Identifying Traffic-Related Air Quality Hotspots through Public Transport-Based Mobile Sensing

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***Abstract*— Urban air pollution is strongly influenced by road traffic, especially in dense urban areas where traffic volumes, congestion and constrained infrastructure conditions affect vehicle operating regimes. Fixed monitoring stations provide robust measurements, but they often lack the spatial coverage needed to capture local pollution variability along the road network. This study proposes a data-driven framework for identifying traffic-related environmental hotspots by integrating mobile air quality measurements collected from a public transport vehicle with trajectories, traffic data and road infrastructure characteristics. The mobile sensing unit enables repeated georeferenced observations across multiple urban locations without requiring a dense fixed monitoring infrastructure. Measurements are processed through a spatial grid approach and combined with traffic and infrastructure indicators to detect critical locations and interpret the conditions contributing to pollutant accumulation. The framework supports evidence-based mobility and environmental policies and provides a structured dataset for future predictive models aimed at anticipating critical pollution conditions.**

Keywords—Mobile sensing, air quality monitoring, , spatial hotpot analysis, public transport, digital twin

I. Introduction

Urban road traffic is one of the main sources of local environmental pressure in densely built areas. Its impact is not only related to the number of vehicles circulating on the network, but also to vehicle operating conditions. Low speeds, acceleration and deceleration phases, queue formation and recurrent stops can significantly affect emission rates and local air quality. These dynamics are especially relevant near intersections, bottlenecks, access roads, bus stops and road sections characterized by constrained infrastructure or irregular traffic flow.

Traditional air quality monitoring systems are mainly based on fixed stations, which provide accurate and standardized measurements and remain essential for regulatory assessment. However, their limited spatial distribution may reduce their ability to capture fine-scale variability across the urban road network. Since local pollution patterns can change substantially over short distances, fixed stations alone may be insufficient to identify localized environmental criticalities or to interpret the transport-related factors that generate them.

Mobile sensing has recently emerged as a promising approach for high-resolution urban air quality monitoring. Sensors installed on moving platforms can collect georeferenced measurements across different parts of the city, increasing the spatial pervasiveness of environmental observations. Public transport vehicles are particularly suitable because they repeatedly travel along predefined routes and cover several urban corridors during the day. Previous studies have highlighted the potential of drive-by and bus-based sensing for cost-effective urban air quality monitoring [1], [2], while research on traffic-related emissions has shown the importance of congestion, speed conditions and real-time traffic data for mapping on-road vehicle emissions [3], [4]. Spatial analysis methods further support the identification of pollutant clusters and hotspots [5], [6]. Building on this background, this study proposes a data-driven framework that integrates mobile air quality measurements, public transport trajectories, traffic monitoring data and road infrastructure characteristics. The objective is to identify traffic-related environmental hotspots and interpret them in relation to the mobility and infrastructure conditions contributing to their formation.

II. Methodological Approach

The proposed methodology is based on the use of an environmental sensing unit installed on a public transport vehicle. The sensor collects air quality measurements while the vehicle moves across the urban network, associating each observation with a timestamp and a GPS position. This enables pollutant concentrations to be measured in several locations without a dense network of fixed monitoring stations. Before the monitoring campaign, the sensing unit is compared with fixed monitoring stations to assess consistency and improve the reliability.

The first step consists of collecting and organizing the mobile sensing data. Each measurement is georeferenced and linked to the corresponding bus position. Since the vehicle repeatedly travels along the same route or set of routes, multiple observations are collected for the same road sections at different times, making it possible to distinguish isolated high values from recurrent pollution patterns.

The second step concerns spatial processing. The study area is divided into a regular grid, for example composed of 70 m x 70 m cells. Each GPS point collected by the mobile sensor is assigned to the corresponding cell. For each cell, pollutant concentration indicators are computed together with the number of bus passages. Transit frequency provides information on the robustness of spatial patterns, since cells characterized by both high concentrations and repeated measurements can be interpreted as more reliable signals of local environmental criticality. The third step consists of producing cumulative pollution maps and identifying environmental hotspots. Spatial hotspot analysis is applied to detect clusters of grid cells characterized by higher pollutant concentrations than surrounding areas. This procedure supports a spatially explicit interpretation of urban air quality conditions and provides a detailed representation of where pollution tends to accumulate along the monitored network.

The fourth step integrates environmental measurements with traffic and infrastructure information. Traffic indicators may be derived from radar sensors, video cameras or other monitoring sources and may include traffic volumes, speed conditions, congestion levels, temporal variability of flows and, where available, vehicle composition. In parallel, infrastructure characteristics are associated with monitored road sections or grid cells, including road hierarchy, number of lanes, intersections, traffic lights, pedestrian crossings, bus stops, parking activities, road width, slope and other elements influencing traffic flow regularity. Through this integration, pollutant concentrations are interpreted as the result of a combined traffic-infrastructure system. Correlation analysis and spatial comparison between pollutant levels, traffic indicators and infrastructure variables are used to investigate whether hotspots are associated with high flows, low speeds, recurrent congestion, specific road configurations or elements that generate stop-and-go dynamics.

III. First Findings and Contribution

The first application of the framework allows mobile air quality observations to be transformed into spatially organized information on pollutant distribution across the urban network. The grid-based representation supports the identification of areas where pollutant concentrations are recurrently higher and where the number of observations is sufficient to provide a reliable indication of local criticality. In this way, the method makes it possible to move from isolated measurements to cumulative environmental maps that describe spatial patterns along the monitored routes. The integration of transit frequency counts represents a key element of the proposed approach, since it helps distinguish between occasional high concentration values and recurrent pollutant accumulation patterns. Consequently, the methodology transforms public transport vehicles into a widespread data-driven sensing infrastructure, capable of supporting high-resolution air quality mapping across multiple urban locations. This granular representation can facilitate the transition from general environmental assessments to targeted, evidence-based mobility and policy interventions.

The contribution of the study is threefold. First, the use of a public transport-based mobile sensing system allows environmental measurements to be collected at multiple locations across the urban network without relying on a dense fixed monitoring infrastructure. This makes the monitoring approach more spatially pervasive and flexible, enabling the detection of local pollution patterns that may not be captured by fixed stations alone. Second, the proposed framework provides an integrated interpretation of pollutant concentrations, traffic conditions and infrastructure characteristics. This supports a better understanding of how traffic dynamics and road configuration influence local environmental quality. In particular, the approach can help identify whether critical conditions are related to traffic intensity, congestion, vehicle operating regimes or infrastructure-induced flow disturbances.

Third, the framework provides useful evidence for sustainable mobility planning and environmental policy design. By identifying traffic-related environmental hotspots and the factors associated with their formation, the method can support the prioritization of targeted interventions, such as traffic management measures, congestion mitigation strategies, route regulation, local access control or low-emission policies. The proposed framework provides an operational basis for data-driven environmental monitoring of urban mobility systems. By integrating repeated mobile air quality measurements with traffic and infrastructure information, it supports the identification of priority areas for intervention, improves the understanding of the conditions that favour pollutant accumulation and enables more informed and proactive mobility and environmental management strategies. In this perspective, the approach can assist public administrations in designing targeted mitigation measures and integrating air quality objectives into sustainable urban mobility planning.

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