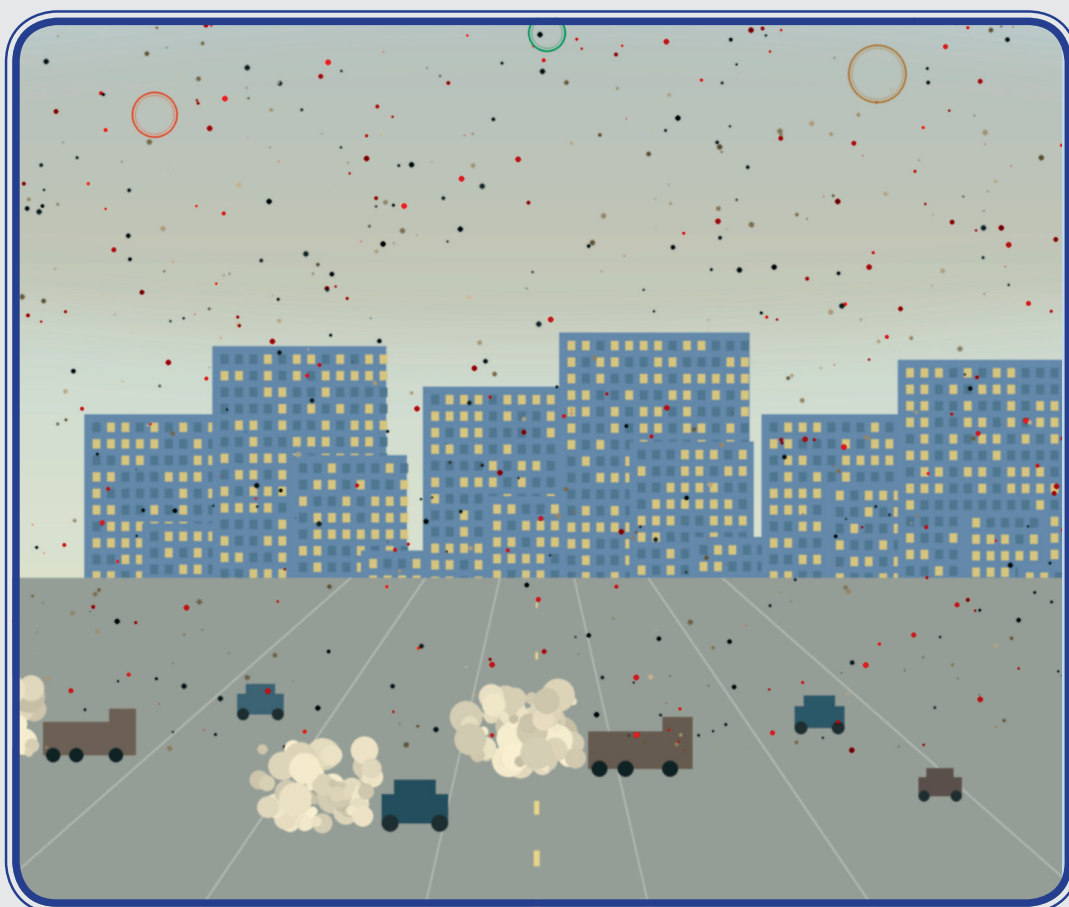


POLICY Bulletin

The Key Drivers of Particulate Pollution from Road Transportation in Indian States



2026

CSIR-NIScPR Policy Bulletin/May-2026/01



CSIR- National Institute of Science Communication and
Policy Research (NIScPR)

Dr. K S Krishnan Marg, Pusa Campus, New Delhi - 110012, India

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Executive Summary

This policy bulletin highlights the rising importance of non-exhaust vehicular emissions in India's urban particulate pollution. Despite major reductions in tailpipe emissions and the broader goals of the National Clean Air Programme (NCAP), ambient $PM_{2.5}$ and PM_{10} levels remain high across many states. The analysis shows that as exhaust emissions decline, non-exhaust sources such as tyre wear, brake wear, and particularly road dust resuspension, are becoming dominant contributors. Road dust resuspension accounts for the largest share, especially for PM_{10} , and in several states total non-exhaust emissions now exceed exhaust emissions. Light-duty vehicles contribute most of the tyre and brake wear emissions due to their large fleet size and high urban usage. Emissions also show strong seasonal variation, increasing during dry periods and decreasing significantly during rainfall.

These sources currently less comprehensively addressed, which can be included in emission inventories and city action plans. The bulletin recommends integrating non-exhaust emissions into policy frameworks through standardized assessment methods, improved road maintenance and mechanized sweeping, performance standards for tyre and brake materials, and consideration of seasonal factors. Addressing non-exhaust sources is essential for sustained particulate matter reduction and achieving long-term air quality goals in India.

Why This Matter Now?

Over the past decade, India has made significant progress in reducing the vehicular exhaust emissions through the nationwide implementation of Bharat Stage (BS-VI) emission standards as per recent studies. This transition to BS-VI has significantly lowered the tailpipe emissions of particulate matter (PM), nitrogen oxides (NO_2), and sulphur content in fuels [5]. Despite these regulatory advances, the ambient concentrations of $PM_{2.5}$ and PM_{10} continue to remain continuously high across many Indian states and urban areas, this raising the concerns regarding the effectiveness of current vehicular emission control strategies in achieving air quality improvements under the National Clean Air Programme. An important but under-addressed factor is the growing contribution of non-exhaust emissions from road transport [8]. Unlike tailpipe emissions, non-exhaust emissions originate from mechanical and physical processes associated with vehicle operation. These include tyre tread abrasion, brake lining wear, and the resuspension of road dust caused by vehicular movement [4]. As highlighted in the study, the relative importance of these sources has increased substantially over the time, particularly as the exhaust emissions decline under stricter regulatory norms [6]. In the several high-vehicle-populated states, non-exhaust particulate emissions were found to approach or in some cases, exceed the exhaust emissions, especially for PM_{10} . In fact, road dust resuspension emerged as the dominant contributor, followed by tyre and brake wear particles, and the light-duty vehicles accounting for a significant share due to their large fleet size and high urban activity. Importantly, these emissions remain largely unregulated and are not systematically monitored within existing air quality management frameworks. Most of emission inventories and city-level action plans primarily focus on exhaust sources, construction dust, and industrial emissions,

while non-exhaust vehicular contributions are either underestimated or excluded. Furthermore, the seasonal and meteorological factors such as dry surface conditions during summer months also boost the resuspension which is leading to episodic spikes in ambient PM levels.

What is Non-Exhaust Emission?

As the particulate matter released from vehicles through mechanical and physical processes other than fuel combustion is referred as non-exhaust emission. These emissions primarily originate from tyre wear [9] (due to frictional interaction between the tyre tread and road surface, generating fine rubber-based particles enriched with compounds such as zinc and synthetic polymers), brake wear [10] (from the abrasion of brake pads and discs during deceleration, emitting metal-rich particles containing copper, iron, and other trace elements, and road dust), and resuspension during routine vehicle operation (Figure 1). Whereas, road dust resuspension identified as the dominant contributor to PM_{10} emissions across several states, it is caused when moving vehicles, disturb and re-entrain previously deposited dust particles back into the atmosphere [7].

Unlike exhaust emissions, non-exhaust emissions occur irrespective of fuel type and therefore persist even in electric vehicles. Their magnitude is strongly influenced by traffic density [3], vehicle speed, braking frequency, pavement condition, road infrastructure, and meteorological parameters [11]. Even, dry and high-temperature conditions significantly enhance dust resuspension, while rainfall and surface moisture suppress emissions. As the exhaust emission controlled after adoption or implementation of various regulation and norms, these non-exhaust sources can also be regulated or curb the urban particulate pollution profile with inclusion of emission factors for non-exhaust sources while framing the emission control policies in future.

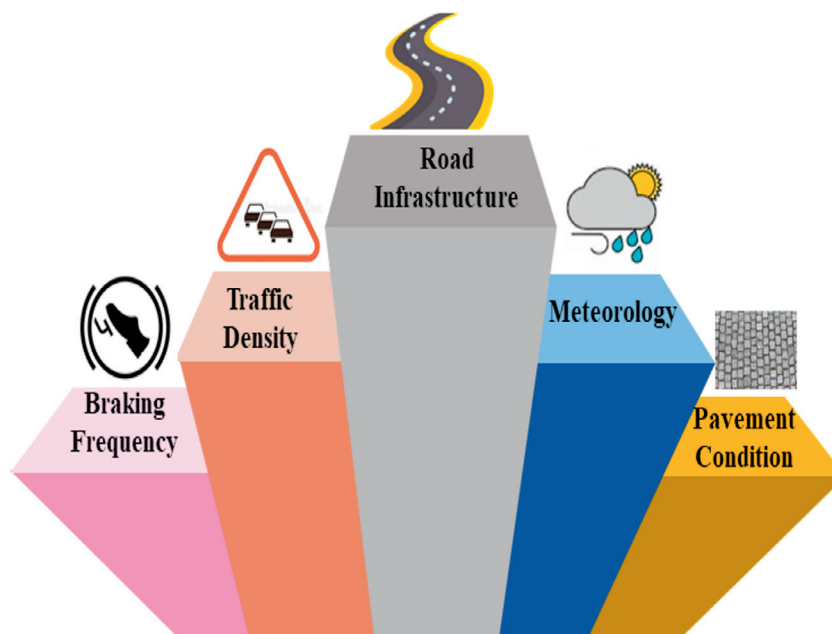


Figure 1: Key influencing factors governing non-exhaust particulate matter emissions.

Road Dust Resuspension as the Dominant Source

The analysis across the ten highly-vehicle-populated states consistently identified road dust resuspension as the largest contributor to non-exhaust particulate emissions. Among the three major non-exhaust components such as tyre wear, brake wear, and resuspended road dust and the latter accounted for the highest share of both PM_{10} and $PM_{2.5}$ emissions throughout the assessment period (Figure 2).

The contribution was particularly noticeable for PM_{10} reflecting the coarse nature of mechanically disturbed road dust particles. In comparison, $PM_{2.5}$ emissions although substantial and represented a smaller fraction of the total resuspended load. It is further observed strong seasonal variability in emission magnitudes. Dry surface conditions during summer and pre-monsoon periods significantly enhanced dust entrainment due to increased vehicle-induced turbulence and reduced the surface moisture. And the states with prolonged dry period exhibited the markedly elevated emission levels during these months. While, monsoon rainfall played a critical role in suppressing emissions by increasing surface wetness and facilitating the particle deposition [1]. The results indicate that rainfall events reduced the road dust resuspension emissions across several states and highlighted the strong meteorological sensitivity of non-exhaust emissions and highlight the importance of seasonal considerations in urban air quality management strategies [12].

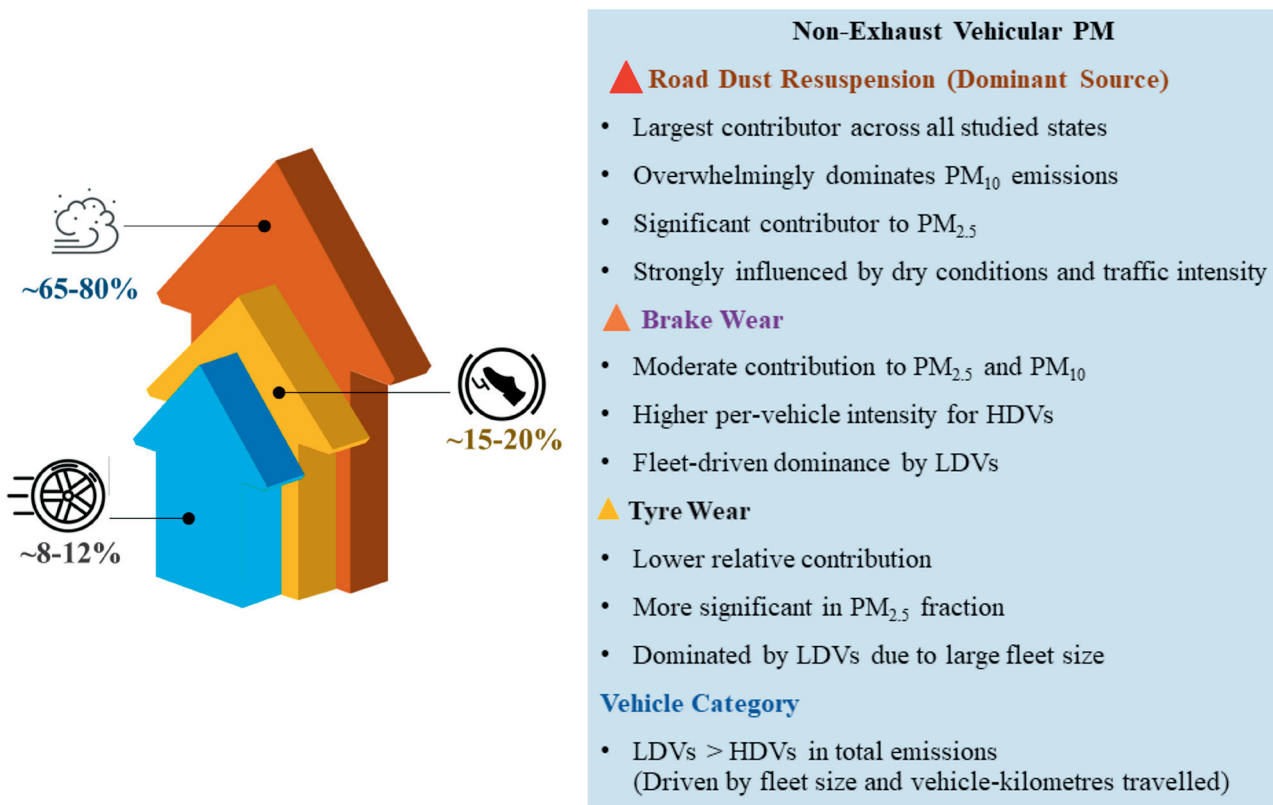


Figure 2: Source-wise distribution and dominance pattern of non-exhaust particulate emissions.

Light-Duty Vehicle's Dominate Emissions

Although heavy-duty vehicles exhibit higher emission factors per vehicle due to greater axle loads and braking intensity [2], the overall contribution to non-exhaust particulate emissions is largely driven by fleet composition. The analysis shows that the light-duty vehicles, including passenger cars and two-wheelers, account for the majority of total tyre and brake wear emissions across the studied states. This dominance is primarily attributable to their substantially larger population and higher vehicle-kilometres travelled in urban areas. In highly motorized states such as Maharashtra, Karnataka, and Tamil Nadu, LDVs contribute more than 90% of tyre and brake wear emissions, showing the critical role of rapidly expanding private vehicle fleets in shaping India's non-exhaust emission profile.

Non-Exhaust PM Often Exceeds Exhaust PM

The comparative assessment of exhaust and non-exhaust emissions reveals that, in several of the studied states non-exhaust particulate matter emissions exceeds than the exhaust emissions by a significant margin. While the implementation of BS-VI standards has led to substantial reductions in tailpipe PM emissions, the decline in the exhaust contributions has simultaneously increased the relative presences of mechanically generated particles. This shift highlights a structural transition in vehicular emission profiles, where non-exhaust sources increasingly dominate the urban particulate pollution levels.

State Level Variation

Higher levels of road dust resuspension were observed in Haryana, Chhattisgarh, Gujarat, Tamil Nadu, and West Bengal, largely driven by high vehicle density, persistent urban congestion, suboptimal pavement conditions, and dry meteorological regimes that favour particle entrainment. In contrast, Maharashtra exhibited comparatively lower resuspension levels, potentially reflecting meteorology and road infrastructure (Figure 3). Even the meteorological adjustments lead to substantial reductions in PM emissions across Indian states, with the highest decline observed in winter (up to 92%). Colder temperatures and higher humidity during winter suppress road dust resuspension, whereas warmer and drier conditions in spring and summer shows relatively smaller reductions. The coastal and humid regions show slightly high reductions due to moisture effects, while altitude and seasonal weather variability further influence state-wise emission patterns.

Policy Implications

As India is continuing to strengthen the vehicular emission control under the National Clean Air Programme and progressively tighter tailpipe emission norms, there exists a strategic opportunity to broaden particulate matter mitigation approaches by systematically incorporating non-exhaust emission sources into the policy framework. The successful implementation of BS-VI standards has substantially reduced the exhaust PM emissions; however, this transition has also altered the relative composition of traffic-related particulate pollution. With declining tailpipe contributions, mechanically generated particles from road dust resuspension, tyre wear, and brake

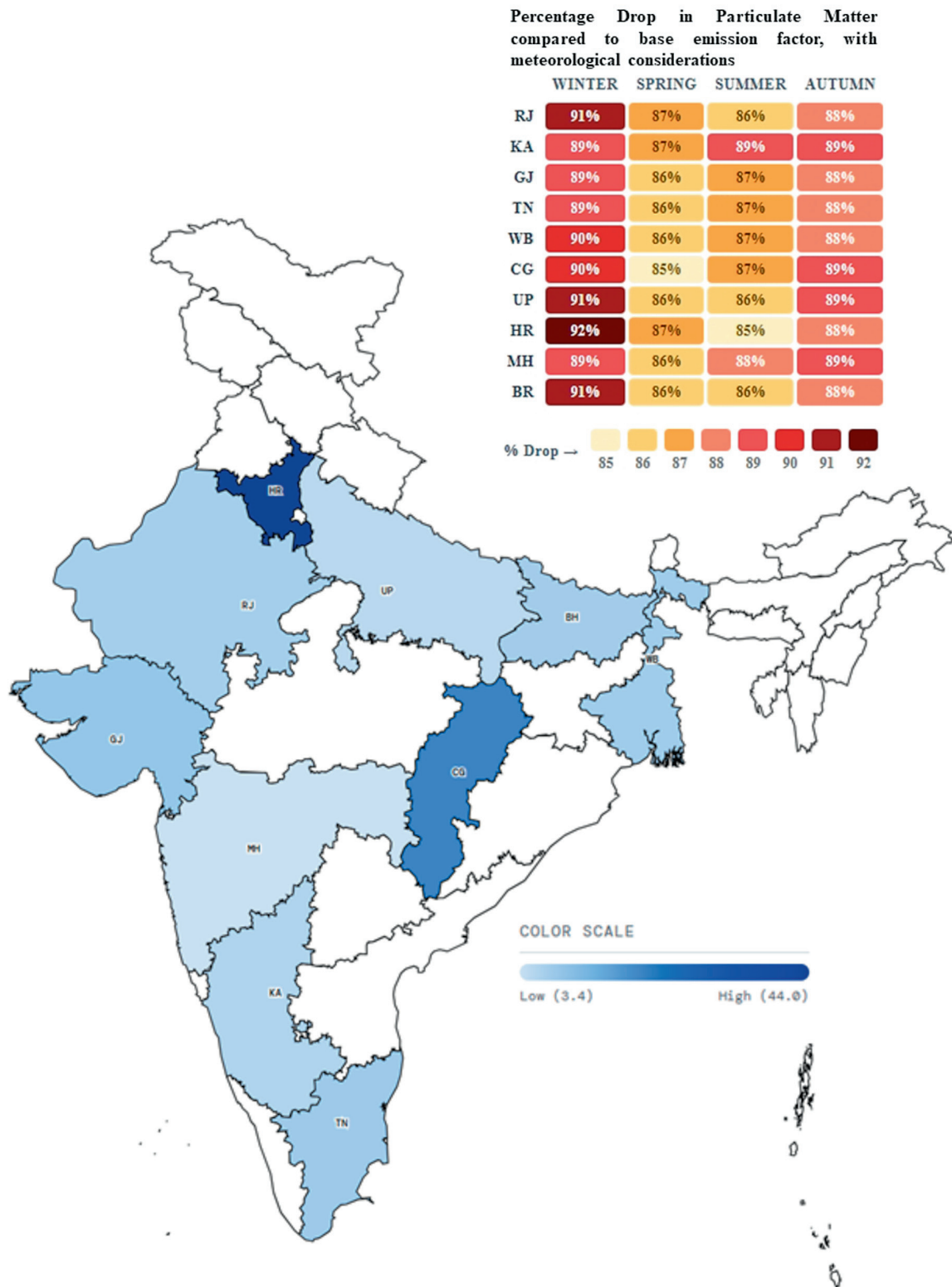


Figure 3: Comparative variation of road dust resuspension spatially and seasonally

wear are increasing noticeable in the overall $PM_{2.5}$ and PM_{10} profile, particularly in high-vehicle-populated and rapidly urbanizing states. The study indicates that road dust resuspension constitutes the largest share of non-exhaust emissions, especially for PM_{10} , while tyre and brake wear contribute meaningfully to the fine particulate fraction. These emissions are strongly influenced by fleet size, traffic density, braking frequency, pavement quality, and vehicle kilometres travelled. Importantly, their magnitude is highly

sensitive to seasonal and meteorological conditions. Dry surface conditions, elevated temperatures, and low humidity enhance particle entrainment, whereas monsoon rainfall and increased surface moisture substantially suppress resuspension. This variability highlighted the need to integrate meteorological parameters and seasonal correction factors into emission inventories and air quality action plans.

Expanding the current regulatory and planning framework to explicitly account for non-exhaust emissions would complement ongoing exhaust-control measures, which will improve the accuracy of emission inventories, and enhance the effectiveness of urban air quality interventions. A more comprehensive vehicular emission management strategy, encompassing the infrastructure design, traffic management, material standards, and inventory refinement, would strengthen existing policy efforts and support sustained progress toward long-term particulate matter reduction targets.

Recommendations

- Integrate non-exhaust emissions into NCAP city action plans and state inventories using standardised methodologies.
- Establish technical guidelines for road dust management, including mechanised sweeping and improved pavement standards.
- Promote the development of performance-based standards for tyre and brake materials to reduce abrasion-related emissions.
- Incorporate seasonal and meteorological correction factors in emission assessment frameworks.
- Align transport infrastructure planning and congestion management with air quality goals, supported by India-specific emission factors and testing protocols.
- The strategic urban planning with vegetation covers and green spaces can effectively reduce road dust resuspension and such strategies can be integrated in air quality management plans for urban regions.

Limitations

- The state-level estimates could be made more robust by incorporating the inter-state vehicle movement, especially for heavy-duty transport, along with the regional variations in the geography, climate, and road conditions, which significantly influence road-dust generation and with the overall emission profiles.
- And expanding the discussion to include the full spectrum of mobility-related non-exhaust emissions such as across conventional, electric, and non-motorized modes such as cycling and along with clearer alignment of assessment-related recommendations, would provide a more balanced and comprehensive policy framework.

Acknowledgement

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