emissions via drone sounding Taiwan/2025	Field study; UAV-based plume sampling + GC–MS/FID VOC analysis	Environmental air samples (no direct human subjects)	VOCs: ethane, propane, ethyne, benzene, acetone, MEK, benzaldehyde, nonanal, decanal, TMSiOH	Inhalation via ambient air.	Risks from carcinogenic VOCs (benzene); marker potential for TMSiOH.	Incinerators mainly emit benzene & short-chain VOCs; landfills emit aldehydes; TMSiOH abundant in both, proposed as emission marker.	No direct health data; limited time points; semi-quantitative for some compounds.	Novel UAV-based real-time plume sampling; first to identify TMSiOH as landfill/incinerator marker.
2	Berger, et al. [27]	Analysis of Volatile Organic Compounds from Compost USA / 2025	Experimental field study; dual sampling (impinger + sorbent tube) with HS-GC-FID and TD-GC-MS	Compost piles (yard waste vs food/yard waste) – no human subjects	VOCs (methanol, ethanol, acetone, terpenes: alpha-pinene, beta-pinene, D-limonene, eucalyptol, etc.)	Inhalation (air emissions from compost piles)	Potential respiratory and systemic effects if exposures occur; methanol levels exceeded OSHA PEL (200 ppm)	Higher VOC emissions in food/yard waste piles; ethanol up to 27,400 ppm, methanol up to 3812 ppm; higher temperature piles released more VOCs; middle of pile > top location	Specific compost piles at one facility may not represent all sites; no direct human exposure data; no seasonal variation assessed	Developed effective dual-method capturing both water-soluble and insoluble VOCs; clear evidence of hazardous VOC levels; provides data for risk assessment and regulation
3	Kamdi, et al. [28]	Health risk assessment and characterization of PM2.5 bound bioaerosols at the municipal solid waste landfill site of Nagpur, India India / 2024	Field study; seasonal sampling (winter & pre-monsoon); PM2.5 & bioaerosol measurement; microbial ID (culture & molecular); antibiotic resistance test; USEPA health risk model	Landfill workers and nearby residents (0.5–1 km)	PM2.5-bound bioaerosols (bacteria, fungi, antibiotic-resistant strains)	Inhalation, dermal	Respiratory and systemic infections; risk especially in landfill workers	PM2.5 well above WHO/USEPA/India limits; high bioaerosol in winter; 30% virulent bacteria (β-hemolysis); some multi-drug resistant strains; HQ>1 in male workers in winter	Does not discuss children; limited to cultivable microbes; no long-term health follow-up; only two seasons	India's first study focuses on PM2.5-bioaerosol from landfills; combines microbiological data, antibiotic resistance, and health risk modeling; robust field design
4	Wu, et al.	Evaluation of	Field sampling	Landfill	Bioaerosols and	Inhalation	Respiratory	Excavation increased	One site only;	Multi-matrix

	[29]	pathogen spread risk from excavated landfill China/2024	(refuse, soil, plants, air, water) + microbial culture + risk assessment (HQ, inhalation model)	materials, nearby residents (modeled exposure)	pathogens (coliforms, hemolytic bacteria, *S. aureus*, *Salmonella*, enterococci)	(main), dermal (minor)	infections, microbial contamination risk	microbial release; refuse up to 10^{10} CFU/g; air in excavation 3.3×10^4 CFU/m³; downwind peak 6.56×10^4 CFU/m³ at 330 m; HQ_in >1 even at 500 m → risk to residents	culture-based (may underestimate non-culturable); short-term data	evidence; clear risk link to excavation; strong implications for bioaerosol control & worker protection
5	Tehrani, et al. [30]	Tracking bioaerosol exposure among municipal solid waste workers using hematological and inflammatory biomarkers Iran/2024	Observational study, Air sampling, inflammatory and hematological biomarker analysis	30 waste management workers, 30 park workers as a control group	Bioaerosols (fungi and bacteria)	Inhalation	Elevated inflammatory (hs-CRP, IgG) and hematological (WBC, PLT) biomarkers	Exposed workers showed significant increases in WBC, PLT, and hs-CRP levels compared to the control group. Aspergillus flavus and Staphylococcus aureus were the predominant species.	Lack of longitudinal data, only measuring culturable microorganisms	Use of inflammatory biomarkers to assess the health impacts of bioaerosol exposure
6	Kurbatova, et al. [31]	Concentration and health risk assessment of volatile organic compounds from a closed solid waste landfill site: The role of flaring system Rusia/2024	Observational studies: Measurement of VOC concentrations, health risk assessment	Workers at the landfill and residents in the nearby residential area	Volatile organic compounds (VOCs)	Inhalation	High carcinogenic and non-carcinogenic health risks to workers and surrounding residents	The carcinogenic risk to workers is 1.7×10^{-1}, well above the acceptable limit. The carcinogenic risk to residents after combustion is 1.13×10^{-4}, also above the acceptable limit	Does not take into account spatial variations in pollutant concentrations, as well as uncertainties in VOC measurements	Use of comprehensive, data-driven risk assessment methods to determine the health impacts of VOC exposure
7	Vinti, et al. [32]	Municipal Solid Waste Management and Health Risks: Application of Solid Waste Safety Plan in Novi Sad, Serbia	Case study: Data collection through interviews, observations, and technical document analysis	Residents living around the landfill site in Novi Sad	Landfill gas: Methane (CH_4), Carbon dioxide (CO_2). Volatile organic compounds (VOCs): Benzene,	Inhalation, dermal contact	Health risks from soil and water contamination, as well as potential injury to landfill workers	High risks to public and worker health related to groundwater contamination, air emissions, and workplace injuries	High risks to public and worker health related to groundwater contamination, air emissions, and workplace	Implementation of a comprehensive waste safety plan for health risk management

		Serbia/2024			toluene, xylene, chloroform Particulates: Solid particles from waste combustion				injuries	
8	Liang, et al. [33]	The exposure risks associated with pathogens and antibiotic resistance genes in bioaerosol from municipal landfill and surrounding area China/2023	Analysis of bioaerosol characteristics, pathogens, and antibiotic resistance genes using sequencing and qPCR	Samples from 11 points at the landfill and surrounding areas	Bioaerosols: Pathogens (Bacillus, Burkholderia) and allergenic fungi (Aspergillus, Cladosporium). Antibiotic Resistance Genes (ARGs): tetC, acrB, acrF, mdtF, bacA	Inhalation	Risk of respiratory infections, allergies, and the spread of antibiotic-resistant bacteria	Bioaerosols in landfills contain pathogens and ARGs; the highest bioaerosol levels are in the active sector	Limitations in environmental data sampling and analysis	A comprehensive approach to understanding health risks associated with bioaerosols in landfill environments
9	Li, et al. [34]	Health risk assessment of volatile organic compounds (VOCs) emitted from landfill working surface via dispersion simulation enhanced by probability analysis China/2023	Combination of an artificial neural network model (ANN) and a dispersion simulation model (ModOdor) with a probabilistic approach	Samples from landfill work surfaces that receive 10,000 tons of MSW per day	VOC: Etilbenzena, benzena, kloroform, 1,2-dikloroetana, 1,2-dikloropropana, tetrakloroetena	Inhalation	Non-cancerous and cancerous health risks; some VOCs show a minor to moderate risk of cancer	The health risks of VOCs are generally acceptable, but there is a potential risk of cancer in extreme conditions	Uncertainty in parameter inputs, meteorological data, and model configuration	The probabilistic approach provides a more comprehensive health risk profile
10	Bhoyar, et al. [35]	Prevalence, Dispersion and Nature of Bioaerosols over a Solid Landfill Site in Central India	Measurement of PM2.5 and bioaerosol (bacteria and fungi) concentrations using culture	Samples from landfill and surrounding areas (upwind and downwind)	Bioaerosols: Bacteria (Bacillus, Escherichia) and fungi (Aspergillus, Cladosporium)	Inhalation	Health risks include respiratory infections and allergies due to exposure to bioaerosols.	Bioaerosol concentrations are higher in landfills compared to surrounding areas.	Limitations in sampling and inadequate analysis	The first study on bioaerosols in a landfill in Nagpur, provides important baseline data

		India/2023	methods							
11	Fang, et al. [36]	Health risks of odorous compounds during the whole process of municipal solid waste collection and treatment in China China/2022	Data collection on the concentration of 86 odorous compounds from various waste treatment facilities	Waste treatment facilities: landfills, transfer stations, landfills, composting plants, and anaerobic fermentation plants	Odorless compounds, including aromatic and halogenated hydrocarbon compounds	Inhalation	Cancer and non-cancer risks; some compounds show significant cancer risk	The impact distance from the transfer station and landfill can reach ~1.5 km and ~5 km respectively.	Insufficient data for some waste treatment facilities	A systematic approach to health risk assessment that can be applied to waste management
12	Urme, et al. [37]	Dhaka landfill waste practices: addressing urban pollution and health hazards Baangladesh/2021	Mixed methods, including geospatial analysis, observation checklists, and qualitative interviews	Residents around the open dump and waste management officers	Odor compounds from waste, including aromatic and halogenated hydrocarbon compounds	Inhalation	Health risks include respiratory infections, allergies, and other health impacts	There is an urgent need to improve waste management systems to reduce health risks	Limitations in data collection and inadequate monitoring	Provides a comprehensive understanding of the health impacts of waste management in Dhaka
13	Samadi, et al. [38]	Characteristics and health effects of potentially pathogenic bacterial aerosols from a municipal solid waste landfill site in Hamadan, Iran Iran/2021	Air sampling, microbial analysis, and health risk assessment	Six locations at the waste disposal site: active zone, leachate holding pond, and others.	Air sampling, microbial analysis, and health risk assessment	Inhalation	Health risks include respiratory illnesses and infections	Highest pathogen bioaerosol concentrations in the active zone; HQ below 1, indicating acceptable risk, but increasing in summer	Limitations in assessing data quality and environmental conditions	Provides important insights into the health risks of bioaerosols at landfill sites
14	Singh, et al. [39]	Open dumping site and health risks to proximate communities in Mumbai, India India/2021	Cross-sectional study with case comparison design	200 respondents from exposed and unexposed communities near the dumping site	Harmful gases (methane, carbon dioxide, hydrogen sulfide). Particulate matter (PM10,	Inhalation	Increased prevalence of respiratory illnesses, eye infections, and stomach problems	The prevalence of morbidity was higher in the exposed group, with significant risk factors related to age and length of stay	The data obtained is subjective and may be influenced by response bias.	Providing evidence on the health impacts of improper waste management in Mumbai

					PM2.5). Volatile organic compounds (VOCs). Pathogenic bacteria					
15.	Norsa'adah, et al. [40]	Community Health Survey of Residents Living Near a Solid Waste Open Dumpsite in Sabak, Kelantan, Malaysia Malaysia/2020	Cross-sectional study with case comparison design	170 respondents from the exposed group and 119 from the unexposed group	Harmful gases (methane, carbon dioxide, ammonia). Particles (PM10, PM2.5). Pathogenic bacteria	Inhalation and dermal contact	Increased prevalence of health problems, including sore throat, diabetes mellitus, and hypertension.	The prevalence of morbidity was higher in the exposed group compared to the unexposed group	Relying on self-reported data, which may be affected by bias	Providing epidemiological evidence on the health impacts of waste disposal sites in Malaysia
16	Al-Khatib, et al. [41]	Assessment of Occupational Health and Safety among Scavengers in Gaza Strip, Palestine Palestine/2020	Analytical descriptive study with survey approach	301 scavengers working at the waste disposal site	Hazardous materials (medical waste, chemical waste) Toxic gases (landfill gas) Pathogenic microbes (bacteria, viruses)	Inhalation and dermal contact	Respiratory diseases, skin infections, gastrointestinal problems, and injuries	Many scavengers suffer from work-related illnesses; there is almost no occupational safety training.	The data obtained is subjective; no safety training was received.	Provides important insights into the health risks of scavengers in Gaza and the need for interventions
17	Odonkor and Mahami [42]	Microbial Air Quality in Neighborhoods near Landfill Sites: Implications for Public Health Ghana/2020	Analytical descriptive study with air sampling	The environment around the waste disposal site and surrounding houses	Pathogenic bacteria (Staphylococcus aureus, Escherichia coli, Pseudomonas aeruginosa) Fungi (Aspergillus niger, Cladosporium spp.)	Inhalation	Respiratory infections, allergies, and possibly other serious illnesses	Microbial air quality near waste disposal sites is poor; bacterial concentrations exceed acceptable limits.	There is no data on effective waste management at the disposal site.	Providing important information about the health risks of waste disposal in Ghana
18	Adetona, et	An exploratory	Cross-	Residents who	PM2.5,	Inhalation	Respiratory	Long-term exposure	No	Providing evidence

	al. [43]	evaluation of the potential pulmonary, neurological and other health effects of chronic exposure to emissions from municipal solid waste fires at a large dumpsite in Olusosun, Lagos, Nigeria Nigeria/2020	sectional study with ordinal logistic regression analysis	live or work near waste disposal sites	Polyaromatic hydrocarbons (PAHs), Harmful gases (CO, NO2, SO2, NH3, H2S)		(difficulty breathing, chest pain), neurological (headache, confusion), and musculoskeletal (back pain) symptoms	is associated with increased frequency of health symptoms; living near a waste disposal site for ≥11 years increases the risk of symptoms.	measurements of personal exposure to pollutants were made	on the health risks of solid waste fire emissions in Lagos

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3.1. Types of Airborne Pollutants from Landfills

The review identified a diverse of airborne pollutants originating from landfill environments (Table 3). Volatile organic compounds (VOCs) were among the most frequently reported, including benzene, toluene, aldehydes, chloroform, methanol, and ethanol, with some studies highlighting novel tracers such as trimethylsilanol (TMSiOH). Particulate matter ($PM_{2.5}$ and PM_{10}) was also commonly documented, often associated with bioaerosols containing pathogenic and allergenic microorganisms such as *Staphylococcus aureus*, *Escherichia coli*, and *Aspergillus* spp. Notably, several studies reported the presence of antibiotic-resistant strains and resistance genes, underscoring broader implications for public health.

In addition, landfill gases (methane, carbon dioxide, hydrogen sulfide, and ammonia) were reported in multiple studies, alongside odorous compounds and combustion by-products such as polycyclic aromatic hydrocarbons (PAHs). Collectively, these findings demonstrate that landfills act as significant sources of complex pollutant mixtures, with inhalation as the dominant exposure pathway. The recurring detection of VOCs, particulates, and bioaerosols, along with exceedances of international air quality standards in several studies, highlights the urgent need for targeted interventions to reduce exposures and protect vulnerable populations.

Table 3.
Types of Airborne Pollutants from Landfills.

References	Category of Pollutant	Types of Pollutants	Frequency of occurrence
Chang, et al. [26]; Berger, et al. [27]; Kurbatova, et al. [31]; Vinti, et al. [32]; Fang, et al. [36] and Urme, et al. [37]	Volatile Organic Compounds (VOCs)	Benzene, toluene, xylene, chloroform, aldehydes (benzaldehyde, nonanal, decanal), methanol, ethanol, acetone, MEK, ethylbenzene, TMSiOH.	8
Vinti, et al. [32]; Singh, et al. [39]; Norsa'adah, et al. [40]; Al-Khatib, et al. [41] and Adetona, et al. [43]	Landfill gases and light greenhouse gases	Methane (CH_4), Carbon dioxide (CO_2), Hydrogen sulfide (H_2S), Ammonia (NH_3), and toxic gases related to combustion (CO, NO_2, SO_2)	5
Kamdi, et al. [28]; Vinti, et al. [32]; Norsa'adah, et al. [40] and Adetona, et al. [43]	Particulate matter (PM)	$PM_{2.5}$, PM_{10} (often also reported as $PM_{2.5}$-bound bioaerosols)	6
Kamdi, et al. [28]; Wu, et al. [29]; Tehrani, et al. [30]; Liang, et al. [33]; Bhoyar, et al. [35]; Samadi, et al. [38]; Singh, et al. [39] and Norsa'adah, et al. [40]	Bioaerosols and Pathogens	Bacteria (Staphylococcus aureus, Bacillus spp., Escherichia), fungi (Aspergillus, Cladosporium), coliforms, Salmonella, enterococci; sometimes multi-drug resistant strains	10
Berger, et al. [27] and Fang, et al. [36]	Odorous / Halogenated aromatic compounds & other odours	Various odorant compounds (aromatic, halogenated hydrocarbons) were detected at transfer stations/landfills/composting	2
Fang, et al. [36] and Adetona, et al. [43]	Polycyclic aromatic hydrocarbons (PAHs) and combustion by-products	PAHs associated with open waste burning / landfill fires	2
Berger, et al. [27] and Liang, et al. [33]	Antibiotic resistance genes (ARGs) / resistance markers in bioaerosols	tetC, acrB, acrF, mdtF, bacA; evidence of antibiotic-resistant bacteria	2

The distribution pattern is further visualized through a bar chart (Figure 3). This visualization shows the differences in reporting rates across pollutant categories, with bioaerosols, VOCs, and particulates emerging as dominant groups compared to other categories. This chart provides a clearer picture of the types of pollutants that have received the most attention in the literature.

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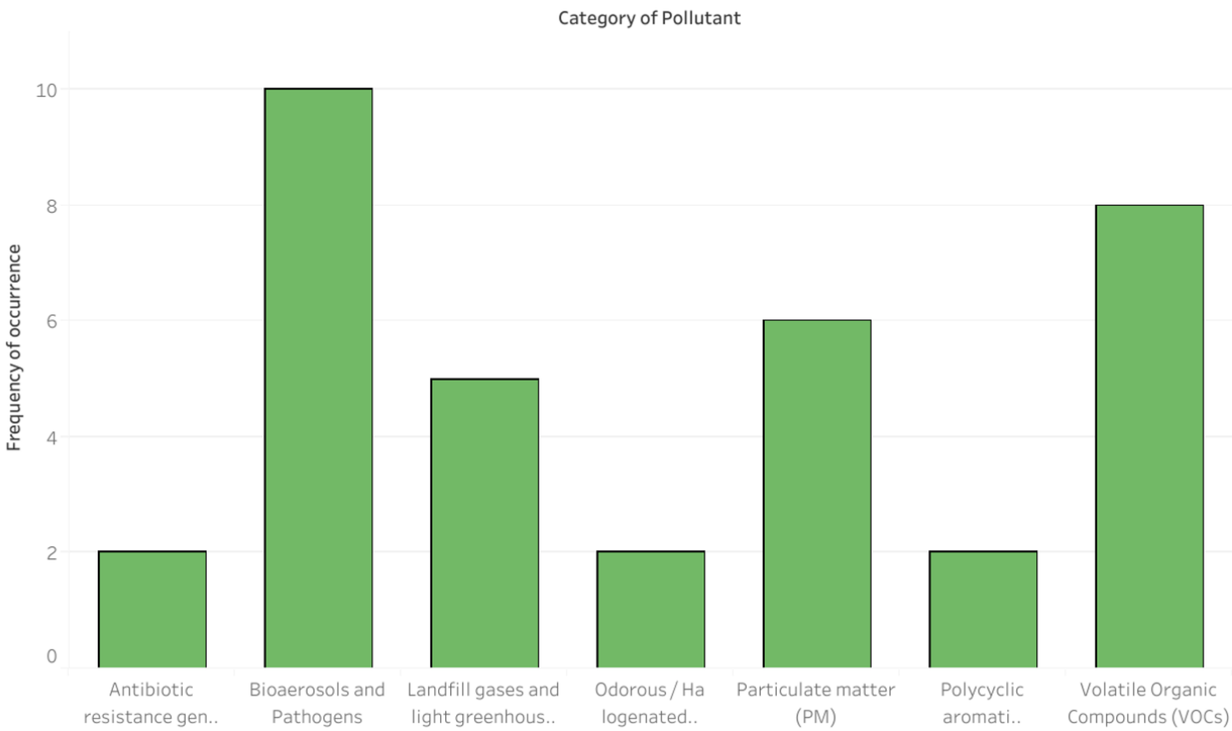

Figure 3.
Frequency of Occurrence of Airborne Pollutant Types.

3.2. Health Effects of Landfill-Related Airborne Pollutants

The reviewed studies strongly link landfill-related airborne pollutants to respiratory health problems (Table 4). VOCs, landfill gases, and particulate matter were associated with airway irritation, asthma, and bronchitis, while bioaerosols containing pathogenic and allergenic microorganisms contributed to infections and allergic reactions. The detection of antibiotic-resistant strains and resistance genes highlights an additional public health concern related to antimicrobial resistance.

Beyond respiratory illness, exposures were also linked to neurological symptoms (headaches, dizziness), dermatological and ocular problems (skin irritation, infections, conjunctivitis), and gastrointestinal complaints. Biomarker analyses indicated systemic effects through elevated inflammatory and hematological parameters, while risk modeling suggested carcinogenic potential from benzene, PAHs, and other VOCs. Overall, the evidence confirms that landfill emissions pose multi-system health risks, which points to the importance of preventive measures and stronger regulatory actions.

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Table 4.
Health Impacts of Landfill-Related Airborne Pollutants.

Reference	Health Effects	Types of Pollutants Causing
Chang, et al. [26]	Carcinogenic risk	VOCs (benzene, aldehydes, TMSiOH)
Berger, et al. [27]	Respiratory disorders	VOCs (methanol, ethanol, acetone, terpenes)
Kamdi, et al. [28]	Respiratory infection, systemic risk; HQ>1 in workers	PM2.5-bound bioaerosols (bacteria, fungi, antibiotic-resistant strains)
Wu, et al. [29]	Respiratory infection	Bioaerosols and pathogens (coliforms, Salmonella, enterococci, S. aureus)
Tehrani, et al. [30]	Elevated inflammatory (hs-CRP, IgG) and hematological (WBC, PLT) biomarkers	Bioaerosols (fungi, bacteria)
Kurbatova, et al. [31]	Cancer and non-cancer risks	VOCs
Vinti, et al. [32]	Respiratory disorders and infections	Landfill gas (CH_4, CO_2), VOCs (benzene, toluene, xylene, chloroform), particulates
Liang, et al. [33]	Respiratory infections, allergies, spread of antibiotic-resistant bacteria	Bioaerosols (Bacillus, Aspergillus, Cladosporium) + ARGs (tetC, acrB, etc.)
Li, et al. [34]	Cancer and non-cancer risks	VOCs (benzene, etilbenzene, chloroform, dll.)
Bhoyar, et al. [35]	Respiratory infections and allergies	Bioaerosols (bacteria and fungi) + PM2.5
Fang, et al. [36]	Cancer and non-cancer risks	Odor compounds (aromatic, halogenated hydrocarbons)
Urme, et al. [37]	Respiratory infections, allergies, public health risks	Odor compounds (aromatic, halogenated hydrocarbons)
Samadi, et al. [38]	Respiratory and infectious diseases, the risk increases in summer	Pathogenic bioaerosols (bacterial aerosols)
Singh, et al. [39]	Respiratory diseases, eye infections, gastrointestinal problems	Landfill gases (CH_4, CO_2, H_2S), VOCs, PM10/PM2.5, pathogens
Norsa'adah, et al. [40]	The prevalence of sore throat, DM, hypertension is increasing	Landfill gases (CH_4, CO_2, NH_3), PM10/PM2.5, pathogenic bacteria
Al-Khatib, et al. [41]	Respiratory diseases, skin infections, gastrointestinal problems, work injuries	Landfill gases, medical/chemical waste, pathogens
Odonkor and Mahami [42]	Respiratory infections, allergies, other potential serious illnesses	Bioaerosols (S. aureus, E. coli, Aspergillus, Cladosporium)
Adetona, et al. [43]	Respiratory symptoms (tightness, chest pain), neurological (headache, confusion), musculoskeletal (back pain)	PM2.5, PAHs, hazardous gases (CO, NO_2, SO_2, NH_3, H_2S)

3.3. Methodological Advances and Innovations

The included studies employed a wide array of methodological approaches, ranging from advanced environmental monitoring to biomarker assessments and community-based surveys (Table 5). Innovative techniques such as UAV-based plume sampling, dual-method VOC collection, molecular sequencing for bioaerosols, and probabilistic dispersion modeling highlighted the increasing sophistication of research on landfill-related exposures. These approaches gave us useful information about pollutant characterization, exposure pathways, and health risks, while some studies uniquely combined environmental monitoring with health indicators, such as inflammatory biomarkers or community morbidity surveys. Collectively, these methodological advances illustrate a growing trend toward integrating multidisciplinary tools to capture the complexity of airborne pollutants and their health implications.

Despite these strengths, studies consistently noted several limitations. Short-term or single-site sampling often limited the generalizability of environmental monitoring, while the reliance on culture-based microbiology undervalued non-culturable organisms. Cross-sectional designs, self-reported health data, and the lack of longitudinal follow-up often constrained biomarker and epidemiological studies, which offered valuable evidence. While modeling approaches offered risk estimates, they heavily relied on assumptions and the quality of input data. Taken together, the strengths and limitations point to the importance of future research to adopt more comprehensive, long-term, and multi-method designs that combine environmental, biological, and epidemiological data for a more holistic understanding of landfill-related health risks.

Table 5.
Methodological Advances and Innovations.

Reference	Innovations/ Main Methods	Strengths	Limitations
Chang, et al. [26]	UAV-based plume sampling + GC–MS/FID for incinerator & landfill emissions; TMSiOH identification	Real-time sampling in hard-to-reach areas; new markers (TMSiOH) for emission sources; Separation of VOC profiles incinerator vs landfill	No human health data; limited time points; some semi-quantitative compounds only
Berger, et al. [27]	Dual-method (impinger + sorbent) + HS-GC-FID/TD-GC-MS on compost pile	Capturing soluble and insoluble VOCs of water; quantitative evidence of harmful VOCs (high methanol/ethanol); basis for regulation	One facility; no personal exposure data; does not judge the variation of the seasons.
Kamdi, et al. [28]	PM2.5 & bioaerosol; culture + molecular; resistance test; USEPA health risk model	Multidisciplinary design; link PM2.5–bioaerosol–AMR–risk; Evidence of Seasons and Workers	Not discussing children; microbes are cultivated only; no long-term follow-up
Wu, et al. [29]	Multi-matrix (air, soil, water, vegetation, refuse) + culture + inhalation HQ model	Strong evidence of the effects of excavation on microbial release; Clear spatial/downwind footprint	One location; cultural approach (underestimating non-cultural); Short-term data
Tehrani, et al. [30]	Inflammatory/ hematological biomarkers (hs-CRP, IgG, WBC, PLT) in workers	Direct biological evidence of exposure response; Clear group control	Not longitudinal; cultivable microbes; Limited sample size
Kurbatova, et al. [31]	VOC measurements in closed landfills; carcinogenic/non-carcinogenic risk assessment; Flaring evaluation	comprehensive risk assessment; Quantification of Worker and Citizen Risk	Spatial variation is lacking; uncertainty of VOC measurements has not been fully characterized
Vinti, et al. [32]	Implementation *of the Solid Waste Safety Plan* (SWSP); policy studies & K3	Integrative risk management framework (worker & public); Relevant for implementation	Duplication of findings entries; Case study-based—limited generalizations
Liang, et al. [33]	Bioaerosol sequencing and qPCR; detection of ARGs (tetC, acrB, acrF, mdtF, bacA)	Detailed molecular approach; reveal the potential spread of AMR	Limited scope of samples and environmental data; No direct clinical outcomes
Li, et al. [34]	ANN+ ModOdor dispersion with a probabilistic approach to VOC risk	More comprehensive risk profile; Explicit Uncertainty	Depending on the assumptions of the model & meteorological data; No biomonitoring verification
Bhoyar, et al. [35]	Culture-based PM2.5 and bioaerosol measurements (upwind/downwind)	The first baseline data for the site; Measured spatial variation	Limitations of sampling and analysis design; without broad molecular confirmation
Fang, et al. [36]	Quantification of 86 odorous compounds across facilities; Risk Assessment & Impact Distance	The scope of the waste management process is wide; Defining the Impact Radius	Some data facilities are lacking; Cross-place inference needs caution
Urme, et al. [37]	*Mixed methods*: spatial analysis, observation, interviews	Technical + social perspective; hazard mapping and risk perception	Limited quantitative monitoring; Data is not continuous
Samadi, et al. [38]	Multi-location air sampling; microbial analysis; Risk assessment bioaerosol	Identify seasonal variations and zoning; Quantified HQ	Limited environmental quality/variables; Other location generalizations are limited
Singh, et al. [39]	Exposed vs. Unexposed Community Survey (Case-Comparison))	Community epidemiological evidence; Identify risk factors	Self-reported data (response bias); No personal measurements
Norsa'adah, et al. [40]	Exposed vs unexposed *community survey*	Quantitative evidence of morbidity; covers several categories of diseases	Dependence on self-report; Potential Selection and Confounding Bias
Al-Khatib, et al. [41]	Scavenger K3 survey (occupational)	Highlight the risks of real work and lack of training; Implications of the intervention	Subjective data; No environmental/personal measurements

Odonkor and Mahami [42]	Microbiological air sampling in settlements around landfills	Evidence of poor microbial air quality; relevant to public health	Without landfill management data; does not assess direct clinical outcomes
Adetona, et al. [43]	Symptom survey; *ordinal logistic regression* analysis on exposure to garbage fires	Attributing chronic exposure to a spectrum of symptoms; Clear statistical analytics	No personal exposure measurements; complex environmental confounding factors

3.4. Gaps and Research Priorities

Even while there is more and more research on airborne pollution from landfills, there are still some important gaps in our knowledge. Most studies conducted thus far have depended on cross-sectional or short-term environmental monitoring, which constrains the capacity to ascertain causal linkages or to document long-term health impacts. There have been very few studies that have used longitudinal or cohort designs, and personal biomonitoring of exposure using biomarkers in blood, urine, or exhaled air is still mostly missing. This gap makes it harder to understand dose–response connections and the overall health burden on Scavengers and the people who live near them.

Another significant drawback is the insufficient representation of vulnerable populations. Much research concentrates on trash workers and adult residents, but children, women, and the elderly who may exhibit distinct vulnerability and exposure patterns are hardly examined. Most of the evidence comes from low- and middle-income nations, but it's sometimes hard to get good data since there aren't enough resources. This means that researchers have to rely on self-reported health outcomes or basic culture-based microbiology. Advanced molecular, toxicological, and modeling methodologies are predominantly found in studies originating from high-income contexts, resulting in a global imbalance in study quality and scope.

Subsequent research should emphasize longitudinal epidemiological investigations that amalgamate environmental monitoring with biomonitoring and clinical outcomes. There is an urgent necessity to broaden research on antimicrobial resistance in waste bioaerosols and the carcinogenic potential of complex pollutant mixes. Research must progress from mere characterization to intervention, assessing the efficacy of engineering controls, protective measures for Scavengers, and community-level health risk reduction programs. These efforts will not only fill in gaps in the knowledge but they will also make it easier to turn scientific discoveries into policies that protect the most vulnerable people and promote environmental justice.

4. Discussion

4.1. Types of Airborne Pollutants from Landfills

Landfills function as dynamic biogeochemical systems where organic matter decomposition, volatilization of nitrogenous compounds, and microbial processes generate a wide spectrum of airborne contaminants. The findings demonstrate the presence of H_2S, NH_3, VOCs, PM, and bioaerosols as dominant pollutants. Each represents not only a byproduct of waste degradation but also an indicator of inadequate waste stabilization and emission control, underscoring systemic weaknesses in landfill management across both developed and developing contexts.

The heterogeneity of pollutants reflects temporal and spatial variability within landfill sites. For instance, H_2S concentrations tend to peak in the early stages of organic decomposition, while PM and bioaerosols are often linked to physical disturbances of waste layers, such as excavation or open burning. VOCs, by contrast, persist as long-term emissions, contributing to chronic health exposures. This diversity suggests that assessing a single pollutant in isolation may underestimate the cumulative exposure burden faced by nearby populations.

Moreover, these pollutants interact synergistically in ways that amplify toxicity. For example, VOCs can adhere to fine particulates, facilitating deeper penetration into the respiratory tract, while bioaerosols may act as carriers of chemical pollutants. Such co-exposures complicate toxicological profiles and present challenges for both environmental monitoring and epidemiological research. Policy frameworks, which often compartmentalize risk assessments, have not consistently addressed these complex interactions.

Understanding the landfill as a multi-pollutant ecosystem necessitates the implementation of integrated strategies that blend environmental engineering solutions with health protection measures. Continuous monitoring with multi-sensor technologies and predictive modeling of emission dynamics would enable a more accurate characterization of risks. Without such integrative approaches, communities and scavengers will continue to face disproportionate and poorly quantified health threats.

4.2. Health Effects of Landfill-Related Airborne Pollutants

The reviewed evidence indicates that exposure to landfill-related emissions translates into diverse health consequences, particularly affecting respiratory and systemic functions. While respiratory diseases remain the most frequently reported, the range of observed effects spanning cardiovascular, neurological, dermatological, and infectious outcomes suggests that pollutants act on multiple biological systems simultaneously. This multi-organ impact aligns with toxicological insights that chronic exposure to mixed pollutants can disrupt metabolic, immunological, and cellular pathways.

Importantly, scavengers represent a uniquely vulnerable group due to both occupational and social determinants. Extended daily exposure, lack of protective equipment, and frequent contact with waste materials magnify their health risks compared to the general population. Socio-economic constraints, such as limited access to healthcare services and weak social protection mechanisms, further exacerbate these risks. Scavenging not only presents as an occupational hazard, but also serves as a lens that highlights structural health inequalities.

Communities near landfills also experience disproportionate risks, particularly affecting children and marginalized households. Evidence linking chronic exposure to pollutants with developmental issues and increased susceptibility to infections suggests that there must be targeted interventions in these populations. The environmental justice dimension becomes evident here: those least equipped to mitigate exposure are those who endure the heaviest health burdens.

The convergence of chemical and biological exposures amplifies uncertainty regarding long-term health trajectories. Bioaerosols, often overlooked in standard air quality assessments, have been shown to contribute to infectious disease transmission, adding another layer of vulnerability. The absence of longitudinal data on chronic outcomes such as cancer or neurodegenerative disorders points to an urgent research priority. Without addressing this evidence gap, current policy measures risk underestimating the true scale of landfill-related health impacts.

4.3. Methodological Advances and Innovations

The study's most important finding is that landfill study methods are becoming more advanced. GIS-based spatial modeling, dispersion simulations, and biomarker analysis of exposed populations are all changing the quality and detail of the data that is out there. These new ideas make it easier to identify pollutant hotspots and their health effects more accurately. This presents scientists a basis for targeted interventions and budget allocation.

Even with these improvements, methodological discrepancies are still a big problem. Studies vary significantly in their sample times, detection limits, and definitions of exposure, complicating the comparison of results across different contexts. This kind of diversity makes it harder to do pooled analysis and makes it harder to apply findings to other situations. Additionally, the prevalence of cross-sectional designs in contemporary research impedes the establishment of causation between exposure and health outcomes, rendering policy approaches susceptible to challenge.

Combining socio-economic indicators with environmental and biomedical data is a new area of research in this discipline. Assessments of vulnerability that include livelihoods, gender roles, and access to healthcare provide a more complete picture of how vulnerable people are. For scavengers and nearby communities, these kinds of studies help find both the biological and social ways that garbage contamination affects health.

Consequently, forthcoming research should promote methodological uniformity while concurrently fostering interdisciplinarity. Longitudinal cohort designs, multi-pollutant exposure models, and participatory research frameworks can produce information that is scientifically robust and socially pertinent. Without these kinds of changes to the way research is done, studies about landfills could stay broken apart and not really reflect the complicated lives of the people who live near them.

4.4. Gaps and Research Priorities

The existing literature highlights several significant gaps. Most studies focus on individual pollutants such as H_2S or NH_3, but relatively few investigate the combined or synergistic effects of multiple exposures. This reductionist approach underestimates the complexity of landfill environments, where chemical and biological contaminants interact continuously. Similarly, bioaerosols remain understudied despite their demonstrated role in respiratory and infectious disease pathways.

Geographic imbalances also limit the comprehensiveness of existing knowledge. A disproportionate number of studies originate from certain regions, leaving significant data voids in areas where landfill management practices are weakest. This uneven distribution of research risks perpetuating global health inequities, as the populations most vulnerable to landfill pollution are also those least represented in scientific evidence.

Another gap lies in the limited exploration of socio-economic and gender-based dimensions of exposure. While some studies acknowledge that scavengers face structural disadvantages, few systematically analyze how poverty, gender, or child labor interact with pollutant exposure to produce compounded vulnerabilities. Addressing these dimensions is essential for informing equitable health and environmental policies.

Moving forward, research priorities should include multi-pollutant epidemiological studies, gender-sensitive analyses, and longitudinal designs that track health outcomes over time. Furthermore, aligning research with policy needs such as safe landfill siting, emission control technologies, and occupational health protections can ensure that evidence translates into actionable reforms. By bridging these gaps, the knowledge base can more effectively contribute to reducing landfill-related health risks and advancing environmental justice.

4.5. Policy Implication

The findings of this study confirm the need for integrated policies that combine environmental, health, and social aspects in landfill management. Regulations must be strengthened through the implementation of multi-pollutant emission standards, routine monitoring of air quality, and the application of gas and leachate control technology. In addition, public health protection needs to be integrated into environmental policies through risk education programs, increased access to health services, and the provision of personal protective equipment for scavengers as the most vulnerable group.

Furthermore, the issue of environmental justice must be a priority in policy formulation. This includes formal recognition of waste pickers' contributions to waste management, their economic empowerment through inclusion in official waste management systems, and the protection of marginalized groups around landfills, particularly women and children. By linking scientific findings with evidence-based policy interventions, these strategies can strengthen public health resilience while supporting sustainable development goals.

5. Conclusion

This scoping review highlights that landfills are significant sources of airborne pollutants, including H_2S, NH_3, VOCs, particulate matter, and bioaerosols, which collectively threaten the health of Scavengers and surrounding communities. The evidence demonstrates associations with respiratory problems, infectious diseases, cardiovascular risks, and potential carcinogenic effects, with vulnerable groups disproportionately affected due to inadequate protective measures and socio-economic disadvantages.

While methodological advances such as spatial modeling and molecular analyses have improved the understanding of pollutant dispersion and health outcomes, the predominance of cross-sectional studies, limited biomonitoring, and underrepresentation of marginalized populations restricts comprehensive risk assessment. Addressing these challenges calls for longitudinal and biomarker-based research, coupled with policy interventions that integrate sustainable landfill management, occupational safety standards, and environmental justice principles to safeguard public health and reduce inequities.

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