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Neighborhood-scale spatial PM_{2.5} variability from dense low-cost sensor networks: the role of urban land-cover patterns in Santiago, Chile

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Recent advances in low-cost air quality sensors have substantially expanded the capacity to monitor air pollution at fine spatial and temporal scales, enabling analyses that are not feasible with sparse regulatory networks. Here, we use a dense network of low-cost PM_{2.5} sensors to investigate neighborhood-scale variability in winter air pollution and its relationship with urban land-cover patterns in Santiago, Chile, a highly polluted metropolitan area.

We deployed 55 sensors across four residential neighborhoods during winter 2021, generating high-resolution PM_{2.5} measurements that capture strong intra-neighborhood variability. These data were combined with high-resolution land-cover maps to quantify both compositional (e.g., land-cover proportions) and configurational (e.g., patch size and aggregation) metrics within multiple buffer distances (30–480 m) around each sensor. Scale-dependent relationships were evaluated using linear mixed-effects models across different PM_{2.5} concentration ranges.

The sensor network consistently detected spatially structured PM_{2.5} patterns that would not be observable using sparse reference stations. Built-up land cover showed positive association with PM_{2.5} concentrations, particularly during high-pollution episodes, while seasonal soil and deciduous tree cover were negatively associated with PM_{2.5} at specific spatial scales. Configurational metrics, especially the size and aggregation of land-cover patches, were also associated with PM_{2.5}, indicating that how land cover is arranged can be as relevant as overall land-cover extent.

Our findings demonstrate that dense low-cost sensor networks can support robust scientific analyses of urban air quality, despite higher measurement uncertainty compared to reference-grade instruments. By enabling fine-scale assessments of land-cover–air pollution interactions, low-cost sensors offer significant opportunities for advancing urban air quality research and informing neighborhood-scale mitigation strategies, particularly in cities with limited monitoring infrastructure.