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WORKING PAPER

Silt load measurement and investigation of the effectiveness of road dust cleaning mechanisms in three Indian cities

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Highlights

- India faces air quality challenges from high levels of particulate matter (PM) pollution. Road dust is a significant contributor to localised PM levels.
- The National Clean Air Programme (NCAP), launched by the Government of India (GoI) to reduce air pollution, has sanctioned money to polluted cities to mitigate road dust pollution.
- Road dust cleaning mechanisms include manual sweeping, mechanised sweeping, and water flushing. However, we lack data on their effectiveness in reducing road dust, especially the resuspendable fraction of road dust, or silt load.
- This exploratory study measures silt load values across different road types in three Indian cities (Mumbai, Indore, and Ahmedabad). In addition, it evaluates the effectiveness of road cleaning mechanisms and the speed at which silt load reaccumulates after cleaning.
- We find that silt load (in gram per square metre) varies significantly by road type, from 1 to 20, even within the same city. Mechanical cleaning methods are more effective than the manual and water-based cleaning methods evaluated, regardless of machine size or operational capacity. Silt load values returned close to pre-cleaning levels within four to eight days after cleaning, highlighting the need for regular and optimised cleaning schedules.

Executive summary

In India—through increased vehicular activity and transportation-related emissions, along with other anthropogenic sources—the growing population and urbanisation contributes to rising air pollution. The impacts of rapid urbanisation and industrialisation on urban air quality are well explored (Zhang et al. 2022; Sharma and Ghuge 2024). Construction activities and vehicular and industrial emissions contribute to the increase in air pollution. However, a significant contributor to increased concentrations of ambient particulate matter in India is dust from roads resuspended due to vehicular movement (silt load) (Jose and Srimuruganandam 2021). In India, approximately 10,000 deaths annually are attributable to pollution by PM2.5 (ambient fine particulate matter with size less than 2.5 microns) from road dust (Katiyar et al. 2024). Therefore, strategies that reduce road dust effectively can play an important role in improving air quality and, thereby, reducing the health burden attributable to air pollution.

The National Clean Air Programme (NCAP), the flagship initiative of the Government of India (GoI) launched to reduce air pollution in India, has identified dust from resuspension and construction activities as the second-largest contributor to PM2.5 pollution. Silt load—the resuspendable fraction of road dust—varies by city, reflecting the diversity of urban ecosystems in the country. On roads, high silt load can result from a combination of sources and enabling conditions. Direct sources include soil spillage from vehicles, nearby construction activities, and brake and tire wear emissions, all of which contribute PM to the road surface (Wagner et al. 2024). Enabling conditions that facilitate the accumulation and persistence of silt include road type, poor road quality, the presence of unpaved or partially paved roads, and inadequate road design.

Although road dust control is included in city clean air action plans, assessing actual dust and pollution reduction remains challenging. Currently, a variety of road cleaning mechanisms—manual cleaning, mechanised cleaning, and water-based cleaning methods—exist, each with different cost and labour bases. However, in the absence of data on the effectiveness of road cleaning methods, the method of choosing a road cleaning mechanism raises concerns over the efficacy of investments cities make in tackling road dust.

About this working paper

This study presents measurements of silt load across different types of roads in three Indian cities (Mumbai, Indore, and Ahmedabad), evaluates the effectiveness of different road cleaning mechanisms used by city administrations to reduce road dust, and examines silt reaccumulation patterns in Mumbai and Ahmedabad. This exploratory study examines how silt load varies by road type in the study cities and assesses the effectiveness of different road cleaning methods in reducing silt load. This study also provides a basis for more comprehensive assessments of road cleaning methods and their effectiveness, thereby supporting evidence-based implementation strategies.

To assess the different characteristics of silt load, we collected multiple samples of road dust across the road types identified in this study. We adopted the methodology of the United States Environmental Protection Agency (USEPA) to sample road dust and analyse (drying, sieving, and weighing) it in a laboratory (USEPA 2020a, 2020b). In addition to reporting silt loads, the study evaluates the effectiveness of road cleaning mechanisms by analysing the silt load values of the samples we collected before and after road cleaning operations—water-based, mechanical, and manual. To understand the reaccumulation patterns of road dust, we analysed the silt load values from the samples of road dust we collected before deep cleaning, four days after deep cleaning, and eight days after deep cleaning.

Key findings

Silt load values vary significantly by road type and lane configuration. The variations observed in silt load values (in gram per square metre), which ranged between 1 and 20, could be attributed to land use and traffic load, among other factors that require further investigation to substantiate. Greater amounts of dust were found to have accumulated on collector and sub-arterial roads.

Among the three road cleaning methods, mechanical cleaning methods—irrespective of machine size or capacity—are most effective at reducing road dust. In comparison, cleaning methods that utilize water at high- and medium pressure are less effective and present greater operational challenges, owing to the need for manual oversight.

Silt load returned close to pre-cleaning levels within four to eight days after cleaning. The reaccumulation results can help cities in optimising their cleaning frequencies across different road types. Such data can also support cost-effective road dust management by enabling cities to prioritise roads with faster silt build-up. This can help balance operational costs, resource allocation, and fuel and water consumption while maintaining lower silt load levels.

Recommendations

Cities should integrate silt load assessments into routine evaluations of measures to reduce and mitigate dust. To optimise resource utilisation and maximise the reduction of road dust, it is necessary to strategically deploy and operate road cleaning mechanisms. The accumulation of silt and the effectiveness of cleaning also depend on the type and condition of roads. Road design plays an important role in cleaning effectiveness; for example, well-designed roads with efficient drainage systems are easier to clean.

The findings from this study can serve as an initial step toward strengthening policy discussions and supporting city-level planning for road dust reduction and evaluation of the effectiveness of mitigation measures undertaken. While the evaluation of road cleaning mechanisms helps identify the most effective cleaning method, reaccumulation patterns can help optimize cleaning frequency.

Introduction

Air pollution is a major public health, environmental, and economic issue (Manisalidis et al. 2020). Worldwide, in 2023, 7.9 million deaths were linked to air pollution (HEI 2025). Low- and middle-income countries bear the largest burden. India alone accounts for about 2 million of these deaths; in 2019, premature deaths and illness related to air pollution were estimated to cost 1.36 percent of its gross domestic product (GDP) (Pandey et al. 2020).

Particulate matter (PM) pollution is one of the most pressing air quality challenges in India. Around 84 percent of the population is exposed to levels of fine ambient particulate matter (PM2.5) that exceed the national annual standard (40 microgram per cubic metre) and almost the entire country experiences concentrations above the World Health Organization (WHO) guideline (5 microgram per cubic metre) (Apte and Pant 2019). The major sources of PM pollution include industrial activities, transport, and the burning of biomass for residential purposes (Kurmi et al. 2024). In addition, less-studied sources such as road dust play a substantial role, contributing an estimated 30–60 percent of ambient PM10 (particulate matter with size less than 10 microns) and PM2.5 (particulate matter with size less than 2.5 microns) levels (Ghosh et al. 2023). In India, annually, more than 10,000 deaths are attributable to PM2.5 pollution from road dust alone (Katiyar et al. 2024). Low-income households, particularly roadside vendors and informal workers—and vulnerable groups such as children and the elderly who live or work near busy or unpaved roads—experience disproportionately higher exposure to road dust emissions (Barthwal et al. 2022). Given this significant contribution of road dust to particulate pollution and in response to this air pollution crisis the Government of India (GoI) launched the National Clean Air Programme (NCAP) in 2019.

The NCAP identifies more than 130 cities that do not meet the National Ambient Air Quality Standards (NAAQS), referring to them as "non-attainment" cities. In these cities, the NCAP aims to reduce PM levels by 20–30 percent, from 2017 levels; the reduction target in PM10 has been revised to 40 percent over an extended timeline (Ganguly et al. 2020; Lal and Nagpure 2026). The NCAP provides financial support to the identified cities, linking part of the funding to performance in reducing air pollution levels, and encourages cities not only to implement pollution control measures but also to demonstrate measurable improvements in air quality (Guttikunda et al. 2025). Given the significant contribution of road dust to particulate pollution, a large share of NCAP funding was utilised in managing road dust in non-attainment cities between 2023 and 2025 (nearly 63–68 percent) (Choubey 2025; CREA 2026).

Measures such as regular road cleaning are expected to help reduce the public exposure to PM pollution (Amato et al. 2010a). Generally, in India, road cleaning is carried out through manual, mechanical, and water-based methods, and, in some cities, vacuum-assisted sweeping. Many cities have shifted from manual sweeping to mechanised cleaning. However, these cities have expanded their fleet without accurate data on the efficacies of existing dust clean-up operations (Singh 2026) and the evidence on how effective these methods are under local conditions is limited. In addition, evaluating the effectiveness of road dust management measures requires a clear understanding of how road dust behaves; and although policy and city-level clean air action plans recognise the risk posed by road dust, the need to reduce road dust and the importance of tracking reductions in road dust, tracking actual reductions remains difficult. Under Swachh Sarvekshan—India's annual survey of cleanliness, hygiene, and sanitation—cities report indicators such as the length of roads cleaned, the number of machines used, or the frequency of cleaning (Swachh Sarvekshan Toolkit 2026). These indicators are useful but do not directly show how much dust has been removed or pollution been reduced. To strengthen the NCAP framework, it is important to show how effective road cleaning methods are under local conditions and how much dust has been removed or pollution been reduced.

A key step in this process is measuring silt load, defined as the mass of fine dust particles with a diametre of 75 microns (μm) or less present per unit area of road surface that can become airborne again (USEPA 2001). An indicator commonly used to understand the amount of road dust available for resuspension into the air, silt load varies widely by road conditions, surrounding polluting activities, maintenance practices, and cleaning frequency (Teng et al. 2007). Roads that are poorly paved or not regularly maintained tend to accumulate more dust, increasing the likelihood of it being resuspended into the air (Svensson et al., 2023). Silt load varies widely by city: the values (in gram per square metre) range from as low as 0.5 to as high as 137 (Katiyar et al. 2024). The burden of road dust is higher in northern Indian cities: silt load levels (in gram per square metre) tend to be higher (30–100) for cities in the Indo-Gangetic Plains than in coastal and hilly regions (0.5–5.8) (Guttikunda and Jawahar 2014; Suryawanshi et al. 2016; Katiyar et al. 2024). This variation reflects differences in local conditions, including climate, land use, traffic intensity, fleet mix, road quality and maintenance practices, and other urban activities (for a list of silt load values reported in earlier studies, including Indian and representative global studies, see Table A1). However, the variability observed even within individual cities is large and the large variability suggests that local conditions and site-specific characteristics—poor road maintenance, high traffic volumes, and extensive construction activities—play a major role in determining silt accumulation.

Experiences from other countries show that road dust can be managed through targeted approaches, such as improved street cleaning, the use of dust suppressants, and better road materials (Amato et al. 2010b). Cities in India report higher levels of silt load than in cities in developed countries and in some other developing countries: the silt load level (in gram per square metre) ranges between 0.03 and 4.2 in Las Vegas (the US) (Fitz et al. 2020), between 0.006 and 0.066 in Milan (Italy) (Amato et al. 2017), and between 0.30 and 24.22 in Beijing and Baoding (China) (Chen et al. 2019; Rienda and Alves 2021; Wang et al. 2023). Higher and more variable silt load values are common in rapidly urbanising settings where road conditions, maintenance practices, traffic, type of fleet, and surrounding activities differ from those in developed countries.

In India, most silt load assessments are conducted as part of emissions inventory studies, which document the amount of pollutants discharged into the atmosphere from various polluting sources and sectors. Usually based on one-time measurements, these assessments do not include repeated sampling to capture time-based changes (CSTEP 2022; TERI 2021). Only a few studies in India have taken a more comprehensive approach; for example, Katiyar et al. (2024) conducted a multi-city assessment that covered silt load measurements, estimation of road dust contributions to PM2.5 emissions, modelling of PM2.5 concentrations, and associated health impacts. Most of the earlier studies (Table A1) are based on limited silt load data and aimed only to estimate road dust PM emissions.

In contrast, the exploratory study we conducted uses silt road data, generated through fieldwork, to generate evidence on road dust levels and the effectiveness of cleaning practices. By conducting repeated sampling before and after cleaning, the study examines how much road dust is removed through current cleaning methods and how quickly dust reaccumulates. This study does not seek to compare results across cities or cleaning methods; rather, it is intended to serve as a foundation for comprehensive comparative studies on road cleaning methods and their effectiveness. The study measures silt load in three geographically and demographically distinct Indian cities (Mumbai, Indore, and Ahmedabad), assesses the effectiveness of road cleaning mechanisms in reducing silt load, and demonstrates that outcomes differ by approaches. Based on this study, this working paper

- presents the measurements of silt load in three study cities across road types (access, collector, sub-arterial, arterial, and highways;)
- assesses the effectiveness of multiple wet and dry road cleaning mechanisms adopted by the Mumbai city administration and of dry road cleaning mechanisms in Indore; and
- investigates the patterns of silt reaccumulation in Mumbai and Ahmedabad.

However, this study is subject to certain limitations. Sampling was not conducted simultaneously across all study cities. The number of samples collected from cities and the road types assessed were not uniform. The study assumes negligible seasonal variability in silt load as it combines silt load data from road dust samples collected during different months of the year. Our analysis of the effectiveness of road cleaning and of the re-accumulation of silt load is limited to two of three study cities. Industrial areas were considered only in Ahmedabad, based on the city administration's suggestion. The statistical significance of some of the results may be limited as the sample size is limited.

The differences in sampling periods, sample distribution, and road types across cities and the assumption of negligible seasonal variability may have affected the comparability of some results.

The reaccumulation analysis was limited to Mumbai and Ahmedabad, and the cleaning effectiveness analysis was limited to Mumbai and Indore. In addition, the reaccumulation analysis was limited to two time points following deep cleaning, restricting the understanding of when accumulation reaches saturation and how natural factors, such as wind, influence the removal of silt content due primarily to operational challenges encountered in the individual study cities. Even though we considered socio-economic status (SES) and land use in identifying the road stretches, we did not present the silt load measurements by SES or land use because the sample size was limited.

However, despite these shortcomings, the study that this working paper is based on presents a data-informed perspective on road dust and cleaning mechanisms and addresses policy-relevant questions to promote discussions on and encourage evidence-based decision-making, The findings of this working paper can support urban local bodies, pollution control authorities, and policymakers in designing evidence-based road dust management strategies, optimising road cleaning interventions, and prioritising mitigation measures to reduce road dust emissions and their contribution to ambient PM10 and PM2.5. To the best of our knowledge, this working paper is one of the few that use silt load data to investigate the effectiveness of road dust cleaning mechanisms adopted by cities.

Methodology

In the three cities in India we studied—Mumbai, Indore, and Ahmedabad—we collected data on road dust by conducting primary surveys and supporting data through secondary data sources (such as city master plans and the Census of India) (Figure 1).

The methodology we adopted in this study involved identifying stretches for collecting road dust samples, conducting laboratory analysis to measure silt load levels, and subsequently analysing the data.

Figure 1 | **Study cities (dark blue dots) overlaid on the India map with state boundaries**

Source: WRI India Authors.

Study cities and road dust management challenges

We selected the cities based on pollution level, geographic and demographic diversity, WRI India's engagement level with city authorities, and the regions in which WRI India operates. Mumbai and Ahmedabad are located in western India. Indore is located in central India. Few comprehensive assessments exist of silt load in either region: we could not identify any comprehensive study on silt load for Indore and Ahmedabad (Table A1), though silt load values are reported for Mumbai (NEERI 2019).

The National Clean Air Programme (NCAP) classifies the study cities—Mumbai, Indore, and Ahmedabad—as non-attainment cities because their PM pollution levels between 2011 and 2015 exceeded the NAAQS.

Mumbai

Lying along the western coast at latitude approximately 19.08°N and longitude 72.88°E, Mumbai—the financial capital of India, and the most populous city in the state of Maharashtra—covers an area of 483.14 square kilometre (sq. km.) and, in 2023, its population was estimated at 13 million.

Mumbai falls under the jurisdiction of the Municipal Corporation of Greater Mumbai (MCGM). The total road network is about 2,050 km, including around 1,950 km maintained by MCGM and about 50 km of state highways. The city aims to wash 600–1,000 km of roads daily, but actual cleaning coverage is only about 86–100 km per day, highlighting a major gap between planning and implementation (Pinto 2023).

During a recent intensive drive, the corporation reported washing 676 roads covering 1,888 km (about 92 percent of the city's road length), deploying around 14,000 sanitation workers, 300 water tankers (around 3,000 cubic metre of water), and 120 misting vehicles (Express News Service 2025).

Road dust management, particularly the effectiveness of road cleaning efforts for air pollution control, faces several operational and institutional challenges that continue to undermine sustained road dust mitigation efforts: limited equipment and workforce, high water requirements, traffic constraints, uneven implementation across wards, and continual dust generation from construction and road repair activities.

Indore

Located at approximately latitude 22.72°N and longitude 75.86°E in the western part of the state of Madhya Pradesh, Indore covers 276 sq. km. The largest and most populous city in the state, its population was estimated at about 2.7 million (Census of India 2011). Under the Swachh Bharat Abhiyan, Indore has consistently been ranked as the cleanest city in India since 2017.

Governed by the Indore Municipal Corporation (IMC), the city is divided into 19 zones and 85 wards. Indore has a road network of about 2,260 km. Road dust is a major contributor to air pollution, accounting for 55 percent of PM2.5 and 74 percent of PM10 emissions (The Times of India 2025a). However, the city's response focuses mainly on short-term measures, such as mechanical sweeping, water sprinkling, and hotspot-based cleaning. The city is implementing initiatives such as pothole-free roads and daily mechanical sweeping (The Times of India 2025b) but, largely, the approach remains reactive, and the dust that construction activities and road cleaning operations generate continuously reduces the effectiveness of these interventions further. The gaps in implementation and enforcement are evident in the instructions from the Pollution Control Board to increase sweeping operations and improve dust control at construction sites (The Times of India 2019).

Ahmedabad

Located at about latitude 23.03°N and longitude 72.58°E, Ahmedabad, situated on the banks of the Sabarmati river, is the largest city in Gujarat. Spanning an area of 464.16 sq. km., its population was estimated at 7.6 million in 2023. Administered by the Ahmedabad Municipal Corporation (AMC), the city is divided into 7 zones and 48 wards.

In Ahmedabad, the road length totals approximately 2,580 km. Road dust contributes around 36 percent to PM10 emissions; therefore, the city focuses a large share of air pollution control funding on this sector. Operationally, the city's road dust management strategy uses 62 mechanical road sweepers and 16 truck-mounted mist machines, but this heavy reliance on short-term measures to suppress dust does not adequately address the underlying causes of dust generation (Snigdha 2024) and these short-term efforts continue to be undermined by rising traffic, construction activity, and increasing vehicle ownership (Express News Service 2026).

Factors considered for road stretch selection

Road dust levels can vary both across and within cities. To capture these variations and select road stretches for sampling in the study cities, we considered different factors and classes within the factors (Table 1).

Table 1 | **Factors considered for identifying the study road stretches**

FACTOR	CLASSES CONSIDERED
Land use categories	Residential, commercial, industrial, and mixed
Socio-economic status (SES) categories	High and low
Road types	Highway, arterial, sub-arterial, collector, and access roads
Cleaning mechanisms	Manual, mechanical, and water-based cleaning

Source: WRI India Authors.

Based on these criteria, we initially identified about 60–80 road stretches, and following reconnaissance surveys and practical considerations—traffic-related safety, encroachments, etc.—we finalised 10–20 stretches for sampling and considered 5 road types (highways, arterial, sub-arterial, collector, and access). Highways are high-capacity road corridors designed for fast and uninterrupted long-distance travel. Arterial roads are major urban roadways that serve as connectors between different parts of a city. Sub-arterial roads function below arterial roads in the urban road hierarchy, providing important links between arterial and collector roads. Collector roads are intermediate roads that collect and distribute traffic between local and access roads and higher-order roads. Access roads are primarily intended to provide direct access to residential, commercial, or institutional properties (IRC 2018). Further, each road type is differentiated by the number of lanes.

Sampling: design and frequency

To align the design and frequency of the sampling with the study objectives and based on the cleaning frequency observed, we grouped the 10–20 road stretches selected into 3 categories: regular cleaning, occasional cleaning, and no cleaning. For stretches with regular cleaning, we collected samples before and after cleaning. For stretches with occasional cleaning, we collected pre-cleaning (baseline) samples and post-cleaning samples along with additional samples after four days and eight days of dust build-up to assess mid-week and end-of-week conditions. We carried out all the sampling during non-rainy days. No rainfall was recorded between pre- and post-cleaning sampling in the study cities.

Silt load measurement

The silt load measurement involves two key steps: collecting road dust and laboratory analysis of the collected road dust. The current study precisely adopted the standardised field and laboratory protocols of the United States Environmental Protection Agency (USEPA 2020a; USEPA 2020b). The

Clean Air team of WRI India carried out all the fieldwork. We outsourced the laboratory analysis to laboratories accredited with the National Accreditation Board for Testing and Calibration Laboratories (NABL) in the respective study cities. From each identified road stretch, we chose three sampling locations, either equidistant along continuous road segments (≥2.5 km) or randomly where interruptions existed (Figure 2).

At each location, we collected samples from the active carriageway (excluding shoulders), covering 1–10 feet (around 0.3 to 3 metres) for paved roads and 1 feet (around 0.3 metres) for unpaved roads.

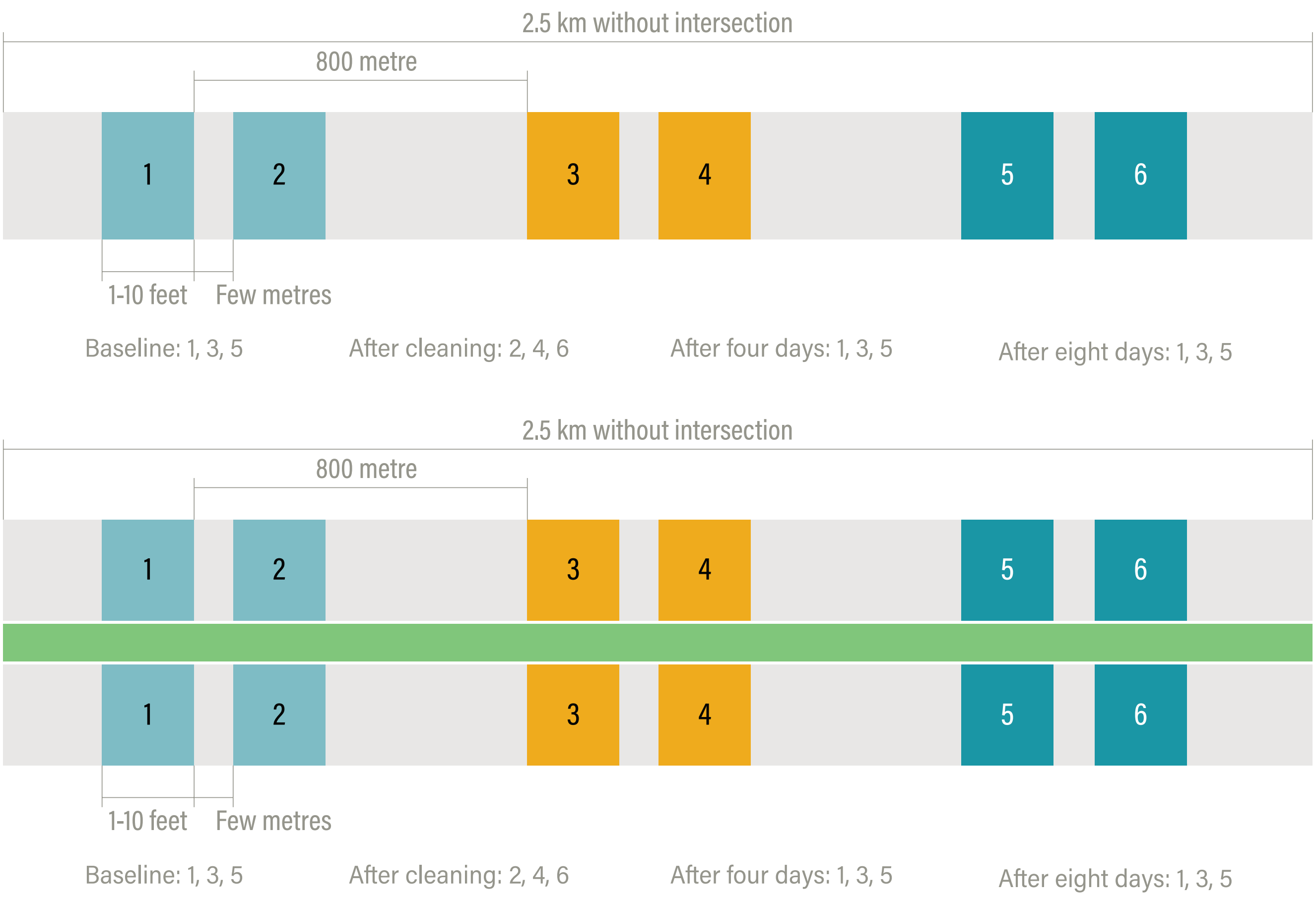
First, we removed larger debris using a broom and pan, and then, we vacuumed the finer dust (Figure A1). For divided roads, we conducted sampling in both directions and combined samples from each stretch and stored it in labelled bags. We carried out most of the sampling close to the end of the morning peak traffic period (between 10 AM and 12 PM), although the exact timings depended on logistical considerations and road safety conditions in the study cities.

For the laboratory analysis, first, using the coning and quartering method, we reduced the field samples on a clean surface to a manageable and representative size. We removed oversized particles (>0.6 mm) and weighed them separately. Then, by oven drying at 110°C, we calculated the moisture content of the reduced sample (typically 0.4–1.8 kg).

To estimate silt content, we performed dry mechanical sieving. We weighed broom-collected and vacuum-collected fractions for paved roads. We sieved samples through a standard set of mesh sizes, including mandatory No. 20 and No. 200 sieves. To determine the silt content, we used the proportion of material passing the 200-mesh sieve (75 μm).

Finally, the silt load is expressed as the weight of the silt content per unit sampling area in the unit of gram per square metre.

Figure 2 | **Schematic depicting the configuration of the road dust sampling locations across an identified road stretch. Top row represents a road stretch without median, while bottom row represents a road stretch with median**



Note: The numbers represent various sampling locations across the road stretch. Baseline samples were collected on the sampling locations numbered 1, 3, and 5. Post-cleaning samples were collected on locations numbered 2, 4, and 6. Re-accumulation samples were collected again on locations numbered 1, 3, and 5

Source: WRI India Authors.

Cleaning mechanisms

Water-based cleaning

The variants of the water-based cleaning method investigated included high-, medium-, and low-pressure cleaning (Wang et al. 2024).

The high-pressure cleaning system uses water at high pressure to clean dust along the edges of roads. The system is mounted on a heavy-duty vehicle (HDV) that is equipped with a 10,000-litre water tanker and a pipe fitted with a 1-mm nozzle.

The medium-pressure cleaning system uses a jet spray system mounted on a light commercial vehicle (LCV) equipped with a 3,000-litre water tanker and a diesel pump. The jet spray system uses a 0.2-mm nozzle to generate the water pressure required to clean dust.

The low-pressure cleaning system uses a water tanker fitted with a pipe containing irregular apertures (2–3 mm and larger). Targeting primarily the road median and allowing water to flow by gravity towards the road edges, the system removes dust by flooding roads with water.

Mechanical vacuum cleaning

One of the most used methods for removing road dust, mechanical vacuum cleaning typically uses a rotating side broom to move dust and debris towards the centre, where a main broom and a high-power vacuum lift the material into a hopper (Figure 3).

Mechanical vacuum cleaning machines can cover large areas in a short time; however, on roads with encroachments, uneven surfaces, or with limited width, their effectiveness may be reduced.

Manual cleaning

In manual cleaning, the traditional method of cleaning roads, brooms and shovels are used to remove dust, debris, and litter. Manual cleaning is labour-intensive but useful where mechanical sweepers cannot operate. Effective dust collection is essential to prevent material from re-entering stormwater drains, which would otherwise increase silt load.

Sample size and analysis framework

For each study city, we aggregated the data on silt load from the road dust samples we collected across months and seasons. This subsection describes the sampling period, the number of road stretches covered for dust sampling, the number of samples collected, and the cleaning mechanisms investigated (Table 2). Figure 4 describes the methodology we used to achieve the study objectives.

Figure 3 | **Pictures showing water-based, mechanical, and manual cleaning of roads**

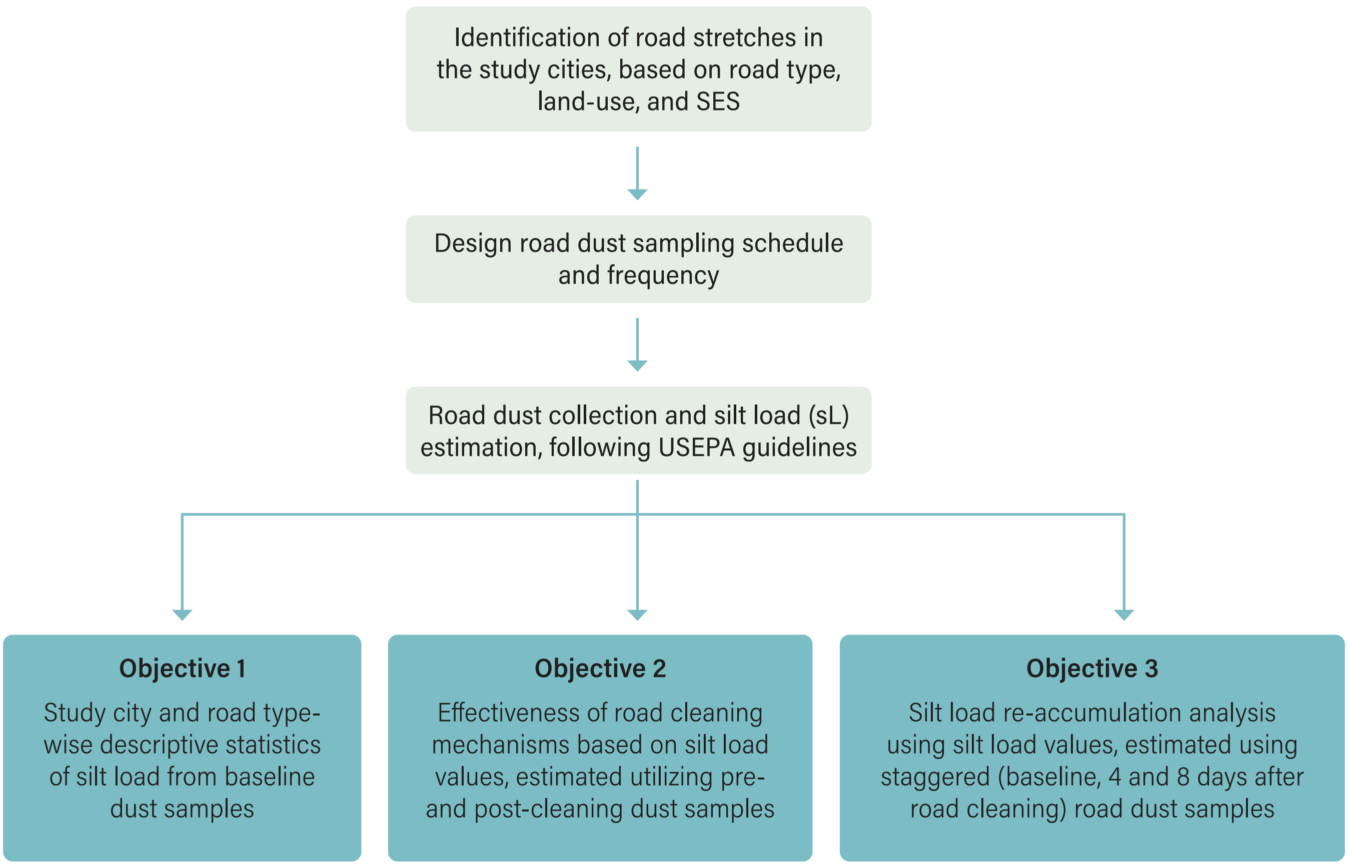
Source: WRI India.

Table 2 | **Factors considered for identifying the study road stretches**

STUDY CITY	SAMPLING PERIOD	NUMBER OF ROAD STRETCHES	LAND USE TYPE OF ROAD STRETCHES	NUMBER OF ROAD DUST SAMPLES COLLECTED	CLEANING MECHANISMS INVESTIGATED
Mumbai	December 2023 to June 2024	22	Residential: 5 Commercial: 6 Mixed (residential + commercial + industrial): 11	66	Mechanised (vacuum) cleaning; manual cleaning; water -based cleaning (no, medium and high pressure)
Indore	September-October 2024; April-May 2025	23	Residential: 17 Mixed (residential + commercial + industrial): 6	69	Mechanised (vacuum) cleaning (three capacities)
Ahmedabad	May 2024; March 2025	9	Industrial: 5 Mixed (commercial +residential): 4	27	No cleaning mechanisms investigated

Source: WRI India Authors.

Figure 4 | **Flowchart showcasing the study methodology**



Source: WRI India Authors.

Findings

The results corresponding to the different study objectives are presented in separate subsections.

Silt load measurements

This section presents the city-wise results of the silt load measurements.

Mumbai

In Mumbai, we carried out the sampling during the winter (December and January) of 2023 and the summer (April, May, and June) of 2024. The sampling covered four road types: access, collector, sub-arterial, and arterial. Across the city, the sample-wise silt load values (in gram per square metre) ranged between 1.25 and 10.13 and by road type, the mean values ranged between 2.30 and 6.78 (Figure 5).

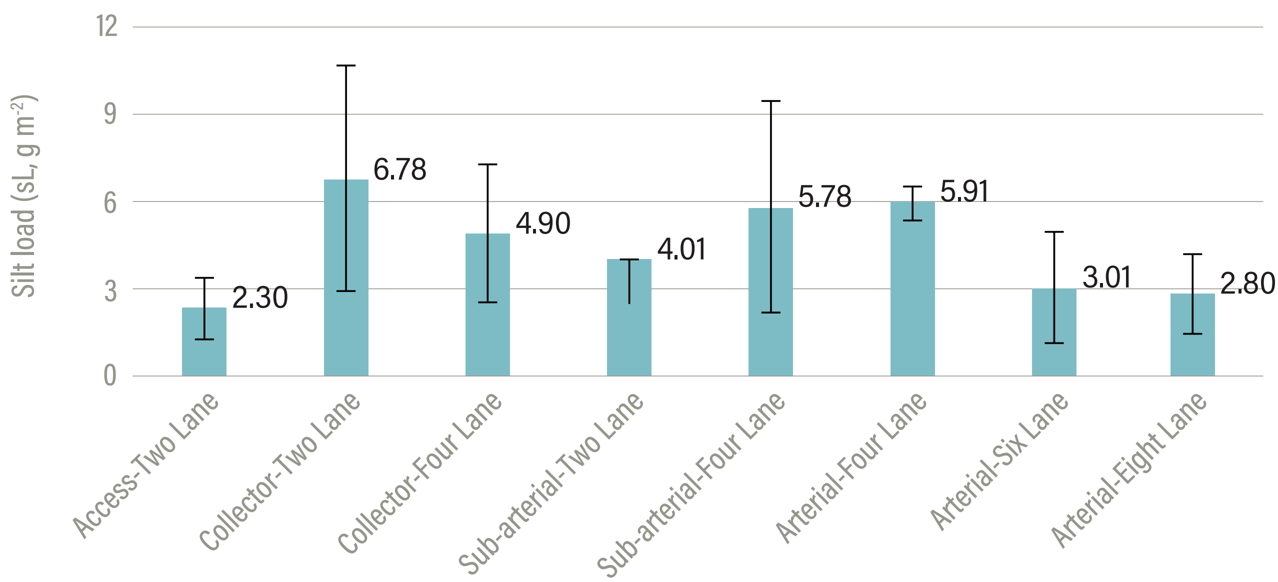
The silt load values observed in this study were well within the range reported in the literature for Indian cities (Table A1).

Higher silt load values were observed for collector roads, followed by sub-arterial roads, arterial roads, and access roads. A significant variation in silt load values was observed for two-lane collector and four-lane arterial roads. While silt load decreased with increasing lanes in arterial roads, contrasting trends in collector and sub-arterial roads were observed. Table A2 presents the silt load statistics by road type for all the study cities.

Indore

In Indore, we conducted sampling during the post-monsoon months of 2024 and the summer months of 2025. The sampling covered sub-arterial roads, arterial roads, and highways. Across the road types covered, the sample-wise silt load values (in gram per square metre) ranged between 1.24 and 10.60 while the road type-wise mean values ranged between 3.67 and 4.87 (Figure 6). While four-lane sub-arterial roads exhibited the highest mean silt load values, the variability in silt load values across and within road types was comparatively lower in Indore.

Figure 5 | **Road type-wise mean silt load values for Mumbai. The whiskers represent the standard deviation, while bars without whiskers indicate the availability of only one data point for the respective road type**

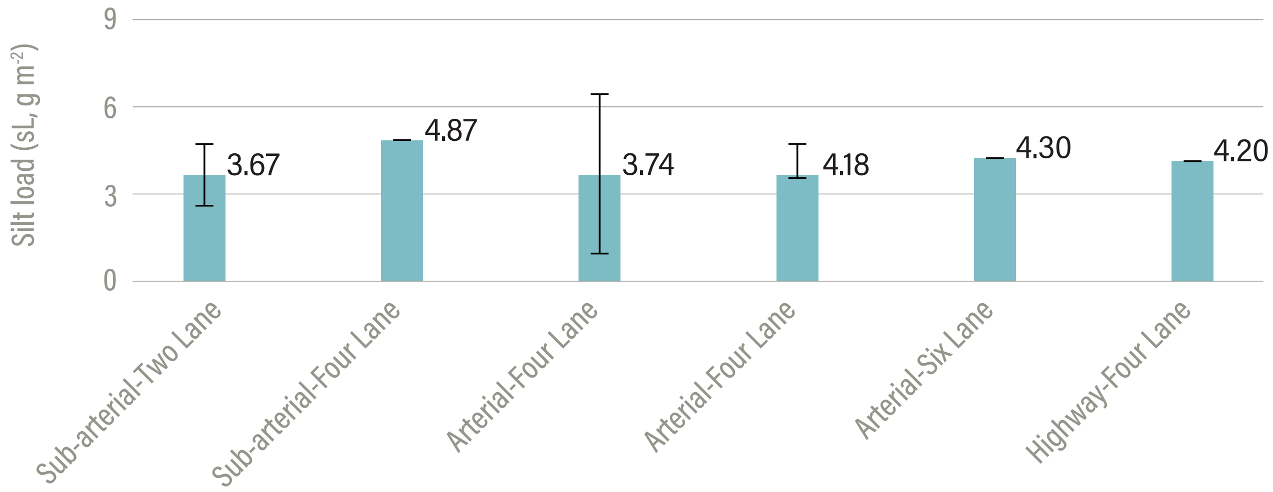


Source: WRI India Authors.

Ahmedabad

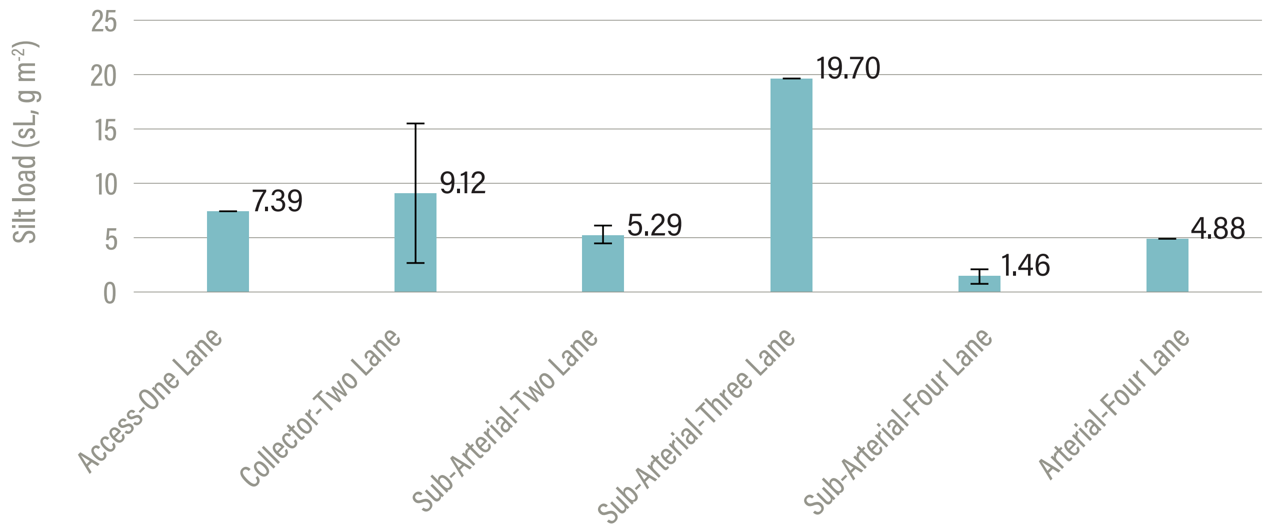
In Ahmedabad, road dust samples were collected from an industrial area during the summer months of 2024 and 2025. The sampling covered access roads, sub-arterial roads, and arterial roads. Across the road types covered, the sample-wise silt load values (in gram per square metre) ranged between 0.99 and 19.70, while the road type-wise mean values ranged between 1.46 and 19.70 (Figure 7). The highest mean silt load value was observed for three lane sub-arterial roads while the lowest was observed for four-lane sub-arterial roads. Significant variability in silt load values was observed for two-lane collector roads.

Figure 6 | **Road type-wise mean silt load values for Indore**



Note: The whiskers represents the standard deviation, while bars without whiskers indicate the availability of only one data point for the respective road type.
Source: WRI India Authors.

Figure 7 | **Road type-wise mean silt load values for Ahmedabad**



Note: The whiskers represents the standard deviation, while bars without whiskers indicate the availability of only one data point for the respective road type.
Source: WRI India Authors.

Evaluation of road cleaning mechanisms

In this subsection, we evaluate the effectiveness of different road cleaning mechanisms in removing road dust.

For the purpose of this study, we operationally defined effectiveness as the percentage reduction in silt load between pre-cleaning and post-cleaning conditions relative to the pre-cleaning silt load value. We used silt load data from road dust samples collected before (pre-) and after (post-) road cleaning for this analysis.

For dry cleaning methods, we collected post-cleaning samples as soon as possible after the cleaning activity whereas, for wet cleaning methods, post-cleaning samples were collected after 24 hours to allow the roads to dry.

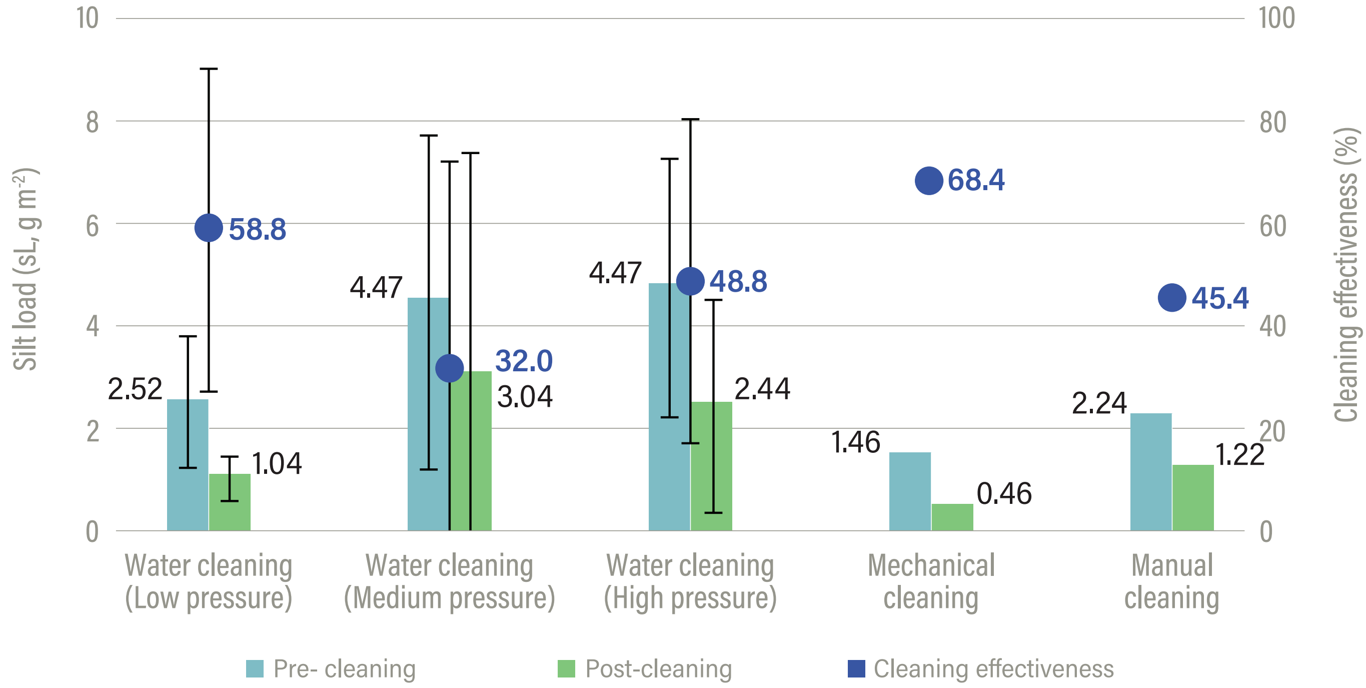
Both dry and wet cleaning mechanisms were evaluated in Mumbai and only dry cleaning mechanisms in Indore. We aggregated the pre- and post-cleaning silt load values across different road types, and we present the mean results.

Mumbai

In Mumbai, we evaluated the effectiveness of cleaning for five different clean mechanisms over four road types (access, collector, sub-arterial, and arterial). Here, we present the average silt load values derived from dust samples (pre- and post-cleaning road) along with the corresponding cleaning effectiveness (Figure 8).

Across all cleaning methods, the post-cleaning silt load values were substantially lower, indicating a reduction in road dust levels due to road cleaning. The highest cleaning effectiveness, approximately 68 percent, was observed for mechanical cleaning. This was followed by low-pressure water cleaning with an effectiveness of approximately 59 percent, high-pressure water cleaning with approximately 49 percent effectiveness, and medium-pressure water cleaning with approximately 32 percent effectiveness. A large variability in the cleaning efficiencies was observed for water-based cleaning mechanisms. Manual cleaning achieved an effectiveness of approximately 45 percent. High- and medium-pressure water cleaning methods involve an operator handling the hose, and efficiencies are, therefore, subject to operator behaviour. It should be noted that the efficiencies for mechanical and manual cleaning were derived from single-point observations.

Figure 8 | **Road cleaning mechanism-wise pre- (blue bar) and post-cleaning (green bar) mean silt load, cleaning effectiveness (dark blue dot) observed in Mumbai**



Note: Whisker represents the standard deviation. Bars and dots without whiskers indicate the availability of only one data point for the respective cleaning type.
Source: WRI India Authors.

Indore

In Indore, the effectiveness of mechanical cleaning was assessed on three types of roads: arterial, sub-arterial, and highway. We assessed three types of mechanical cleaning machines equipped with high-pressure vacuum systems and combined with jet spray mechanisms. In this document, we refer to these machine types as M1, M2, and M3 (Table 3). Each type varies in operational specifications, including hopper capacity, water tank capacity, number of nozzles and brushes, and operating speed.

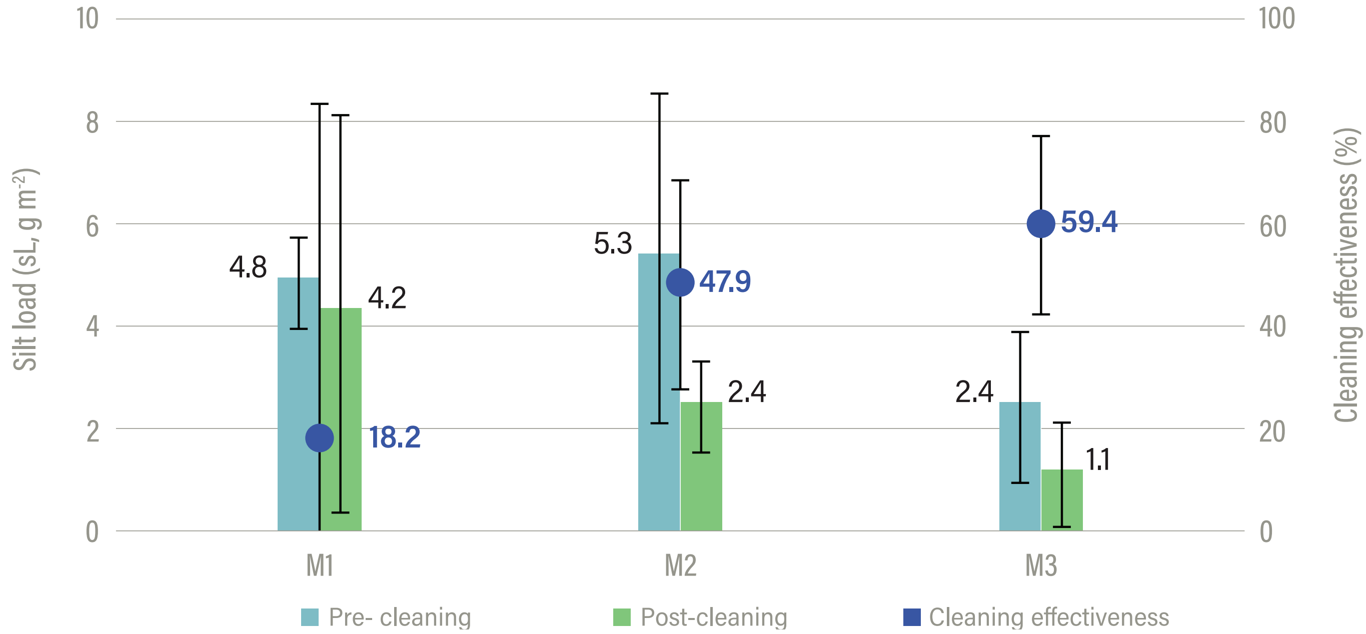
Figure 9 presents the average silt load values derived from pre- and post-cleaning road dust samples, along with the corresponding cleaning efficiencies for all three variants of the mechanical cleaning mechanisms. The mean cleaning effectiveness was approximately 18 percent for M1, 48 percent for M2 (with a variability of around 20 percent), and 59 percent for M3 (with a variability of around 17 percent).

Table 3 | **Technical specifications of the different mechanical cleaning machines considered**

PARAMETRE	M1	M2	M3
Dust collection hopper capacity	6 m^3	2.5 m^3	5 m^3
Water tank capacity	600 litres	833 litres	600 litres
Refilling frequency	After 10–12 km of road cleaned	After 6–9 km of road cleaned	After 10–15 km of road cleaned
Number of nozzles	12 nozzles	2 spray nozzles	13 nozzles
Nozzle diametre	6 mm	Not specified	6 mm
Number of brushes	3 brushes	Not specified	2 brushes
Average operating speed	10–12 km h^{-1}	3–8 km h^{-1}	10–12 km h^{-1}

Source: WRI India Authors.

Figure 9 | **Mechanical cleaning machine-wise pre- (blue bar) and post-cleaning (green bar) mean silt load, cleaning effectiveness (dark blue dot) observed in Indore**



Source: WRI India Authors.

Silt reaccumulation analysis

This subsection presents an overview of the rate of silt accumulation on roads by analysing road dust samples collected (from the same sampling spot) at three points in time: just before deep cleaning of the road (baseline), after four days of cleaning, and after eight days of cleaning.

Based on our requests, city administrations carried out deep cleaning. We selected road stretches with either no regular cleaning or only occasional cleaning for this exercise. We implemented this sampling and analysis configuration in Mumbai and Ahmedabad (industrial area). In Ahmedabad, due to operational challenges, we carried out the repeat sample collection after two and four days of cleaning.

Mumbai

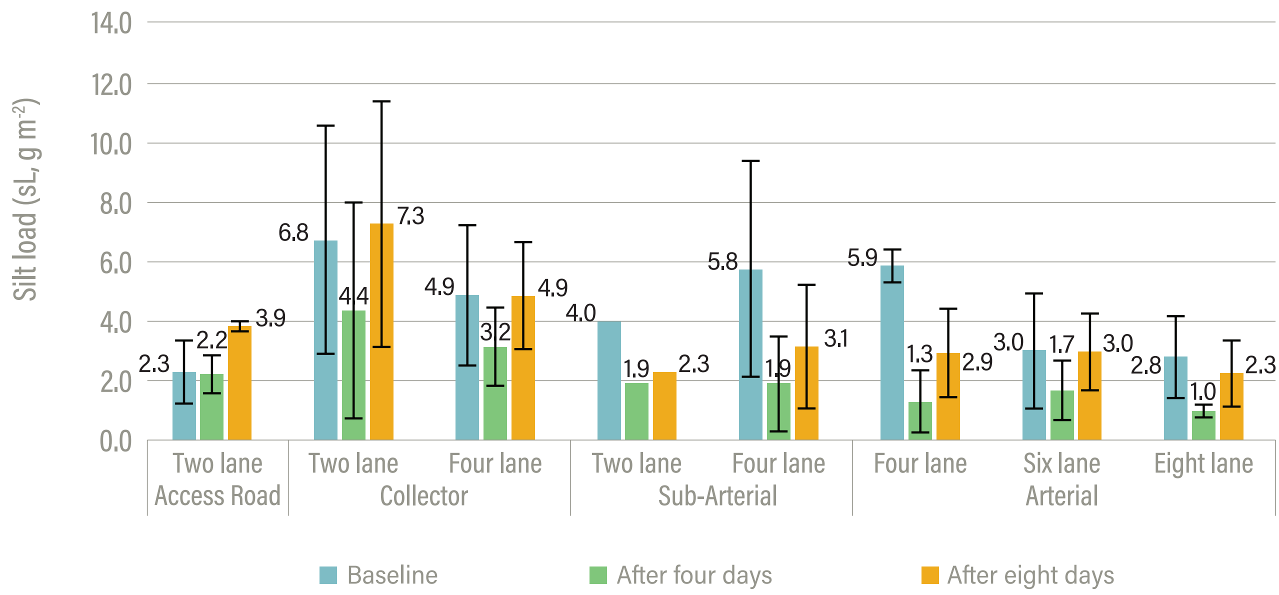
Figure 10 shows the silt load results by road type based on repeat sampling before road cleaning (the baseline), four days after cleaning, and eight days after cleaning.

The plot shows that the pre-cleaning silt load values are higher than (or comparable to) the silt load values obtained after four days of cleaning and after eight days of cleaning. This indicates that for most road types, it takes more than eight days for the silt content to return to pre-cleaning levels.

On the two-lane access road, where the baseline values (2.3 gram per square metre) were already lower, the silt load values returned to the baseline level within four days and exceeded the baseline value after eight days (3.9 gram per square metre). Interestingly, the rate of silt accumulation was higher on collector roads than on other road types.

Overall, considerable variations in silt accumulation were observed across different road types. In general, silt accumulation is influenced by external factors, such as nearby polluting activities, including construction and maintenance activities, as well as traffic dynamics.

Figure 10 | **Road type-wise baseline, elapsed four and eight days after cleaning silt load values, depicting the rate of silt accumulation**



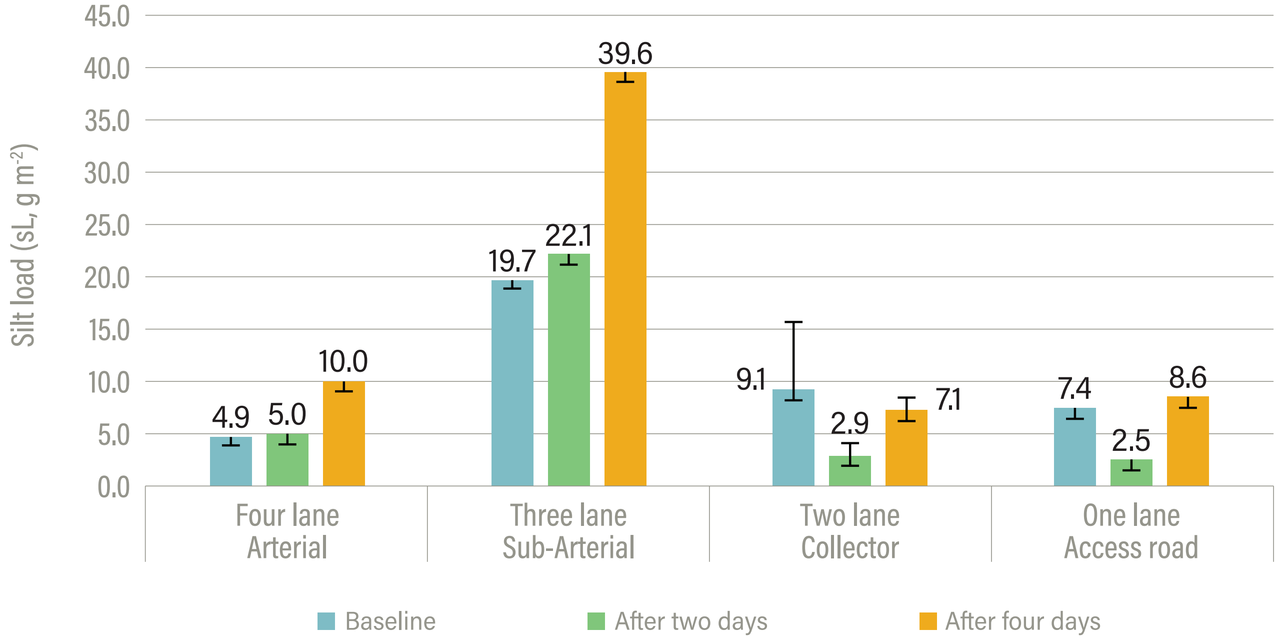
Source: WRI India Authors.

Ahmedabad

Figure 11 presents the rate of silt accumulation results for Ahmedabad. We collected the samples for this exercise from an industrial area.

The results show that the build-up of silt is higher on arterial and sub-arterial roads in the industrial area and lower on collector and access roads, due possibly to local activities and the movement of heavy vehicles.

Figure 11 | **Road type-wise baseline, elapsed two and four days after cleaning silt load values, depicting the rate of silt accumulation**



Source: WRI India Authors.

Conclusions

Following a well-established methodology and through road dust sampling and a laboratory procedure, this study assessed the abundance of road dust by measuring silt load across multiple road types and lane configurations in three Indian cities—Mumbai, Indore, and Ahmedabad. The silt load values, observed to be 1–20 gram per square metre, were within the range reported for Indian cities in the literature. The variability observed in silt load underscores that more granular data is needed to support evidence-based road cleaning strategies.

The study findings can serve as an initial step towards strengthening policy discussions, conducting further comprehensive studies, and supporting study cities in developing evidence-based road dust management policies and in planning to reduce road dust. Further, leveraging the strategic repeat sampling of road dust, the study investigated the effectiveness of various road cleaning mechanisms being used in these cities and the reaccumulation behaviour of silt content.

In Mumbai, the evaluation of cleaning mechanisms indicated that efficiencies vary across different methods and mechanical cleaning appeared to show higher effectiveness. However, these results should be interpreted cautiously because the number of samples is limited. Among water-based cleaning mechanisms, low-pressure water-based cleaning was found to be relatively effective. In Indore, among the three variants of mechanical cleaning machines, no distinct pattern emerged in cleaning efficiency.

Improving road cleaning effectiveness through sustained reductions in silt load can help to reduce road dust emissions and contribute to improvement in ambient air quality. The reaccumulation analysis showed that within eight days of deep cleaning, the silt content nearly returned to its pre-cleaning levels. In industrial areas, the rate of reaccumulation was observed to be faster.

The NCAP recognises road dust; in practice, however, reductions in road dust emissions are not tracked quantitatively, for example, through silt load assessments. One comprehensive study on silt load was conducted in Mumbai several years ago, but no such study was identified for the other study cities. This creates a disconnect between implementation efforts and actual air quality outcomes.

To improve road dust control, most cities have adopted and expanded mechanised sweeping in place of manual sweeping to improve road dust control and increased both the coverage and frequency of sweeping operations. New Delhi is an example (Singh 2026). Cities commonly report indicators such as road length swept, number of sprinklers deployed, and frequency of cleaning (Manuja et al. 2020). However, these metrics do not address the critical policy question of how much dust is actually being reduced and how quickly it reaccumulates.

To effectively reduce silt load, policy recommendations should consider factors such as traffic flow, fleet mix, nearby construction activities, road type, and the cleaning methods used. By integrating the findings across the study objectives, cities can optimise cleaning frequency and identify the most suitable cleaning methods for different road types. Going forward, cities should integrate silt load assessments into routine evaluations of dust reduction and mitigation measures.

Overall, the findings generated evidence on road dust levels and the effectiveness of road cleaning practices. The evidence can strengthen policy discussions on road dust management, improve road dust management strategies, and support more effective air quality interventions in Indian cities.

As a way forward, in addition to addressing the limitations of the current study and expanding similar research to other geographies, future research should focus on understanding the drivers of road dust accumulation, including heavy traffic movement, and other polluting sources contributing to road dust. This requires chemical speciation of the silt load.

Chemical speciation studies of road dust have been conducted in Jordan (Massadeh et al. 2007); England (Charlesworth et al. 2003); Hong Kong (Li et al. 2001); and Nigeria (Ogunsola et al. 1994), to name a few countries, but in India, such studies are very limited. With a sufficiently large sample size, source apportionment studies can be undertaken to identify and quantify the major contributors to silt content. Therefore, future studies could focus on the chemical speciation of silt content. These kinds of studies can help identify the source of road dust, enabling proactive road dust management.

As an exploratory effort in this direction, WRI India is currently conducting chemical analysis of silt content collected from roads in Mumbai.

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Appendix

Table A1 | **Silt load values observed in various Indian and global cities**

COUNTRY	STATE	CITY	sL RANGE (g m^{-2})	REFERENCE
India	Bihar	Patna	30–100	Guttikunda and Jawahar (2014)
	Delhi	New Delhi	3–40	Suryawanshi et al. (2016)
	Gujarat	Surat	1.5–2.6	TERI (2021)
	Himachal Pradesh	Baddi	4.5–5.8	Katiyar et al. (2024)
		Damtal	0.7–1.3	
		Nalagarh	0.6–1.4	
		Kalaamb	0.7–1.2	
		Paonta Sahib	0.5–1.5	
		Sundarnagar	0.8–1.2	
		Parwanoo	0.6–1.4	
	Jharkhand	Dhanbad	15.2–44.3	Kumar et al. (2021)
	Karnataka	Bangalore	3.6	CPCB (2011)
	Maharashtra	Pune	9	ARAI (2010)
		Mumbai	0.534	NEERI (2010)
	Punjab	Patiala	0.9–4.2	Katiyar et al. (2024)
		MGG	1.3–17.6	
		Khanna	1.0–9.9	
		Nangal	1.5–7.8	
		Jalandhar	1.8–9.9	
		Dera Bassi	1.9–30.7	
		DBN	1.9–5.4	
		Amritsar	2.3–11.6	
		Ludhiana	0.64–4.05	PSCST and TERI (2020)
	Rajasthan	Jaipur	4.0–102.4	Katiyar et al. (2024)
		Alwar	4.0–137.8	
	Tamil Nadu	Chennai	3–34	Greater Chennai Corporation, and Tamil Nadu Pollution Control Board (2021)
	Telangana	Hyderabad	0.2–8.6	
	Uttar Pradesh	Kanpur	75.7–112	Sharma et al. (2010)
		Kanpur Nagar	2.1–10.1	Katiyar et al. (2024)
		Rae Bareli	3.5–7.9	
		Anpara	3.5–7.9	

COUNTRY	STATE	CITY	sL RANGE (g m^{-2})	REFERENCE
India	Uttar Pradesh	Bareilly	3.9–6.3	Katiyar et al. (2024)
		Gajraula	4.1–6.1	
		Jhansi	4.1–6.0	
		Noida	4.1–8.5	
		Moradabad	5.4–9.9	
		Kanpur Dehat	5.4–9.9	
		Agra	6.8–9.2	
		Khurja	7.4–9.9	
		Firozabad	14.8–17.1	
		Varanasi	18.3–26.3	
		Prayagraj	18.7–25.4	
	West Bengal	Kolkata	0.2–0.46	NEERI (2019)
		Howrah	0.37–0.51	
USA		Las Vegas	0.03–4.2	Fitz et al. (2020)
Italy		Milan	0.006–0.066	Amato et al. (2017)
South Korea		Icheon & Seoul	2.5 & 5	Han and Jung (2012); Sharma et al. (2014)
Spain		Madrid & Barcelona	1.35–4.40	Karanasiou et al. (2014)
Netherlands		Utrecht	1.35–4.40	Karanasiou et al. (2014)
Poland		Krakow	0.220–1.250	Bogacki et al. (2018)
China		Beijing & Baoding	0.30–24.22	Wang et al. (2023a); Casotti Rienda and Alves (2021); Chen et al. (2019)

Source: WRI India authors' analysis.

Figure A1 | **Photographs captured during the field work (road dust sample collection)**

Source: WRI India.

Table A2 | **City- and road type-wise silt load statistics**

CITY	ROAD TYPE	NUMBER OF ROAD STRETCHES	AVERAGE (MIN., MAX., SD) sL IN G M^{-2}
Mumbai	Access road-two lane	2	2.3 (1.54,3.06,1.07)
	Collector-two lane	3	6.78 (2.55,10.13,3.86)
	Collector-four lane	2	4.9 (3.22,6.57,2.37)
	Sub-arterial-two lane	1	4.01 (4.01,4.01,0)
	Sub-arterial-four lane	2	5.78 (3.19,8.38,3.67)
	Arterial-four lane	2	5.91 (5.52,6.3,0.55)
	Arterial-six lane	5	3.01 (1.66,6.31,1.93)
	Arterial-eight lane	3	2.8 (1.25,3.97,1.4)
Indore	Sub-arterial-two lane	7	3.67 (2.35,5.32,1.05)
	Sub-arterial-four lane	1	4.87 (4.87,4.87,0)
	Arterial-two lane	11	3.74 (1.24,10.6,2.74)
	Arterial-four lane	2	4.18 (3.78,4.58,0.57)
	Arterial-six lane	1	4.3 (4.3,4.3,0)
	Highway-four-lane	1	4.2 (4.2,4.2,0)
Ahmedabad	Access road-one lane	1	7.39 (7.39,7.39,0)
	Collector-two lane	2	9.12 (4.6,13.64,6.4)
	Sub-arterial-two lane	2	5.29 (4.72,5.87,0.82)
	Sub-arterial-three lane	1	19.7 (19.7,19.7,0)
	Sub-arterial-four lane	2	1.46 (0.99,1.93,0.66)
	Arterial-four lane	1	4.88 (4.88,4.88,0)

Source: WRI India.

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About WRI India

WRI India, an independent knowledge organisation registered as India Resources Trust, provides objective information and practical proposals to foster environmentally sound and socially equitable development. Through research, analysis, and recommendations, WRI India puts ideas into action to build transformative solutions to protect the earth, promote livelihoods, and enhance human well-being.

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