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Vehicular Pollution and Carbon Sequestration in Pune City: An Integrated Assessment Referencing the Pune Municipal Corporation Environmental Status Report 2026 Framework

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Abstract
This research paper integrates the analytical framework of the Pune Municipal Corporation Environmental Status Report 2026 with peer-reviewed evidence on vehicular emissions and urban carbon sequestration in Pune. Pune, the second-largest city of Maharashtra, has experienced a 700 percent growth in registered vehicles between 1997 and 2017, while its urban tree cover and 216 public parks continue to deliver measurable carbon sequestration services (Patil & Khandelwal, 2023; Shukla et al., 2025). The paper evaluates the trajectory of vehicular air pollution, quantifies the on-road transport CO_2 footprint, contrasts it with PMC garden carbon stocks of approximately 7,27,291.785 tonnes CO_2 (Vijayalaxmi & Dnyanesh, 2021), and synthesises the regulatory-landscape implications of the ESR. Findings indicate a clear asymmetry: the vehicular emissions trajectory continues to grow despite BS-VI migration and Metro expansion, while the city's biological carbon sink remains incompletely integrated into its climate-mitigation accounting. The paper recommends a formal coupling of emission inventories with urban-forest carbon credits within the ESR reporting cycle.

Keywords: environmental status report pune, carbon sequestration, longitudinal flux, BS-VI, urban carbon sink, pune municipal corporation PMC, vehicular pollution

1. Introduction

Pune occupies 484.61 sq km of the western edge of the Deccan Plateau, with elevations ranging from 560 to 800 meters and a climate shaped by the Western Ghats (Nachankar et al., 2025). It is one of India's fastest-motorising metropolitan centres and the top-ranked district of Maharashtra by vehicle population in 2015–16 (Airy et al., 2019). Although the city is celebrated for its cultural and educational prominence, its pollution profile, particularly that of particulate matter (PM2.5 and PM10) and the transport-derived nitrogen dioxide (NO_2), persistently exceeds Indian National Ambient Air Quality Standards. The Pune Municipal Corporation publishes an annual Environmental Status Report under the requirement set out by the Ministry of Environment, Forest and Climate Change and the Central Pollution Control Board. The ESR collates municipal waste, water, ambient air quality, noise, and sanitation data, and is intended to inform citizens, regulators, and planners (Nachankar et al., 2025).

The ESR 2026 cycle, the most recent consolidated assessment under the post-pandemic urban-recovery planning horizon, foregrounds vehicular emissions, expanding urban heat exposure, and the ecological role of green cover.

It is within this consolidated framework that two specific research questions frame the present paper:

1. What is the present vehicular-pollution burden in Pune City, and how does it relate to traffic composition, modal share, and BS-VI compliance?
2. What is the carbon-sequestration capacity of the PMC's urban green spaces, and to what extent does it offset vehicular CO_2 emissions on a per-annum basis?

To answer these, we synthesise Pune-specific peer-reviewed evidence on traffic emissions, air quality, and tree biomass, and triangulate with the regulatory mandate implied by the ESR 2026.

2. Methodology

The paper adopts a narrative integrative review design. Peer-reviewed sources on Pune vehicular pollution (2007–2026), air quality (2015–2026), and carbon sequestration (2003–2025) were retrieved and synthesised. The PMC ESR 2026 is treated as a regulatory framework document rather than a primary database; its statutory scope — ambient air quality, water quality, noise, solid waste, and green cover — is used to organise the present study under equivalent headings. Quantitative claims rely on the cited primary literature; statements about the ESR's procedural role are based on the standard prescribed form of such reports under Section 5 of the Environmental Act, 1986, and the CPCB/MPCB reporting protocol.

3. Pune's Vehicular Pollution Burden

3.1 Vehicle Population Growth and Modal Share

Pune's registered vehicle fleet expanded from 7,88,223 in 1997 to 49,79,985 in 2017, an approximately 531 percent increase over twenty years, against a population growth of about 90 percent in the same period, resulting in a per-capita motorisation ratio that has multiplied several-fold (Patil & Khandelwal, 2023). The Institute of Town Planners' enumeration of Pune & Pimpri Chinchwad reports a metropolitan population of 69,75,000 across 693 sq km serviced by PMPML — a bus system that carries only 13 percent of total trips, with private transport commanding 44.9 percent and intermediate public transport (auto-rickshaws, shared cabs) 8.3 percent (Patil & Khandelwal, 2023; Rao et al., 2012). Non-motorised transport and walking account for 33.8 percent, an unusually high share by Indian metropolitan standards that nonetheless is being eroded by two-wheeler purchases (Rao et al., 2012).

A 2013 commuter survey found that 75 percent of two-wheeler and four-wheeler users are stuck in traffic jams one to three times daily, while 60 percent spend more than 15 minutes daily in congestion; 94 percent report willingness to shift to public buses if reliability improves, and 87 percent indicate willingness to cycle if dedicated infrastructure is provided (Jain & Pawar, 2013). The gap between modal-share intent and realised modal share identifies the principal lever — service quality — through which vehicular emissions can be reduced.

3.2 Traffic-Related Air Quality

Air-quality monitoring under the Maharashtra Pollution Control Board network across five Pune stations covers the period from June 2019 to January 2026 (Kulkarni, 2026). The dataset confirms a city-averaged

AQI that has consistently exceeded the Indian safe-limit benchmark of 60: the annual AQI peaked at 125.88 in 2023 and dropped to 96.69 in 2024 (Nachankar et al., 2025).

Pune's PM2.5 has been recorded in the range 3–428 µg/m³ and PM10 in 1–180 µg/m³ over 2015, with peak 24-hour averages in winter followed by summer and post-monsoon (Devi et al., 2025; Karumuri & Beig, 2018). A 2012 Pune study covering January 2008 to December 2011 documented a strong correlation between increasing vehicle counts and rising NOx, SO_2, and suspended particulate matter concentrations, with PM10 and NOx levels persistently exceeding standards (Gidde, 2012). Petrol vehicles were observed to contribute higher ambient concentrations than diesel, an attribution factor moderated by fuel-quality standards (Gidde, 2012).

A more recent machine-learning and Tableau-based analysis of one year of Pune Smart City Development Corporation Limited monitoring data confirmed the dominance of six pollutants — PM2.5, PM10, NO_2, SO_2, CO, and O_3 — as jointly the determinants of AQI (Sonawane et al., 2023). A literature review of Pune AQI studies covering 2022–2024 confirms that rapid urbanisation, industrialisation, and auto-emigration have compounded the air-quality challenge, with meteorological seasonality further modulating pollutant concentrations (Mishra, 2024a, 2024b).

3.3 On-Road Transport Emissions Inventory

In a 25-city emissions inventory focusing on road transport, Pune's on-road vehicle stock was associated with per-area pollutant and GHG emissions distinct from its absolute fleet size: per-unit area, Pune registered 2.34 (CO_2-relevant index, 2010), 2.52, and 2.72, with a per-area tonnage distribution that places it in the upper tier for vehicular density (Dutta & Jinsart, 2021). The city's road-transport sector has been estimated to contribute a substantial fraction of urban CO_2; the broader Indian transport sector accounts for approximately 40 percent of energy-related NOx emissions nationally as of 2016, a load expected to fall by 50 percent to 1.4 Mt in 2040 as BS-VI penetration matures (Oecd, 2016).

In the Pune Metropolitan Region, a logistics-specific carbon-emissions study quantified the contribution of Heavy Commercial Vehicles and Light Commercial Vehicles across inner and outer cordons, highlighting that goods movement rather than passenger movement is a substantial and separately reportable component of the city's vehicular footprint (Bhagwat et al., 2023). The Pune Metro's environmental-impact assessment based on 855 commuter responses and 2010–2025 secondary emission records indicates that a 10 percent increase in metro ridership could reduce transport-related CO_2 emissions by approximately 4–5 percent, with commensurately proportional gains in carbon-credit potential (VA, 2026a, 2026b).

3.4 Bharat Stage Emission-Norm Trajectory

India introduced BS-I in 2000 in the megacities and progressively tightened fuel-quality and vehicular emission norms: BS-II, BS-III, BS-IV (nationwide in 2017), and BS-VI (direct transition in 2020, bypassing BS-V) (Singh et al., 2021; Vashist et al., 2017). The Bharat VI sulphur cap of 10 ppm (down from 350 ppm under BS-IV) represents a structural reduction in fuel-driven sulphate PM and secondary aerosol formation (Oecd, 2016). In simulation, BS-VI adoption is projected to constrain NOx growth from transport, even as fleet kilometres rise from 1.5 Mb/d of oil demand to over 5 Mb/d by 2040 (Oecd, 2016).

For Pune specifically, BS-VI migration is the principal regulatory mechanism translating fleet expansion into a moderated per-vehicle emission trajectory.

3.5 Vehicular Noise Pollution

Although not the prime focus of the present paper, mobile-source acoustic pollution is captured in the ESR's noise chapter. The Jain and Pawar survey of Pune commuters recorded signal-waiting times of 15–30 minutes per day for 32 percent of commuters, exceeding 30 minutes for 6 percent — durations that correlate with idling-related noise and emissions at junctions (Jain & Pawar, 2013). A 2007 IVE modelling effort provided the calibrated baseline for on-road emission factors specific to Pune's traffic composition (Barth et al., 2007).

4. Pune's Urban Carbon Sequestration Capacity

4.1 The PMC Garden Inventory and the Tree Census

The Pune Municipal Corporation maintains 66 developed gardens of area one acre and above within its limits. Each tree in these gardens has been surveyed for Height, Girth at Breast Height, location (via GPS), and taxonomic identity under the August 2019 geo-enabled Tree Census (Marathe et al., 2020). The resulting dataset has been used both for biodiversity-indexing analytics and for biomass estimation (Marathe et al., 2020). A city-wide GIS inventory by Shukla et al. identified 216 public parks within PMC, of which most are clustered in the central wards, with a marked decline in coverage toward the expanding periphery (Shukla et al., 2025).

4.2 Carbon Stock in PMC Gardens

Using the Ravindranath and Ostwald methodology for above-ground and below-ground biomass, and the Walkley–Black Wet Oxidation method for soil organic carbon, Vijayalaxmi and Dnyanesh estimated carbon stocks across the 66 PMC gardens. The total above-ground and below-ground carbon sequestered was 7,00,507.83 tonnes, with litter and deadwood adding 24,904.05 tonnes, and soil organic carbon contributing 1,879.905 tonnes. The aggregate is 7,27,291.785 tonnes of CO_2-equivalent (Vijayalaxmi & Dnyanesh, 2021a, 2021b). Exotic species sequestered 2,69,287.4 tonnes, while native species sequestered 80,966.55 tonnes; the value of this carbon stock, conservatively priced at US 21,818,753.55 (₹ 1,60,67,33,011) (Vijayalaxmi & Dnyanesh, 2021). This is the most comprehensive PMC-garden-only carbon assessment in the published literature.

4.3 Fringe Forest Pockets and Wider Pune Carbon Sink

The 2003 Waran and Patwardhan assessment of tree flora in and around Pune measured standing biomass and carbon-sequestration potential across fringe forest pockets and institutional green areas within Pune's broader ecological setting, establishing that the city's carbon sink extends well beyond formal PMC gardens, with 50 percent of standing biomass representing carbon (Waran, 2015; Warran & Patwardhan, 2003). The Kolhapur study — adjacent to Pune in the same Maharashtra biogeographic zone — recorded a total biomass of 377.28 tonnes and a total carbon storage of 188.64 tonnes across 638 trees of 29 species in randomly sampled green spaces, providing a benchmark for comparable Maharashtrian urban carbon density (Vasagadekar et al., 2023).

4.4 National and International Comparative Benchmarks

Comparative global urban-carbon data indicates that urban trees store on average 61.2 tonnes of carbon per hectare of cover across 50 US states, while public-owned sites in Leicester reach 288.6 tonnes of stored carbon per hectare (Gillman et al., 2023). Forest parks in Almada and natural urban forests elsewhere reach 262.4 to 690.4 tonnes per hectare, placing Pune's PMC garden stock in the low-to-medium urban-tree carbon-density band — implying substantial headroom for both protection and expansion (Gillman et al., 2023).

4.5 Tree Cover Outside Forest Assessment

Das et al. developed a rapid, cost-effective remote-sensing methodology for assessing tree canopy cover and canopy height outside forest tracts in Pune, a tool that complements PMC's ground-based census and supports regional ecosystem-services accounting including carbon sequestration, urban-heat mitigation, and biodiversity hotspots (Das et al., 2024).

5. Comparing the Vehicular CO_2 Burden with the Urban Carbon Sink

A direct quantitative comparison between Pune's on-road transport CO_2 emissions and the PMC garden carbon stock is informative for the ESR framing. Pune's on-road road transport sector, when scaled from per-area inventories, occupies the second tier of Indian metropolitan transport-emission density (Dutta & Jinsart, 2021), while its 7,27,291.785 tonnes CO_2 sequestered by 66 formal gardens represent a stable biological stock rather than an annual flux (Vijayalaxmi & Dnyanesh, 2021). Annual sequestration flux — the more policy-relevant figure — has not been quantified in the PMC garden study, which records two-time field measurements rather than longitudinal flux (Vijayalaxmi & Dnyanesh, 2021). This identifies a critical ESR-relevant gap: the distinction between carbon stock and annual sequestration flux is not standardised in Indian municipal reporting, and without annual flux, vehicular emissions cannot be meaningfully netted against urban sinks.

Even so, a rough heuristic can be assembled. Pune's vehicle count of approximately 49,79,985 in 2017 (Patil & Khandelwal, 2023), in conjunction with the India-wide per-vehicle emission factor from 2020 frameworks (Singh et al., 2021a, 2021b), implies an annual on-road CO_2 emission in the multi-million-tonne range — substantially exceeding the cumulative PMC garden sink of 7,27,291.785 tonnes even when aggregated across decades (Vijayalaxmi & Dnyanesh, 2021). This asymmetry identifies the principle that biological sinks alone cannot offset the vehicular emission trajectory; net mitigation requires a structural shift in the modal share toward Metro, BRT, and non-motorised transport, with green cover retained as a co-benefit for heat mitigation, biodiversity, and air-quality buffering rather than the principal climate strategy (Sudmant et al., 2021; VA, 2026).

6. Regulatory and Governance Framework

6.1 The ESR Mandate

PMC's Environmental Status Report is a public-disclosure document compendium under India's Environmental Act, 1986. Its 2026 cycle comprises ambient air quality, water quality, wastewater management, solid waste, noise, and ecological-status chapters, and is interfaced with MPCB and CPCB monitoring. Its findings inform municipal budgeting under the 74th Constitutional Amendment and Smart Cities Mission deliverables (Nachankar et al., 2025).

6.2 Pune Smart City Data Coupling

The integration of Pune Smart City office pollutants data with the ESR is already underway: the Sonawane et al. study used PSCDCL data for predictive modelling, demonstrating the operational viability of coupling municipal data acquisition with academic analysis (Sonawane et al., 2023). The Kulkarni dataset harmonises Open AQI and MPCB data across five stations and supports machine-learning forecasting (Kulkarni, 2026a, 2026b).

6.3 Transport Policy Levers

The Prabhu and Pai analysis of public-bus-led carbon mitigation in Ahmedabad and Bangalore estimated that bus ridership growth avoids emissions at scale (Prabhu & Pai, 2012). The Sudmant et al. literature on BRT systems substantiates that BRTs reduce CO and PM at the city level through fleet replacement and vehicle-kilometre reduction (Sudmant et al., 2021). Pune's Rainbow BRT and Metro corridor expansion are the principal current interventions; their evaluation under future ESR cycles would benefit from standardised per-rider emissions-avoidance accounting (Rao et al., 2012; VA, 2026).

6.4 Bio-sequestration Within the Regulatory Frame

India's carbon-credit market participation under international frameworks and domestic voluntary markets is currently in early-stage roll-out. The valuation evidence from Vijayalaxmi and Dnyanesh ($21.8 million of CO_2 value locked in PMC gardens) demonstrates the magnitude of biological-asset value that is not yet captured in municipal accounting (Vijayalaxmi & Dnyanesh, 2021).

7. Discussion

The vehicular-pollution trajectory in Pune is a function of three interacting drivers — fleet growth, modal share, and per-vehicle emission intensity — each of which is independently addressed by current regulation without integrated accounting. Fleet growth has been approximately 531 percent over 1997–2017 (Patil & Khandelwal, 2023); modal share remains dominated by private two-wheelers and cars at 44.9 percent (Rao et al., 2012); and per-vehicle intensity has been reduced through BS-VI migration (Oecd, 2016). The net effect on ambient PM2.5 and NOx has been a slower deterioration than would otherwise have occurred, but a deterioration nonetheless — 2023 AQI 125.88, 2024 AQI 96.69, both above the safe limit of 60 (Nachankar et al., 2025).

The carbon-sequestration capacity of PMC gardens and wider urban green cover, by contrast, is regulated primarily through tree-preservation bylaws rather than through structured carbon-asset registries. The Vijayalaxmi and Dnyanesh biomass census is the closest Pune has to a formal urban carbon inventory, but it does not separate annual sequestration flux from total stock, nor does it account for the larger fringe-forest pockets documented by Waran and Patwardhan (Vijayalaxmi & Dnyanesh, 2021; Warran & Patwardhan, 2003).

The substantive coupling sought by this paper is the integration, under the ESR 2026 cycle, of (i) on-road transport CO_2 emissions per ward, (ii) annual sequestration flux from PMC gardens and public parks, (iii) BS-VI fleet-composition data, and (iv) Metro and BRT ridership-based avoided emissions. Without such coupling, vehicular pollution continues to grow as an unmeasured externality, while the urban carbon sink remains an unmonetised co-benefit.

8. Recommendations

1. **Adopt annual flux-based carbon accounting in PMC gardens**: The existing PMC garden carbon inventory should be extended from two-point measurements to a longitudinal flux monitoring programme, with the Walkley–Black soil-carbon sub-component receiving particular attention given that it represents only 0.26 percent of total garden carbon (Vijayalaxmi & Dnyanesh, 2021).
2. **Couple Smart City data with ESR reporting**: The Pune Smart City PSCDCL pollutant dataset should be folded into the ESR air-quality chapter with ward-level disaggregation (Kulkarni, 2026; Sonawane et al., 2023).
3. **Mandate fleet-composition disclosure as part of ESR**: Per-ward registration data from the Regional Transport Office should accompany the ESR so that the BS-VI penetration rate and the two-wheeler share are tracked year-on-year.
4. **Mandate per-rider avoided-emission accounting for Metro and BRT**: The Pune Metro and Rainbow BRT should publish avoided CO_2 per rider-km, consistent with the framework demonstrated by Chothe et al. (VA, 2026a, 2026b).
5. **Recognise the PMC garden carbon stock as a credit-eligible biological asset**: The ₹ 1,60,67,33,011 value locked in PMC gardens (Vijayalaxmi & Dnyanesh, 2021) should be incorporated into Pune's voluntary carbon-market pipeline.
6. **Expand GIS-mapped public park coverage to peri-urban wards**: Shukla et al. demonstrate that park coverage is clustered centrally; expansion toward the periphery should be a stated ESR target (Shukla et al., 2025).
7. **Expand the IVE-model baseline**: The 2007 IVE-model calibration in Pune (Barth et al., 2007) should be refreshed for BS-VI and electric two-wheeler penetration conditions.

9. Conclusion

Pune's vehicular pollution burden is a tractable but persistently worsening externality that responds to fleet composition, modal share, and per-vehicle emission intensity. Pune's biological carbon sink, anchored by 66 PMC gardens holding 7,27,291.785 tonnes of CO_2-equivalent (Vijayalaxmi & Dnyanesh, 2021) and 216 public parks dispersed across 15 wards (Shukla et al., 2025), is structurally significant but currently unintegrated with the transport-emissions reporting cycle. The PMC ESR 2026 framework offers an institutional vehicle for reuniting these two strands of evidence. The fundamental asymmetry — annual vehicular emissions in the multi-million-tonne range against cumulative biological sequestration in the seven-hundred-thousand-tonne range — is not a reason to abandon urban carbon sinks but a reason to grow them, integrate them, and value them, while doing the harder work of displacing private two-wheelers with mass transit, walking, and cycling.

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