CUNY CREST HIRES

The City College of New York

India: Analysis of Neighborhood Scale Air Quality

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Introduction

Urban air quality and microclimates can vary over short distances, especially in densely populated cities like Mumbai (Bhanage et al., 2022). As part of a multi-year study, student teams conducted walking surveys in India along predetermined routes in selected neighborhoods – the upper middle class Santa Cruz, the Dharavi slum, and Old/New Delhi – with pollution logging equipment. The results were then averaged into 100 m boxes for comparison among variables measured at many points distributed along each route. We focused on data from January 2024 and 2025 and used Python to perform analyses.

Our main objective was to examine how local sources (traffic, cooking, etc.) and environmental factors (vegetation cover and sea breeze) affect pollution and temperature (Gallo et.al, 1993). The data collection was funded by the National Science Foundation's International Research Experience for Students (IRES) program, with collaborators from the Indian Institute of Technology in Mumbai and Delhi.

Instrumentation

The IRES program primarily funds international internships rather than equipment, so one goal was to assess whether using low-cost sensors in bulk can offset their lower stability compared to research grade instruments. The students carried two types of instrument sets with data loggers. Each had its own GPS unit that could be used as a backup if the other had failure points during the route.

The first was a custom set of sensors collecting at a rate of once per minute assembled with a controller board, containing the following:

- *Piera 7100 Optical Particle Counter*: uses pulsed light scattering to infer particle sizes and counts by statistical analysis of the moving stream of air. It counts in size bins of 0.1, 0,3, 0.5, 1.0, 2.5, 5.0 and 10 microns.
- *Spec Analog Gas Sensors:* A cheaper option than digital, for which an electrochemical plate is covered by a filter specific for each gas. We had sensors for NO, SO_2, CO, and O_3. These sensors required a warm-up period we were unaware of the first year.
- *Adafruit SDIR-30 CO2 Sensors:* operating by infrared absorption.

The second set of sensors used the Vernier LabQuest data logger with associated instruments, providing constant readout.

- *Thermocouple Thermometer :* This was on a single wire projected into the air, so had low heat capacity and quick response time. A foil radiation shield was used.
- *Relative Humidity Sensor:* conductivity is converted into relative humidity
- *CO_2 Sensor:* This was more stable than the Adafruit sensor used above.

Data Collection and Processing

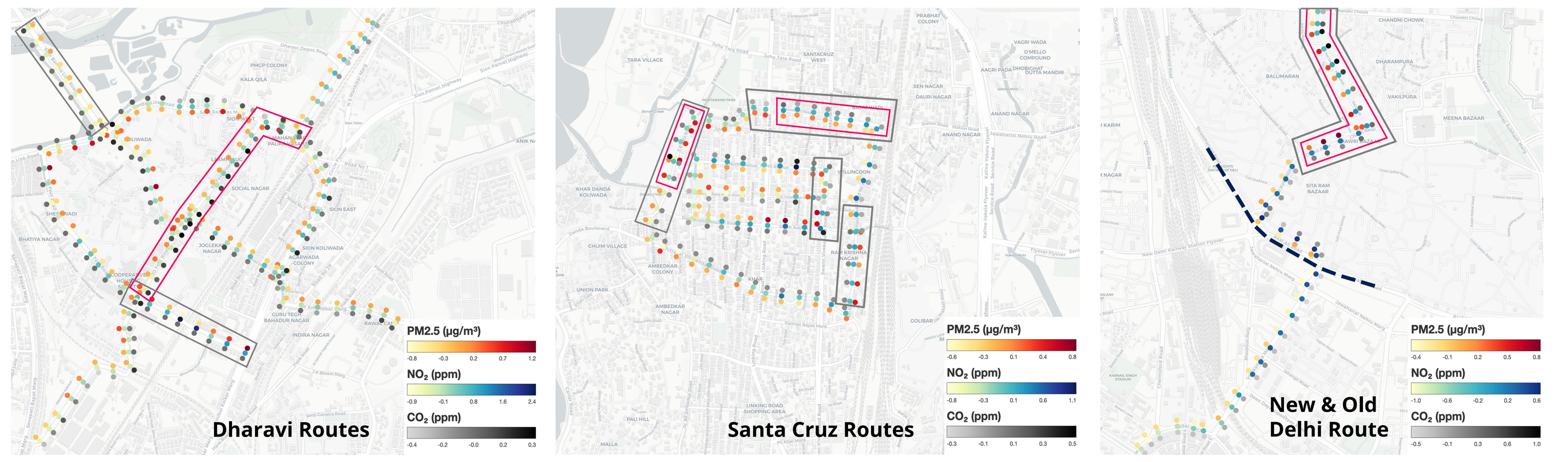
Air pollution data was collected along urban routes described above using backpacks fitted with sensor packs. Observations were recorded to capture pollution sources such as foot and vehicle traffic, cooking, construction sites, and street geometry features.

Each route was divided into spatial bins (boxes), and the data points within each box were averaged to produce localized values for both pollutant levels and source observations. These averaged values were then normalized using Z-scores to allow for comparisons without calibration. By comparing pollution patterns between Dharavi and Santa Cruz, we examined differences across socio-economic and infrastructure contexts within Mumbai, while differences between New and Old Delhi provided insight into the effect urban planning and infrastructure have within a city.

Results and Observations

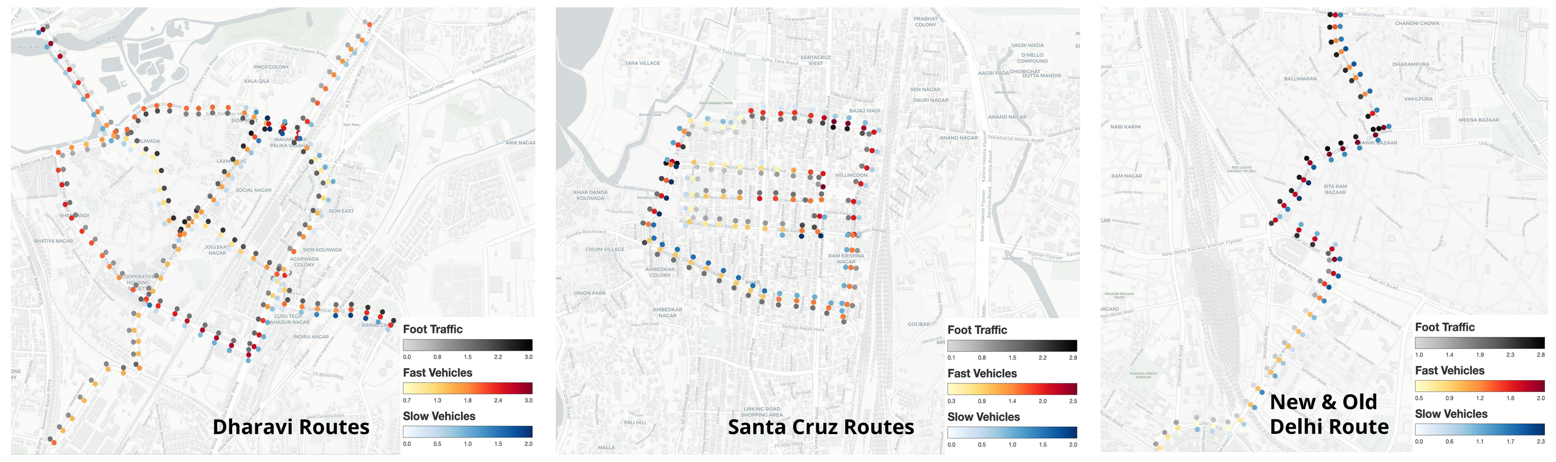
Dharavi, one of the largest slums in the world, is characterized by dense housing, minimal vegetation, and high dust levels. Santa Cruz, a middle-class residential neighborhood, features wider streets and significant vegetation. Old Delhi is highly compact, with narrow streets and consistently heavy traffic congestion. In contrast, New Delhi has broader roads, lower building density, and more green space.

Pollution Maps



Pollution intensity maps for PM2.5, NO_2, and CO_2 along routes in Dharavi, Santa Cruz, and Delhi (left to right). Color gradients represent normalized Z-scores, allowing comparison of pollution intensity across micro-locations within and between neighborhoods. Pink boxed areas indicate local market areas, grey boxed areas indicate heavy traffic, and the dashed line in the Delhi map delineates New and Old Delhi.

Source Observation Maps

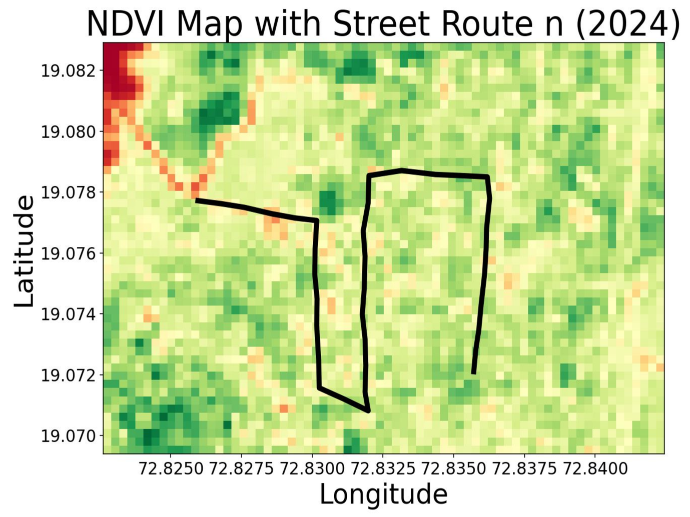


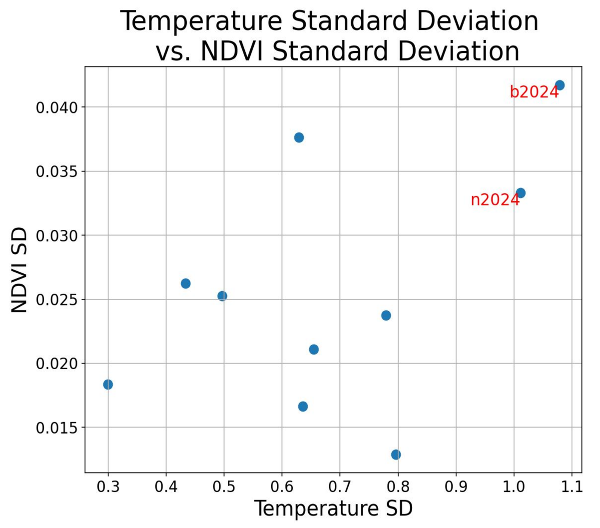
Source observation maps showing pedestrian and vehicle traffic across Dharavi, Santa Cruz, and Delhi (left to right). Observation data were collected during field walks and scored from zero to three based on intensity of foot traffic and moving or idle vehicles. Color gradients represent normalized Z-scores.

Vegetation and Urban Temperature

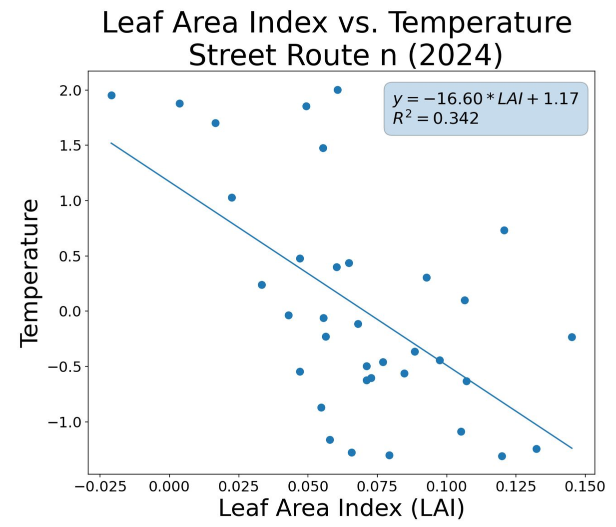
To investigate how vegetation affects urban temperature, Landsat data was used to calculate Normalized Difference Vegetation Index (NDVI) and Leaf Area Index (LAI). The NDVI is calculated using the formula (NIR - Red) / (NIR + Red). NDVI indicates vegetation greenness while LAI estimates leaf cover area. NDVI values in Santa Cruz were lower than expected, likely due to the air pollution, as seen in RGB imagery.

Most routes had a negative correlation between LAI and temperature but lacked enough variation in vegetation to show a clearer pattern. Route N had the strongest correlation due to its higher variability, which matches the expected cooling trend of vegetation. Although Route B had a high NDVI and temperature standard deviation as well, it showed a positive trend. Adding building confinement (whether a route was in open or enclosed spaces) as a second variable in a multivariable regression improved most fits, suggesting that both vegetation and structure influence local temperature.

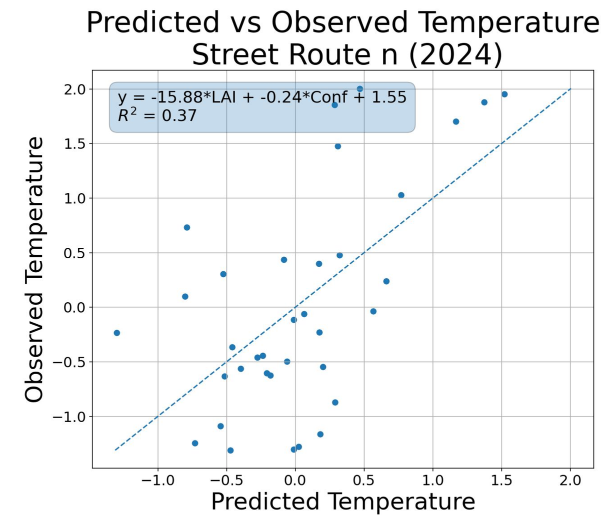




A scatter plot of the temperature standard deviation vs. NDVI standard deviation for all routes in 2024 and 2025. Route N and B from 2024 are labeled.

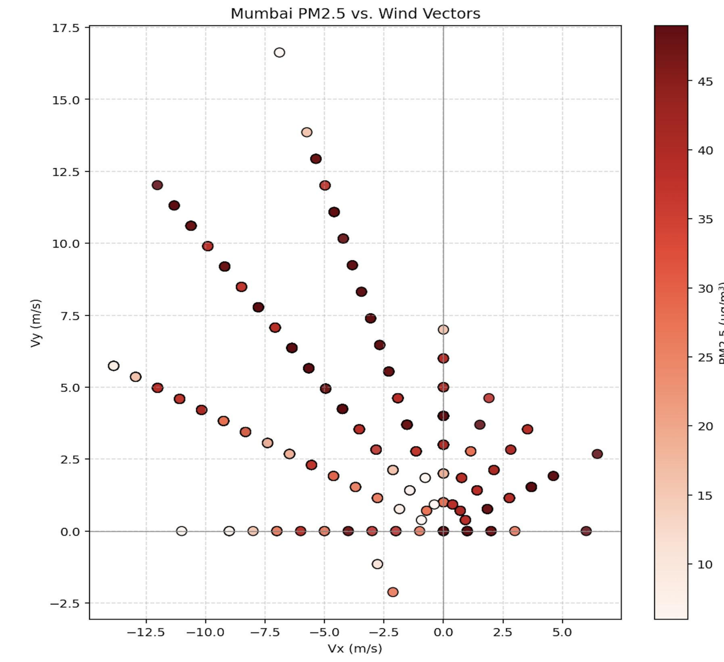


Scatter plot of Leaf Area Index (LAI) and normalized temperature for Route N in 2024. It shows a negative correlation.



Scatter plot with linear regression of predicted vs. observed temperatures for Street Route N, taking into account building confinement and Leaf Area Index.

Wind Vector Analysis

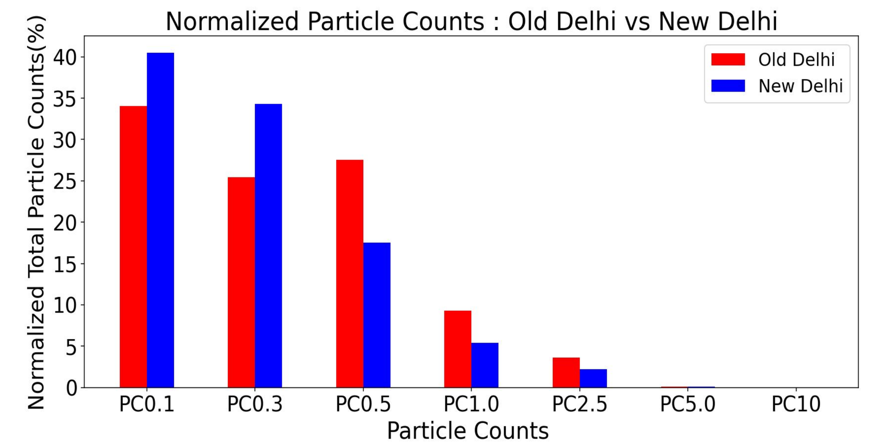


A diagram of Wind Directions and Pollutions in Mumbai for March 2024

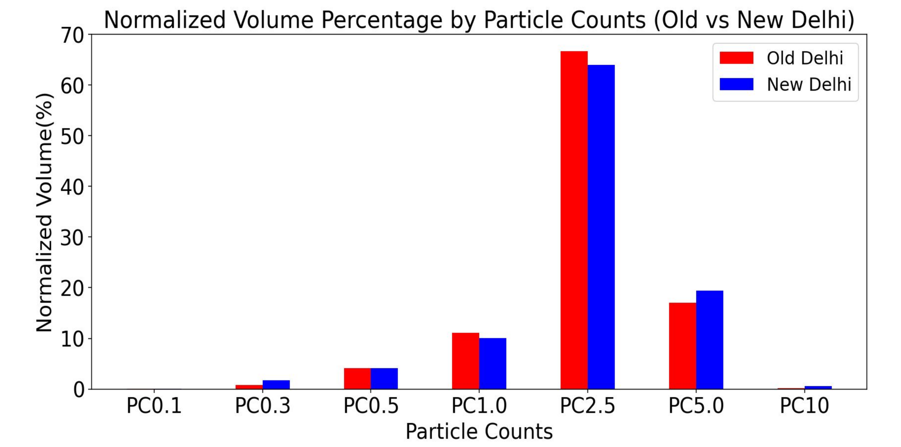
This wind vector plot shows wind speed and direction by the location of the points and PM2.5 loading by color. Wind speed is lower when it is travelling over the land (east) versus ocean (west). The plot shows that particle counts (PM2.5) in Mumbai are influenced by both wind speed and surface type. In the northwest, higher wind speeds generate and carry more particles—likely due to salt aerosols from the Arabian Sea being included in PM2.5 measurements. In contrast, the northeast (urban area) shows consistently high particle counts regardless of wind speed. Typically, stronger winds should reduce particle levels by dispersing emissions, but the steady counts here suggest that this simple model doesn't apply.

There is a very little wind from the southwest and it has lower particle counts, possibly due to a mixture of wind flowing from the sea and urban areas.

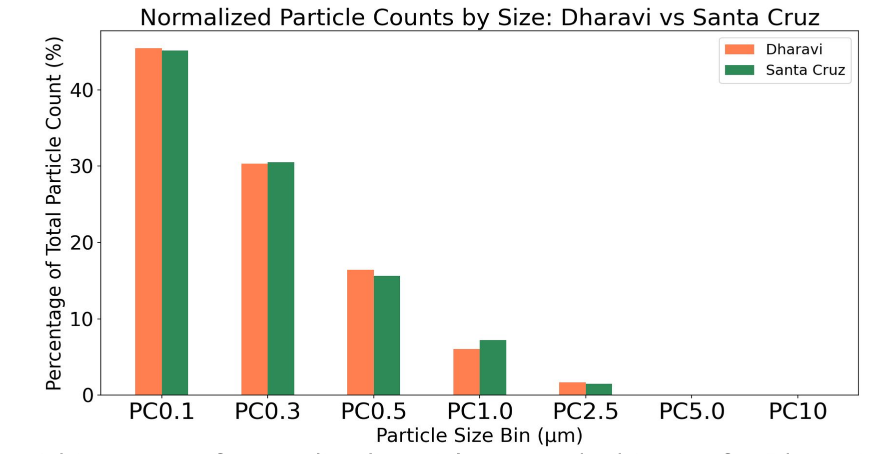
Particle Count and Volume Distributions



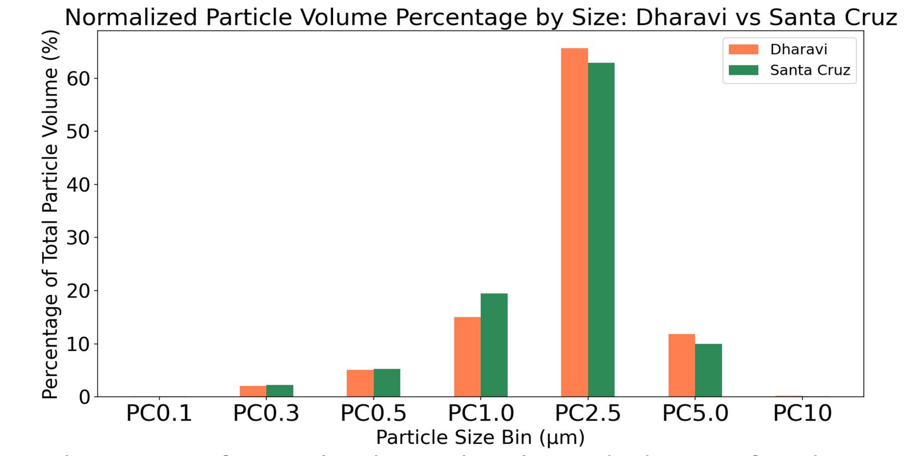
A histogram of normalized particle counts by bin size for Old Delhi and New Delhi



A histogram of normalized particle volumes by bin size for Old Delhi and New Delhi



A histogram of normalized particle counts by bin size for Dharavi and Santa Cruz.



A histogram of normalized particle volumes by bin size for Dharavi and Santa Cruz.

In general, particle counts decrease with size, with the majority of particles in the smallest bin (PC0.1). When comparing Old Delhi and New Delhi, we observed that New Delhi had higher particle counts at the smallest sizes (PC0.1 and PC0.3), but Old Delhi showed higher counts for particles PC1.0 and above. This shift suggests more coarse particles in Old Delhi, possibly from dust and construction, while New Delhi may have more fine pollution from vehicles (Anderson et al., 2012). In terms of particle volume, Old Delhi had a much higher percentage at PC2.5, indicating that larger particles contributed more to overall mass. New Delhi showed a wider spread, with notable volume at PC1.0 and PC5.0, suggesting a mix of both fine and coarse sources. In Mumbai, Dharavi shows slightly higher volumes in the PC2.5 and PC5.0 bins, indicating a greater presence of larger particles compared to Santa Cruz.

Finally, when comparing Delhi to Mumbai, Delhi had higher counts of ultrafine particles overall, while Santa Cruz in Mumbai showed the highest mass from mid-sized particles (PC2.5). This reflects different pollution sources across the cities—vehicle exhaust and combustion in Delhi versus coastal or industrial influence in Santa Cruz.

Discussion & Conclusion

Our analysis investigates how pollution sources (traffic, cooking, etc.) and environmental factors (vegetation cover and sea breeze) contribute to patterns in urban pollution and temperature. We observed increased pollution in market and high traffic areas. Wind vector analysis in Mumbai indicated the generation of sea salt aerosols, but also that pollutant behavior with wind did not conform to expected patterns, indicating a more complex relationship than previously thought. Particle count and volume histograms show distinct pollution profiles across sites, with more coarse particles in the slum areas (Dharavi and Old Delhi) than in higher class areas (Santa Cruz and New Delhi). A clear pattern of cooling from vegetation was not observed among most routes, likely due to limited variation in vegetation and surface reflectance masked by pollution. Only one route showed a moderate correlation between LAI and temperature.

References

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