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WORKING PAPER

City-tier-wise open waste burning (OWB) characteristics

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Working Papers contain preliminary research, analysis, findings, and recommendations. They are circulated to stimulate timely discussion and critical feedback, and to influence ongoing debate on emerging issues.

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Highlights

- Emissions from open waste burning (OWB) are toxic due to the nature of waste materials and low-temperature combustion conditions.
- In India, OWB is one of the important sources of air pollution. Although initiatives such as the National Clean Air Programme (NCAP) recognize the damage from OWB, eliminating it remains challenging—due to technical, governance, administrative, and community-level gaps. The informal nature of OWB and the uncertainties in waste management data necessitate detailed primary data collection that can feed into policymaking.
- This study uses population size to define city tiers. It characterizes OWB across 11 polluted Indian cities by assessing incident density, burned mass, waste composition, and PM2.5 and PM10 emissions and presents the results by city tier.
- Across all city tiers, waste burning is substantially higher in winter than in summer. We find the highest amount of waste is burned in Tier 2 cities in our sample; in Tier 3 cities, winter burning incidents are highest, and burn piles are relatively smaller.
- The study identifies the distinct tier-specific drivers of OWB and highlights the need for context-specific interventions to reduce it. For the cities examined, the priorities—in addition to improving waste management overall—include strengthening monitoring and accountability mechanisms in Tier 1 and Tier 2 cities; implementing scientific vector control measures in Tier 3 cities; and establishing dedicated collection systems for special waste streams.

Executive summary

In India, combustion-related sources like open waste burning (OWB) contribute to rising air pollution and pose a severe public health and economic burden. Emissions—especially of particulate matter (PM)—from burning activities are considered more harmful to human health than emissions from other activities (Donaldson et al. 2005). The health impacts of air pollution depend not only on how much PM is present in the air but also on how toxic the particles are: the more toxic the particles, the greater the health damage (Kampa and Castanas 2008; Chen et al. 2024). However, even without accounting for differences in toxicity, air pollution was estimated to cause around 2 million deaths in 2023 (Health Effects Institute 2025).

Certain groups—including children, older adults, women, people with comorbidities, and people from lower socioeconomic backgrounds—are more exposed and vulnerable to the health impacts of OWB emissions. OWB releases hazardous pollutants in high concentrations. Children are particularly susceptible because their lungs are still developing, while older adults and individuals with preexisting respiratory or cardiovascular diseases are at greater risk of aggravated health outcomes during smoke exposure events. Low-income communities, waste pickers, and sanitation workers often live or work near informal burning sites, leading to repeated and prolonged exposure to the toxic emissions and associated health risks of OWB. Also, poorer areas often receive inadequate municipal services.

OWB—contributing to seasonal air pollution in India—is a growing yet inadequately measured source of pollution. OWB is a widespread problem caused by inadequate waste collection and management systems, the lack of infrastructure, seasonal factors, and existing social and behavioral practices. OWB has serious consequences, but it is not well understood, because detailed, ground-level information does not exist, and the informal and localized nature of OWB makes monitoring and quantification difficult. Data on OWB based on primary on-field surveys can help characterize waste burning better.

About this working paper

This exploratory study aims to characterize winter and summer OWB in multiple Indian cities by assessing incident density, burned mass, waste composition, and emissions PM (PM2.5 and PM10). This study intends to support the objectives of the National Clean Air Programme (NCAP) and provide preliminary insights into OWB across tiers of Indian cities categorized by population size. The study generates city-specific primary field data across 11 polluted cities during winter and summer between 2019 and 2026. The resulting multitier dataset provides valuable insights into improving emissions inventories and designing broad mitigation strategies.

The primary data on OWB were collected using a published methodology (Nagpure et al. 2015) based on transect surveys conducted along selected routes in each study city. The method involves recording visible waste-burning incidents and estimating the mass and composition of the waste burned. Although this approach is efficient, it may miss burning incidents occurring outside the survey period—predominantly morning and evening hours—or beyond the visible survey area. In addition, the estimates of burned mass and waste composition are approximate.

Key findings

The quantity of waste burned was much higher in winter than in summer. Across all the OWB characteristics quantified in this study, the mean winter values by city tier were three times higher than the summer values, likely because during winter waste is burned not only because of poor waste management practices but also for warmth.

The incidence of wintertime OWB was higher in Tier 3 cities than in the other cities in our sample. In winter, the daily incidence of OWB (per square kilometer) was highest in Tier 3 cities (in our sample, the mean daily wintertime incidence increased from 39.4 in Tier 1 cities to 49.6 in Tier 3 cities). In summer, the incidence was highest in Tier 2 cities.

Pronounced socioeconomic disparities were observed in OWB. Across city tiers and seasons, in most cases, the highest daily OWB incidence (as high as 84 incidents per square kilometer) was observed in low socioeconomic status (SES) areas, and the lowest in high-SES areas, indicating a clear socioeconomic gradient. The OWB burden and variability was greatest in Tier 2 cities, particularly in low- and medium-SES neighborhoods.

Significant (a coefficient of variation of around 60 percent) variations were observed in the amount of waste being burned across city tiers. Tier 2 cities recorded higher quantities of waste being burned among the cities assessed, while Tier 3 cities had the lowest estimated citywide burned waste mass, suggesting that the waste piles burned in the cities examined were smaller and lighter; PM emissions followed a similar pattern. However, the annual emissions of OWB per capita were highest in Tier 3 cities.

Paper and plastic products were found to be contributing significantly to the waste being burned. Plastics and paper make up a major portion—up to around 25 percent—of the waste burned across all city tiers, indicating that waste segregation and disposal practices are poor. More of mixed household and combustible waste is burned in winter than in summer, likely due to waste disposal patterns being seasonal and waste collection being less efficient. Moderate amounts of wood residue and smaller shares of textiles, food waste, thermocol, and electrical wires in the waste suggest that a mix of household, roadside, and municipal waste is burned.

OWB was found to be driven primarily by gaps in waste management services—including inadequate collection and disposal—and behavioral practices. Tier-specific drivers included the perception in Tier 3 cities that burning waste controls mosquitoes; burning by municipal staff and contractors in Tier 1 and Tier 2 cities; and waste dumping outside collection areas in Tier 2 and Tier 3 cities.

Recommendations

Across all city tiers, monitoring and control measures require greater attention in winter. Waste-burning activities and associated emissions increase as high as three times in winter compared to summer. OWB is strongly linked to behavioral and social practices in addition to gaps in waste management systems. Therefore, during winter, greater focus should be placed on community awareness and behavioral interventions along with improving waste collection and disposal systems. The higher incidence of OWB observed during winter underscores the need for promoting responsible waste disposal, source segregation, and recycling practices at the neighborhood level.

Tier-specific interventions are needed to address the underlying drivers of OWB in the observed sample. Strengthening monitoring and enforcement measures in the Tier 2 cities assessed in this study may help address OWB. The Tier 3 cities examined could benefit from scientific vector-control approaches and targeted community awareness programs to address mosquito-related burning. The Tier 2 and Tier 3 cities assessed could also consider establishing dedicated collection channels for garden waste, bulk waste, and other special waste streams to reduce their likelihood of being openly burned. In the Tier 1 and Tier 2 cities included in the sample, strengthening supervision and accountability within waste management operations, along with staff training and adequate collection resources, could further support efforts to reduce OWB. These recommendations are based on the patterns observed in the study cities and may require further assessment before being extended to other cities within these tiers.

Introduction

Worldwide, exposure to air pollution is a major public health and environmental concern (Manisalidis et al. 2020). Unlike high-income countries, where pollution levels have declined, low- and middle-income countries experience disproportionately higher levels of air pollution and associated health impacts: central and southern Asian countries, including India, have witnessed a sustained increase in air pollution levels (Shaddick et al. 2020), aggravated by rapid urbanization, unregulated industrial emissions, and dense population growth (Sharma and Ghuge 2024).

In India, air pollution was responsible for approximately 2 million deaths in 2023 (Health Effects Institute 2025); and, annually, it costs businesses nearly USD 95 billion (approximately INR 7 trillion) (Clean Air Fund 2021). Key sources of air pollution include industries, transport, open waste burning (OWB), domestic fuel combustion, construction activities, and roadside dust (Sahu et al. 2023). Combustion-related emissions, particularly particulate matter (PM), are considered more toxic (Donaldson et al. 2005), although toxicity varies with the material being burned and combustion conditions (Mitroo et al. 2024). Emissions from OWB are more harmful than those from non-combustion sources (Kumari et al. 2019); OWB is a significant source of PM2.5, black carbon, and several other toxic pollutants, though it gained wide attention only after being identified as a major contributor to the discoloration of the Taj Mahal and associated with health concerns in Agra (Lal et al. 2016). Now, OWB is banned legally; however, due to social and infrastructural challenges, it remains widespread in cities (Kumari et al. 2019). Official records are absent, making it challenging to track waste burning trends over time and assess intervention impacts. The exposure burden and associated health impacts are not evenly distributed across populations: children, the elderly, and populations from lower socioeconomic backgrounds, are particularly at risk and vulnerable because their exposure is higher and physiological sensitivity is greater (Ramadan et al. 2026). Women may also experience elevated exposure in communities where waste burning is routinely practiced.

The impacts of OWB on air quality are often more severe during winter due to slower waste decomposition rates, increased burning for warmth, and stagnant meteorological conditions that limit pollutant dispersion (Cichowicz et al. 2017). Initial global-scale studies have modeled PM2.5 concentrations arising from OWB, with emissions estimates derived from demographic indicators and municipal waste collection efficiencies (Wiedinmyer et al. 2014; Kumari et al. 2019). Such analyses consistently identify India as a hotspot for OWB-related PM2.5 exposure and associated premature mortality (Kodros et al. 2016).

With rapid urbanization and increasing waste generation, OWB is emerging as a critical environmental challenge in India, which generates nearly 170,339 tonnes per day (TPD) of municipal solid waste (MSW), of which only 54 percent is processed, while 24 percent is sent to landfills (Central Pollution Control Board 2022). The remaining 22 percent constitutes uncollected and untreated waste, a considerable portion of which is often openly burned by households and communities. Despite its significance, there is still no consistent or reliable national-scale estimate of OWB in India.

Existing assessments vary widely because of differences in methodologies, assumptions, and limited ground-level data; for example, Joshi and Ahmed (2016) report that only 12–14 percent of MSW in India is formally treated, with the remainder largely directed to open dumping and landfill disposal. Using model-based assumptions, Wiedinmyer et al. (2014) estimate that nearly 41 percent of the total waste generated in India is openly burned, while Kumari et al. (2019) suggest that around 10–20 percent of daily waste undergoes open burning.

Addressing the issue of underreporting, Chaudhary et al. (2021) estimate that approximately 74 (30–92) million tonnes of waste out of 192 (102–231) million tonnes of waste were openly burned; also, if left unchecked, OWB could become the largest source of PM2.5 pollution in India by 2035 (Chaudhary et al. 2021). Improved understanding of OWB activity is essential not only for developing robust emission inventories but also for accurately estimating the associated health burdens and designing effective mitigation measures. However, evidence on OWB in India remains fragmented, geographically limited, and heavily dependent on secondary assumptions (Nagpure et al. 2015; Kumari et al. 2019; Rana et al. 2019; Rathore et al. 2020). Characterization of OWB based on primary surveys is particularly scarce; only a few studies are conducted across a limited number of cities (Nagpure et al. 2015; Ali et al. 2023). Therefore, generating evidence across multiple cities is critical to support informed and sustainable policy discussions on OWB mitigation in India.

In response to the increasing generation of waste and degradation of the environment, the central and state governments have introduced policies, programs, and regulations: the Solid Waste Management (SWM) Rules, 2016 and 2026; the National Urban Sanitation Policy; and the Swachh Bharat Mission (SBM). The SBM has strengthened the focus on urban cleanliness and SWM, including source segregation, collection, processing, and appropriate disposal of MSW.

The National Clean Air Programme (NCAP) of the Government of India (GoI) targets OWB and aims to reduce the PM10 concentration by 40 percent by 2026 in 131 “non-attainment cities” (cities where the PM concentration in air exceeded the limits permitted by the National Ambient Air Quality Standards (NAAQS) between 2011 and 2015). Implemented under the NCAP, the Swachh Vayu Survekshan (SVS) explicitly assesses city-level measures to improve air quality. Notably, measures to abate emissions from burning biomass and MSW constitute 20 percent of the SVS assessment framework, highlighting the importance given to burning-related emissions alongside road dust, vehicular, and industrial emissions.

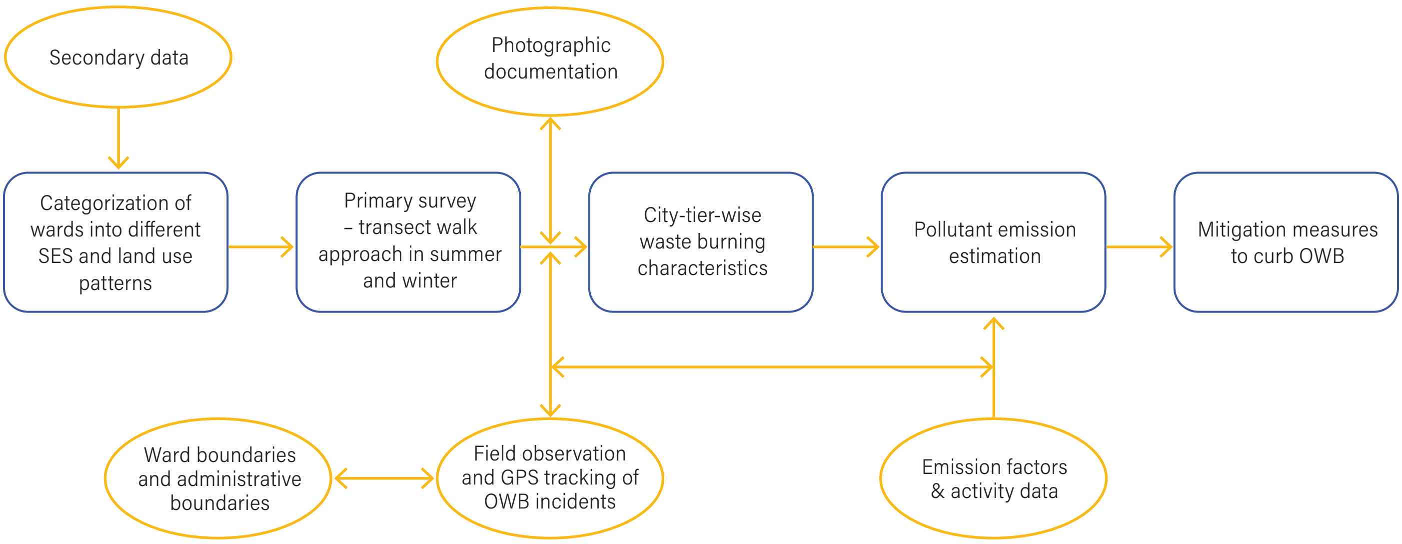
Despite these initiatives, enforcing measures to curb OWB faces challenges at the technical, governance, administrative, and community levels and lead to poor waste diversion; accumulation of mixed waste; and, ultimately, OWB. Systematic measurements of the incidence, quantity, and spatial distribution of OWB can provide evidence to further support and target these ongoing interventions. Eliminating waste burning entirely requires targeted interventions beyond compliance, including system strengthening, stakeholder engagement, and behavior change.

In cities, OWB is closely linked to the state of MSW management. In India, managing municipal waste remains a major challenge due to the large quantities of waste generated daily coupled with environmental and aesthetic concerns. Further, rapid urban expansion has increased the quantity of waste generated (Dutta and Jinsart 2020). A systemic issue driven by multiple factors, OWB reflects inadequate waste collection and management systems; lack of infrastructure; and prevailing social, cultural, and behavioral practices (Ramadan et al. 2026). OWB is particularly common in areas where door-to-door waste collection is irregular, waste segregation is poor, and landfill facilities are either distant or already overloaded.

Despite its significance, the status of OWB in India remains poorly understood because of the lack of comprehensive ground-level data. Monitoring and quantifying OWB is challenging due to its highly informal and localized nature. Consequently, most studies on OWB rely on assumptions, particularly those based on methodologies developed by the Intergovernmental Panel on Climate Change (IPCC), while others depend on interviews, surveys, and household-level assessments for data collection. The substantial uncertainty in waste generation estimates directly affects the reliability of OWB emission estimates (Chaudhary et al. 2021). These uncertainties underscore the urgent need for reliable primary data on OWB incidence and its characteristics.

Developing a comprehensive, multicity dataset on OWB characteristics would strengthen emissions inventories and help bring greater policy attention to this often under-recognized source of pollution. Based on survey data collected across 11 Indian cities, this study supports NCAP objectives by generating robust data on OWB characteristics across multiple non-attainment cities, thereby informing the design and prioritization of mitigation strategies.

Figure 1 | **Flowchart of the methodology**



Note: OWB = open waste burning. SES = socioeconomic status.
Source: WRI India.

1.1 Study objectives

This study aims to examine how OWB characteristics vary across various city tiers and seasons. Using an established transect survey method in two seasons (winter and summer), this working paper aims to characterize OWB, where possible, in terms of incidence, mass, PM (PM2.5 and PM10) emissions, and the composition of burned material. As this study is exploratory and intended to report preliminary results, and given the sensitivity of reporting OWB incidence at the level of individual cities, we analyze OWB characteristics by aggregating cities into city tiers. We use population size to define the city tiers and examine the differences in OWB characteristics by season and SES across city tiers. While the study does not aim to rank individual cities based on the observations, the breadth of data collected and the findings generated may inform and catalyze policy discussions and planning.

Methodology

The transect method (Nagpure et al. 2015) developed to estimate PM emissions involves an observer traveling along the identified route and estimating the incidence of waste burning. Based on data collected through primary surveys conducted in the study cities by the WRI India Clean Air team, this study builds on, adapts, and advances the transect method (Figure 1). We assess as part of the survey data the spatial density, volume, and composition of OWB along the identified transects in each city. In the subsequent subsections, we briefly describe the survey design, data collection, and analysis.

2.1 Cities by tier

Based on the literature, we categorize the 11 cities in the study into

- **Tier 1** (2 cities, developed urban centers with populations above 5 million);
- **Tier 2** (7 cities, emerging urban centers undergoing substantial economic and infrastructural development, with populations ranging from 0.5 million to 5 million); and
- **Tier 3** (2 cities, smaller urban areas with populations less than 0.5 million that are witnessing rapid urbanization and growth in infrastructure and industry) (Vellaturi et al. 2026).

2.2 Transect selection criteria

The transects identified for the primary surveys in each city should be representative of the city and cover various factors influencing waste management and waste burning, subject to practicality and safety.

In this study, we consider land use patterns, the SES of the wards, and road hierarchy as criteria to identify transects (Table 1).

Table 1 | **Criteria considered for selecting the transects**

CRITERIA	DATA SOURCE	METHOD	DOMINANT CLASSES
Land use	Development Plan (DP)/Master Plan and Existing Land Use (ELU) maps	Ward maps were overlaid using GIS based on Development Plan (DP) and Existing Land Use (ELU) maps to identify representative wards	Residential, commercial, industrial, and public and semi-public roads and transportation
Population density	Census of India, 2011	Population density maps were generated for each city	Low, medium, and high population density
Slum population in wards	Municipal corporation records/ websites	Ward-level data were analyzed to identify areas with significant slum populations	High and low slum population density
Road hierarchy	Municipal corporation road network data	Road networks were overlaid with land use, SES, and population density layers	Arterial, sub-arterial, collector, local roads, and streets
Socioeconomic status (SES)	Assets and amenities data from Census of India, 2011	Wealth scores were assigned to wards and classified into SES categories	High, medium, and low SES

Source: WRI India

2.3 Transect survey method

In the transect survey method, fieldwork begins with a pre-survey reconnaissance across wards and neighborhoods in the study cities to identify OWB time windows and assess locally implemented waste management practices. Based on this assessment, transect routes are identified and covered either on foot or by vehicle during the surveys.

During each survey, an observer travels along the transect line to enumerate the incidence of OWB within a predetermined distance, typically within the visible range. Additionally, the geographical coordinates (latitude and longitude) of the observed incidence of OWB are recorded. To estimate the mass of open waste, waste samples are weighed at different stages of burning after sprinkling water to extinguish the fire, and the added weight of water is adjusted subsequently.

The composition of waste is determined by spreading the extinguished material and identifying the partially burned components; those commonly observed include wood, paper, plastic, compostable waste, textiles, rubber, and leather. In each city, surveys are conducted during the frequent burning time windows identified; three repeat surveys, mostly on three consecutive days, are carried out in each season; and, typically, each survey lasts for a few hours (Nagpure et al. 2015).

Finally, based on the number of OWB incidents recorded, transect route length, and transect route width (including street width and building length on either side of the street), the incidence of OWB burning per square kilometer per day is estimated and reported and the mass of the waste burned is expressed in kilograms (kg).

2.4 Extrapolating characteristics of OWB to unsurveyed areas

To estimate the characteristics of OWB citywide, we scaled the data collected along the identified transect routes up to other wards in the city following the approach proposed by Nagpure et al. (2015). However, whereas Nagpure et al. (2015) consider only two SES categories (high and low) for scaling, this study considers three SES categories (high, medium, and low) to make citywide estimates more precise. We use Census of India 2011 data on household amenities and assets to derive the SES of wards for each city.

We use information on access to basic amenities—such as electricity, drinking water, toilet facilities, and drainage facilities, along with literacy rates and the population of working women—to construct a Relative Wealth Index. The index facilitated the application of the ranking system: based on the availability of amenities, we assign scores—high (24–27), medium (18–23), and low (1–17)—and use the scores to define the SES (Kishore et al. 2017). We scale the results obtained from the transect surveys to the city level by considering the number of households in each SES category. The scale-up estimate using this approach represents a first approximation of a land use–informed extrapolation of the observed OWB (for the indexing procedure, see Figure A-1 in Appendix A).

2.5 Estimating PM emissions

We use the survey data to estimate the citywide quantity of waste burned, which we convert into PM emissions using emission factors (mass of PM emitted per kilogram of waste burned) using the equations

$$WB_{SES\text{-}day} = PW_{SES} \times PC_{SES-day} \quad (1)$$

$$WB_{city\text{-}day} = \sum_{SES} \times WB_{SES-day} \quad (2)$$

where

PW_{SES} represents the population of wards belonging to different SES categories, estimated for the study year using the decadal growth rate provided by the respective municipal corporation, and

PC_{SES} represents the per capita waste burned (kg) during different seasons in different SES wards.

We calculate the total quantity of waste burned by summing the waste burned across both seasons for all SES categories (low, medium, and high). We estimate PM (PM10 and PM2.5) emissions by multiplying the quantity of waste burned by the corresponding emissions factors. We adopt the emission factors for PM10 (14 g per kg) and PM2.5 (13 g per kg) from Sharma et al. (2019), who synthesized emission factors from the literature and reported mean values. The study also reports a variability of 5 g per kg for both PM10 and PM2.5 emissions factors. To estimate citywide annual emissions from burning waste, we use the equation

$$E_p = WB_{city\text{-}day} \times EF_p \times non\text{-}rainy\ days \quad (3)$$

where E_p represents the emissions (in tonnes) of pollutant p,

$WB_{city\text{-}day}$ is the amount of waste burned per day (in kg), and

EF_p is the pollutant-specific emission factor (g kg^{-1}).

We calculate emissions separately for the winter (November to February) and summer (March through June) using the season-specific citywide OWB mass burned. We consider the number of rainy days during the winter months to be zero (Dimri et al. 2016) because most Indian regions receive little rainfall during this period, primarily because the dominant seasonal winds blow generally from land to sea, carrying limited moisture, while stable high-pressure conditions promote subsiding air and suppress cloud formation. We obtain the number of rainy days for the summer from the India Meteorological Department (IMD) and incorporate it into the emissions estimates. The number of waste-burning days varies by the geographical location of the city and the number of rainy days.

2.6 Limitations

This study provides useful insights; however, it has certain limitations. The methodology we adopt closely follows the approach developed by Nagpure et al. (2015), in which the authors themselves highlighted several limitations:

- Incidents of OWB may occur beyond the line of sight or the survey time window and, therefore, be missed in counting.
- The coarser nature of the waste mass and composition measurements.
- The study area and transect routes considered are limited to the municipal/corporation limits of the city.

In addition, the current study has a few limitations that warrant cautious interpretation of the results:

- We aggregate the city-wise results—though the number of cities within each tier was not uniform—and present those results as tier-wise estimates.
- The Tier 1 summer and winter results and Tier 3 summer results are based on data from only one city—owing to a combination of factors, including the study timeline and constraints related to obtaining permissions and access for data collection in additional cities.
- We collected the data across different cities over an extended period rather than simultaneously.
- We conducted repeat (multiyear) surveys for a few cities, but we did not survey all the cities during both winter and summer.
- Because we assume the selected transects are representative of a city, any uncertainty in transect selection criteria may introduce uncertainty in the results.
- Because we surveyed a limited number of Tier 1, 2, and 3 cities, this working paper's recommendations do not apply to all the cities in the tiers.
- This study uses SES classifications based on the 2011 Census data. The ward-level SES composition likely may have changed between the 2011 Census and the survey years (2019–2026), particularly in rapidly urbanizing Tier 2 and Tier 3 cities that have undergone significant demographic and economic transitions. Consequently, the extrapolated estimates should be interpreted with caution. However, in the absence of more recent and comparable data, the 2011 Census remains the most robust and consistent source for deriving ward-level SES categories.

Findings

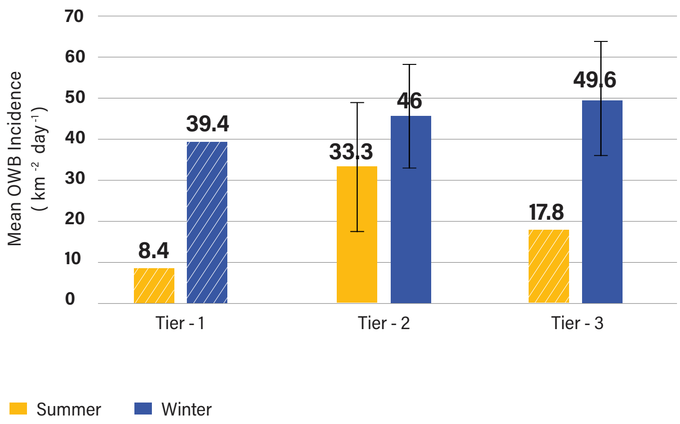
Because this study is intended to catalyze policy discussions on OWB, we aggregate the data collected over this extended time frame and conduct the analysis in accordance with the defined objectives. We conducted all the surveys during non-rainy days. We analyze the data collected during the transect surveys conducted in study cities between 2019 and 2026 (avoiding the COVID-related lockdown periods) (for the tier-wise survey years, see Table A-1 in the Appendix A).

Pre-survey reconnaissance indicates that, across all cities, OWB incidents occurred predominantly during mornings and evenings. Accordingly, we initiated morning surveys at 6 am during summer (March through June) and at 7 am during winter (November through February) and evening surveys at 5 pm. These observations are consistent with the findings reported by Nagpure et al. (2015) (Table 2). The number of transect routes identified for surveys varied from 3 to 12 across cities, with larger cities generally having longer transect routes. Overall, the total route length covered in the study cities ranged from 90 km to 400 km. This transect route accounted for around 5–20 percent of the total city road length.

3.1. Incidents of OWB by city tier

Though we derived Tier 1 summer and winter estimates and Tier 3 summer estimates from observations from a single city, overall, across all city tiers, incidents of OWB were higher during winter than summer (Figure 2), consistent with the general understanding and the literature, and associated with warming activities in addition to waste disposal practices. The trend of OWB incidents (in per sq. km per day) increased with higher city tiers during winter; in summer, the highest density of incidents (about 33) was observed in Tier 2 cities. The seasonal contrast in incidents was smaller in Tier 2 cities than in the other city categories (for detailed statistics on the incidents of OWB, see Table A-2 in the Appendix A).

Figure 2 | **City-tier-wise seasonal mean OWB incidence densities**



Note: Whiskers indicate standard deviations representing between-city variability. Hatched bars without whiskers indicate the availability of only one city data.

Source: WRI India authors' analysis.

The larger number of Tier 2 cities included in the study enabled a better assessment of variability in observed incidence. During summer, the average incident density (in per sq. km per day) in Tier 2 cities was 33.3, with a wide range of 16.8–64.1, and relatively high variability (15.7), indicating substantial intercity differences. In winter, the average increased to 46, with values ranging from 27.2 to 61.8, and comparatively lower variability. Observations for the other city tiers should be interpreted cautiously because the sample size is smaller.

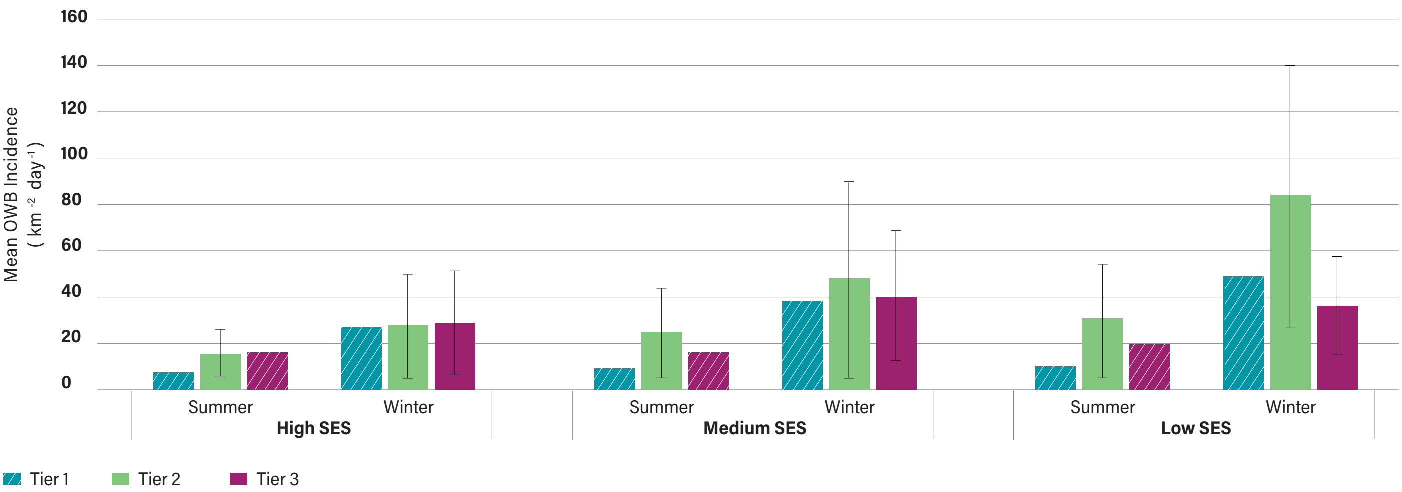
We compare the mean incidence of OWB across high-, medium-, and low-SES areas, and the results reveal clear spatial, seasonal, and socioeconomic variations in OWB incidence: across all SES categories and city tiers, OWB incidence is consistently higher during winter than summer,

Table 2 | **Comparison of the survey timings from various studies using the transect walk method**

	WINTER SURVEY		SUMMER SURVEY	
	Morning	**Evening**	**Morning**	**Evening**
Nagpure et al. 2015	6 am to 10 am	5 pm to 10 pm	6 am to 10 am	5 pm to 10 pm
Das et al. 2019	5 am	Not available	Not available	Not available
Ramadan et al. 2022	Morning—not precisely mentioned	Evening—not precisely mentioned	Not available	Not available
Current study	7 am to 10 am	5 pm to 10 pm	6 am to 10 am	5 pm to 10 pm

Source: WRI India authors.

Figure 3 | **SES- and city-tier-wise seasonal mean OWB incidence densities**



Note: SES = socioeconomic status. Whiskers indicate standard deviations representing between-city variability. Hatched bars without whiskers indicate the availability of data from only one city.

Source: WRI India authors' analysis.

indicating that seasonal factors considerably influence waste-burning practices (Figure 3).

In high-SES areas, OWB incidence remains relatively low, particularly in Tier 1 cities, where the mean value (in per sq. km per day) increases from approximately 7 in summer to 26 in winter. The incidence is slightly higher (around 28–29) in Tier 2 and Tier 3 cities, suggesting that OWB persists across all city categories, even in areas with better socioeconomic conditions.

In medium-SES areas, OWB incidence is substantially higher than in high-SES areas: Tier 2 cities record the highest values, increasing from approximately 25 in summer to 48 in winter, while Tier 3 cities show a winter incidence of about 41. This indicates greater challenges in waste management and behavioral compliance in medium-income neighborhoods, particularly in rapidly urbanizing cities.

The highest OWB incidence is observed in low-SES areas, where waste-burning activities are considerably more prevalent. Tier 2 cities exhibit the greatest OWB burden (in per sq. km per day), increasing from around 30 in summer to nearly 84 in winter, followed by Tier 1 cities (48) and Tier 3 cities (36).

The large error bars, especially for Tier 2 cities, indicate substantial variability among cities within the same tier, reflecting differences in municipal service delivery, waste collection coverage, informal settlements, and local waste management practices.

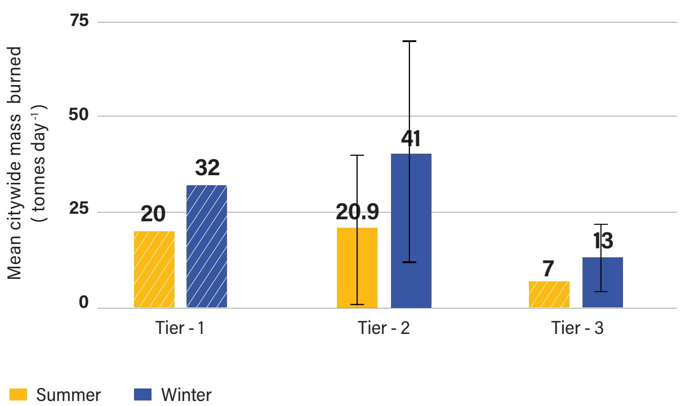
Overall, the findings demonstrate a clear socioeconomic gradient in OWB incidence, with low-SES areas experiencing the highest levels of waste burning, followed by medium-SES and high-SES areas.

From a city-tier perspective, Tier 2 cities consistently show the highest OWB incidence and variability across SES categories, suggesting that rapidly growing intermediate cities may face greater challenges in expanding waste management infrastructure and enforcement mechanisms in line with urban growth.

3.2. Mass and composition of OWB by city tier

Similar to OWB incidence patterns, the quantity of waste burned was higher during winter than during summer across all the cities surveyed (Figure 4).

Figure 4 | **City-tier-wise seasonal mean mass burned**



Note: Whiskers indicate standard deviations representing between-city variability. Hatched bars without whiskers indicate the availability of data from only one city.
Source: WRI India authors' analysis.

However, in Tier 3 cities, the burned mass—unlike the incidence—was lower, suggesting that the waste piles burned in these cities were smaller than in the other city tiers. The burned mass in Tier 2 cities was comparable to that in Tier 1 cities and even exceeded it during winter. Tier 2 cities also showed substantial variability and stronger seasonal contrast. On average, the mass of OWB (in tonnes per day) nearly doubled, from approximately 21 in summer to 41 in winter. The broad ranges observed in both seasons (6.6–61 in summer and 17–109 in winter), along with the relatively high standard deviations (19.4 in summer and 29.3 in winter), indicate considerable heterogeneity among cities.

The mass of waste openly burned per capita annually (summer + winter) is estimated to be highest in Tier 3 cities (6.9 kg), followed by Tier 2 cities (4.0 kg), and Tier 1 cities (0.63 kg).

The composition of the mean summer waste burned across Tier 1, Tier 2, and Tier 3 cities is dominated by combustible waste fractions such as plastics, paper, dried leaves, and textiles (Figure 5).

Together, plastics and paper form a major share across all city tiers, indicating that waste segregation and disposal practices are inadequate. Plastic and paper form the highest proportion of waste burned in Tier 3 cities, indicating that waste management systems are weaker and that reliance on open burning is greater.

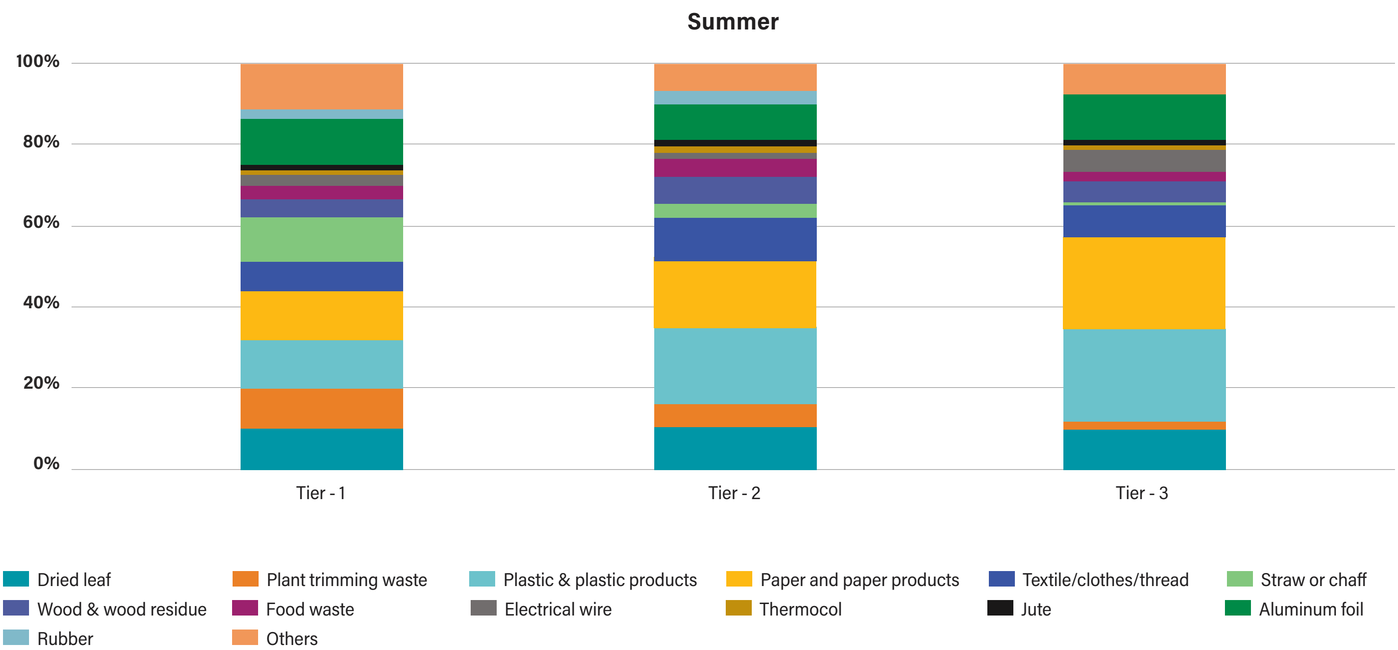
In Tier 1 cities, the waste stream is relatively diverse, with notable contributions from dried leaves, plant trimming waste, straw/chaff, and aluminum foil along with plastics and paper.

Textile waste, food waste, and wood residue contribute moderate shares, while thermocol, rubber, jute, and electrical wires remain minor components. The dominance of plastics and paper increased in Tier 2 cities compared to Tier 1 cities. Moderate shares of textile waste and wood residue indicate mixed household and commercial waste burning. The composition suggests contributions from both municipal and informal waste disposal practices.

The notable contribution of the "Others" category—including coconut husk, flowers, leather/rexine, glass, and metal—highlights the heterogeneous nature of OWB. Tier 3 cities exhibit the highest share of plastic waste, followed by paper and aluminum foil, indicating that mixed municipal and packaging waste is burned frequently, because the waste collection and disposal infrastructure is limited.

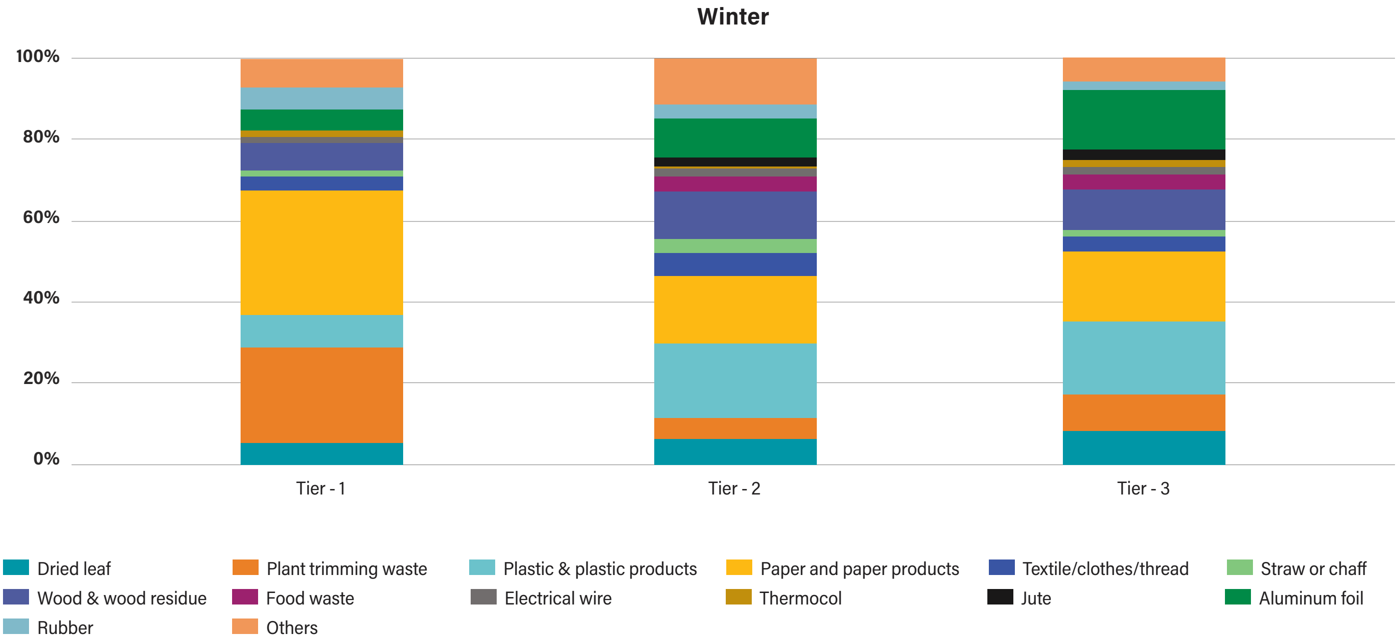
Across all the cities in our sample, winter waste burning is dominated by combustible waste fractions such as paper, plastics, and biomass materials (Figure 6). Burning of mixed household and combustible waste is higher in winter than in summer, likely due to seasonal disposal. In Tier 1 cities, paper and paper products form the largest share of burned waste, followed by

Figure 5 | **City-tier-wise mean composition of waste mass burned in summer**



Source: WRI India authors' analysis.

Figure 6 | **City-tier-wise mean composition of the waste mass burned in winter**



Source: WRI India authors' analysis.

plant trimming waste and plastics, indicating extensive burning of dry leaves, garden waste, and municipal sweepings. Moderate contributions from wood residue and aluminum foil, along with smaller shares of textiles, food waste, thermocol, and electrical wires, indicate burning of mixed residential and municipal waste.

In Tier 2 cities, the composition of waste is more evenly distributed; plastics, paper, and wood residue are the major contributors. The higher share of wood residue suggests increased burning of wood-based materials for heating or disposal. Smaller fractions of textiles, food waste, straw/chaff, and aluminum foil indicate burning of mixed municipal and commercial waste streams.

In Tier 3 cities, the composition of waste is dominated by plastics and paper waste, with noticeable contributions from aluminum foil and wood residue. The composition reflects widespread burning of mixed municipal and packaging waste, while biomass-related waste forms a smaller share. The dominance of non-biodegradable materials points to weaker waste collection and disposal systems.

Across all city tiers and seasons, burning plastics, rubber, thermocol, electrical wires, and synthetic waste is environmentally concerning due to potential emissions of toxic pollutants and fine particulate matter.

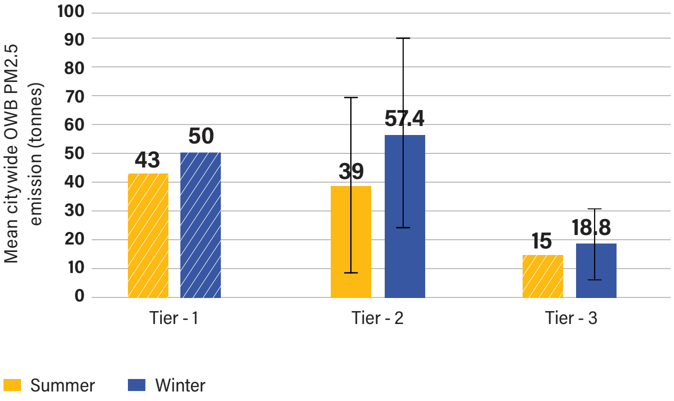
3.3. Emissions of PM from OWB by city tier

Figures 7 and 8 present the tier-wise mean citywide PM2.5 and PM10 emissions generated from OWB. For estimating winter emissions, we consider, on average, around 120 non-rainy days of the year; and, for estimating summer emissions, around 160 days (the remaining non-rainy days). The data on the number of rainy days varied by city and survey year. The tier-wise variation in emissions followed the same pattern as the burned mass, with emissions of PM2.5 and PM10 in Tier 3 cities being lower than those in the other city tiers (for the statistics, see Table A-2 in the Appendix A).

Subsequently, we use the average population to convert these emissions into per capita emissions. We estimate the highest annual per capita OWB PM2.5 emissions (summer + winter) in Tier 3 cities (0.09 kg), followed by Tier 2 cities (0.05 kg) and Tier 1 cities (0.008 kg). These are emissions estimates; no inference can be made regarding individual- or population-level PM exposure based on these results.

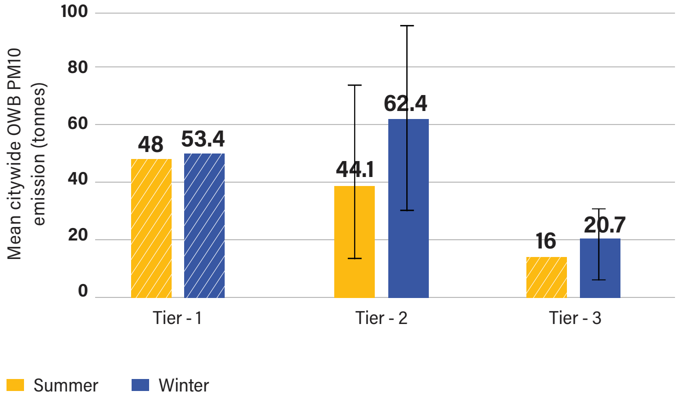
Based on the available literature data on total emissions, the current estimates of PM2.5 and PM10 emissions from OWB contribute less than 1 percent of the total citywide PM2.5 and PM10 emissions. Although the contribution of OWB is modest, mitigation is an important air quality and public health priority. Generally, OWB occurs close to residential neighborhoods, streets, and waste accumulation sites and elevates the short-term exposure of nearby populations to toxic air pollution.

Figure 7 | **City-tier-wise mean citywide OWB PM2.5 emissions**



Note: Whiskers indicate standard deviation representing between-city variability. Hatched bars without whiskers indicate the availability of data from only one city.
Source: WRI India authors' analysis.

Figure 8 | **City-tier-wise mean citywide OWB PM10 emissions**



Note: Whiskers indicate standard deviation representing between-city variability. Hatched bars without whiskers indicate the availability of data from only one city.
Source: WRI India authors' analysis.

Unlike many major emissions sources that require substantial infrastructure investments or long-term technological transitions for mitigation, OWB is a preventable source; therefore, mitigating OWB can deliver disproportionate benefits by reducing human exposure to highly toxic pollutants while simultaneously improving urban waste management sanitation. Mitigating OWB can also help reduce local nuisance from strong odors and smoke-related visibility impairment, lower the risk of fires spreading to nearby structures or vegetation, and reduce climate-relevant emissions such as black carbon.

Conclusions

This study provides one of the first multicity assessments of OWB across 11 polluted Indian cities (10 non-attainment), highlighting significant seasonal, socioeconomic, and city-tier differences in OWB incidence, burned waste mass, and associated PM emissions. Although we conduct the surveys at the individual city level, reporting city-specific OWB data is sensitive; therefore, we present the results by city tier. Wintertime waste burning, burned mass, and associated PM emissions are as high as three times those observed during summer. The results demonstrate a clear socioeconomic gradient in OWB incidence, with low-SES areas experiencing the highest burden of waste burning and high-SES areas the lowest. While OWB incidence density is highest in Tier 3 cities, the quantity of waste burned is greater in Tier 2 cities.

Because we estimate PM2.5 and PM10 emissions using literature-based emission factors and the estimated burned waste mass, the emission patterns closely follow the trends observed for burned mass. We observe the highest per capita annual OWB emissions in Tier 3 cities. The estimates of waste mass and composition are approximate and should therefore be interpreted with caution. Although we do not observe any clear trend in waste composition across city tiers, plastics and paper consistently emerge as the dominant components of burned waste.

To identify the potential reasons for the observed OWB, we synthesize field observations recorded by the enumerators during the reconnaissance and transect surveys aggregating the findings by city tier. Most of the drivers of waste burning are common across city tiers—waste burning is a behavioral practice, and the municipal infrastructure for effective waste collection is limited:

- Door-to-door collection coverage is inadequate.
- The frequency of waste collection is irregular.
- Gaps exist in operation, and collection vehicles often experience breakdowns.
- Space for waste segregation and storage is insufficient.
- Landfill capacity is limited.
- Dried leaves and garden waste are uncollected.

Tier-specific drivers also emerge:

- In Tier 3 cities, waste burning is driven by the perception that it is an effective method of vector control (mosquitoes, for example).
- In Tier 1 and Tier 2 cities, municipal staff and contractors burn waste.
- In Tier 1 and Tier 2 cities, garbage-vulnerable areas are common.
- In Tier 2 and Tier 3 cities, waste streams lie outside municipal collection areas.

To reduce OWB, municipal waste services need to be improved, enforcement strengthened, and behavior-change interventions need to be sustained. Particular attention is needed during the winter months in the Tier 3 cities examined in the study, given their higher per capita emissions. For the Tier 2 cities assessed, stronger monitoring and enforcement measures could help ensure compliance and prevent burning practices.

Based on the patterns observed in the study cities, tier-specific recommendations include the adoption of scientific vector-control measures in Tier 3 cities, such as source reduction, larvicide application, fogging where appropriate, and community awareness programs to address mosquito-related concerns associated with waste burning.

In Tier 1 and Tier 2 cities, supervision and accountability mechanisms could be strengthened, adequate collection resources could be provided, anti-burning clauses could be incorporated into service contracts, and staff training should be conducted to reduce burning by sanitation personnel themselves.

To address garbage-vulnerable areas, rapid-response cleaning teams should be established, routine cleaning schedules should be implemented, surveillance and signage should be installed, and community reporting mechanisms should be developed.

In addition, Tier 2 and Tier 3 cities could develop separate collection channels for garden waste, bulk waste, and other special waste streams to prevent these materials from spilling outside the collection system and openly burned.

In addition to these measures, cities should also consider targeted, context-specific solutions and pilot interventions that account for the influence of local conditions and practices waste generation.

To ensure the successful and sustained implementation of these recommendations across all tiers and socioeconomic settings, cities should prioritize establishing and strengthening a comprehensive waste management system.

4.1. The way forward

Future studies should aim to address these limitations and expand the scope of investigation to include population-level exposure assessment for waste burning.

Given the toxic nature of combustion-related pollution, future research should go beyond estimating the quantity and composition of waste burned and place greater emphasis on exposure and health implications.

This could include detailed chemical characterization of waste-burning emissions and the estimation of their oxidative potential.

Building on this work, WRI India's ongoing longitudinal analyses of the same cities across multiple years will provide insights into temporal changes in OWB characteristics and help identify the factors influencing these trends.

Appendix A

Table A-1 | City-tier-wise survey years

TIER 1	TIER 2	TIER 3
2025; 2026	2019; 2022; 2023; 2024; 2025; 2026	2024; 2026

Source: WRI India authors' analysis.

Table A-2 | City-tier-wise summary statistics of various OWB-related parameters

TIER	NUMBER OF CITIES COVERED	AVERAGE POPULATION (CENSUS 2011)	SEASON	TOTAL NUMBER OF SURVEYS CONDUCTED	OWB INCIDENCE (KM^{-2} DAY^{-1})	CITYWIDE OWB MASS BURNED (TONNES DAY^{-1})	OWB PM2.5 EMISSIONS (TONNES)	OWB PM10 EMISSIONS (TONNES)	OWB PM2.5 EMISSIONS CONSIDERING THE VARIABILITY IN THE EF (TONNES)	OWB PM10 EMISSIONS CONSIDERING THE VARIABILITY IN THE EF (TONNES)
					Mean (min., max., S.D.)	Mean (min., max., S.D.)	Mean (min., max., S.D.)	Mean (min., max., S.D.)	Range	Range
Tier 1	2	11,182,941	Summer	1	8.4 (8.4, 8.4, 0)	20 (20, 20, 0)	43 (43, 43, 0)	48 (48, 48, 0)	26.5–59.5	30.9–65.1
			Winter	1	39.4 (39.4, 39.4, 0)	32 (32, 32, 0)	50 (50, 50, 0)	53.4 (53.4, 53.4, 0)	30.8–69.2	34.3–72.5
Tier 2	7	2,037,931	Summer	7	33.3 (16.8, 64.1, 15.7)	20.9 (6.6, 61, 19.4)	39 (14, 96, 30.8)	44.1 (15, 117, 37.3)	24–54	28.4–59.9
			Winter	10	46 (27.2, 61.8, 12.6)	41 (17, 109, 29.3)	57.4 (25, 129, 32.7)	62.4 (27, 156, 38.2)	35.3–79.5	40.1–84.7
Tier 3	2	389,183	Summer	1	17.8 (17.8, 17.8, 0)	7 (7, 7, 0)	15 (15, 15, 0)	16 (16, 16, 0)	9.2–20.8	10.3–21.7
			Winter	3	49.6 (33.9, 57.6, 13.6)	13 (6, 23, 8.9)	18.8 (9.3, 33, 12.5)	20.7 (10, 36, 13.6)	11.6–26	13.3–28.1

Note: EF = emission factor. OWB = open waste burning. S.D. = standard deviation.
Source: WRI India authors' analysis.

Figure A-1 | **Wealth indexing scores**

1 Housing condition

Good	4
Livable	2
Dilapidated	0

2 Material of wall

Burned brick	4
Unburned/mud brick	2

3 Main source of drinking water

Tapwater from treated source	2
Tapwater from untreated source	1

4 Toilet facility

Yes	4
No	0

5 Waste water outlet connected to

Closed drain	4
Open drain	2
No drain	0

6 Flush/pour flush latrine connected to

Piped sewer line	4

7 Type of fuel used for cooking

Cooking gas (LPG/PNG), electricity	2
Coal, charcoal, kerosene	1
Other fuel	0

8 Availability of assets

Car/ jeep/ van	4
Scooter/ motorcycle/ moped	3
Bicycle	1
None	0

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