

ABSTRACT

Traffic-related air pollution (TRAP) is a major contributor to cardiovascular risk, yet evidence from highly polluted Indian roadside environments remains limited, particularly for the relative roles of particulate mass, particle size, and chemical composition in shaping short-term autonomic cardiac responses. This thesis investigated these relationships through three prospective repeated-measures panel studies conducted in traffic-influenced microenvironments at the Indian Institute of Technology Delhi. Across the three campaigns, 44, 31, and 34 apparently healthy adult male security guards contributed 50, 3,063, and 4,235 valid exposure-response pairs, respectively. Heart rate variability (HRV) was used as a non-invasive marker of cardiac autonomic function, with repeated 5-min Holter ECG segments used to derive SDNN, rMSSD, pNN50, LF, HF and LF/HF. Exposure assessment progressed from PM₁ and PM_{2.5} mass to size-resolved particle number concentrations (PNC), black carbon (BC), non-refractory PM components, trace metals, and water-soluble inorganic ions (WSIIs). Associations were analysed using single-pollutant linear mixed-effects and semiparametric generalized additive mixed models with participant-specific random intercepts; HRV outcomes were log-transformed, and models adjusted for age, body mass index, ambient temperature and relative humidity, with spline terms used for non-linear meteorological effects in the finer-resolution analyses. In Studies 2 and 3, residual PM/PNC terms were additionally used to isolate the effect of the pollutant under study, and lag windows were evaluated using Akaike's Information Criterion.

The roadside particulate exposures were consistently high. In Study 1, mean PM₁ and PM_{2.5} concentrations were 81.4 ± 49.2 and 101.5 ± 55.3 $\mu\text{g}/\text{m}^3$, with PM₁ comprising about 80% of PM_{2.5}. The monthly means ranged from 27 and 36 $\mu\text{g}/\text{m}^3$ during the monsoon to 174 and 156 $\mu\text{g}/\text{m}^3$ in winter, with maxima reaching 303 $\mu\text{g}/\text{m}^3$ for PM₁ and 310 $\mu\text{g}/\text{m}^3$ for PM_{2.5}. In study 3, hourly PM_{2.5} averaged 194.6 $\mu\text{g}/\text{m}^3$ in winter and 244.1 $\mu\text{g}/\text{m}^3$ in the post-monsoon, exceeding the Indian annual standard in all seasons. The study 2 further showed that particle number was overwhelmingly dominated by sub-0.5 μm particles, whereas the 1-10 μm fraction averaged only about 19 particles/cm³; roadside BC averaged 17 $\mu\text{g}/\text{m}^3$ compared with 12 $\mu\text{g}/\text{m}^3$ at the ambient supersite, and organics dominated non-refractory PM₁ (59 $\mu\text{g}/\text{m}^3$ on average). Pollutants were also substantially inter-correlated, which limits strict separation of constituent-specific effects. For example, PNC_{0.1-0.5} was strongly correlated with organics ($r = 0.89$) and BC ($r = 0.82$), organics with nitrate ($r = 0.73$), and ammonium with chloride and nitrate ($r = 0.91$ and 0.81), whereas the smallest fraction (<0.03 μm) showed weak or negative correlations with most larger particle and chemical variables, indicating contributions from fresh nucleation distinct from the more aged accumulation-mode mixture.

Across all three studies, higher short-term particulate exposures were associated with impaired autonomic regulation. In Study 1, per interquartile-range increase, PM₁ was associated with a 26.6% decrease in pNN50 (approximate 95% CI: -45.7%, -0.7%), while PM_{2.5} was associated with a 13.4% decrease in SDNN (approximate 95% CI: -23.3%, -2.3%); reductions in rMSSD and HF and increases in LF and LF/HF indicated a shift toward sympathetic predominance. The study 2 showed a clear size gradient: the strongest decrements

were observed for particles in the 0.03-0.1 μm range, with pNN50 declining by about 12-14%, rMSSD by 8-10%, and SDNN by 4-6% per IQR increase, while effects for 1-10 μm particles were close to null. The roadside BC showed stronger and more coherent inverse associations with HRV than ambient BC, and among PM_{10} components, nitrate and organics were the most consistently associated with lower HRV. The study 3 reaffirmed these findings under more comprehensive co-located monitoring: ultrafine particles (\sim 0.01-0.05 μm) showed the largest reductions in vagally mediated indices, generally from several percent up to around 15%, while BC, trace-metal mixtures, and WSII mass were also inversely associated with HRV, with stronger effects observed for metal groups enriched in Fe, Cu, Ni, V and Pb.

Taken together, the thesis shows that traffic micro-environments, where people spend a considerable part of their daily routine, can expose them to particulate concentrations far exceeding current standards, and that short-term fluctuations in these exposures are sufficient to produce measurable adverse changes in cardiac autonomic function even among healthy individuals without known underlying disease. The findings indicate that $\text{PM}_{2.5}$ mass alone does not adequately capture health-relevant exposure in traffic settings; ultrafine PNC, BC, and chemically reactive submicron constituents better explain acute autonomic disturbance. At the same time, the strong inter-correlations among several pollutants suggest that these associations should be interpreted as effects of correlated traffic and secondary aerosol mixtures rather than fully separable individual components. Overall, the work provides India-specific evidence that particle size and composition are critical for understanding cardiovascular impacts of TRAP and supports more source-focused control of combustion emissions, secondary aerosol precursors, and metal-rich non-exhaust traffic emissions.