

# Tracking air pollution and CO<sub>2</sub> emissions in urban areas

A new multi-pollutant database enables analysis of all urban areas worldwide

Soo-Yeon Kim<sup>1</sup>, Gaige Hunter Kerr<sup>1</sup>, Aaron van Donkelaar<sup>2</sup>, Randall V. Martin<sup>2</sup>, J. Jason West<sup>3</sup>, Susan C. Anenberg<sup>1</sup>

<sup>1</sup>Milken Institute School of Public Health, George Washington University, Washington, DC, USA

<sup>2</sup>Department of Energy, Environmental & Chemical Engineering, Washington University in St. Louis, St. Louis, MO, USA

<sup>3</sup>Department of Environmental Sciences and Engineering, Gillings School of Global Public Health, University of North Carolina, Chapel Hill, NC, USA

## Background

Rapid industrial and economic growth worldwide has significantly increased environmental pollution and greenhouse gas (GHG) emissions, posing major risks to human health and the planet. Air pollution contributes to millions of premature deaths annually, largely from cardiopulmonary diseases and cancer, while climate change caused by GHG emissions harms public health due to more extreme weather, food and water insecurity, ecosystem damage, and other threats. Urban areas, which house over half the global population, are an important area of focus for climate, air pollution, and health because they contribute over 70% of GHG emissions and face higher levels of air pollution than non-urban areas. Recent advances in satellite remote sensing and geospatial modeling methods have enabled detailed assessments of three key pollutants, particulate matter (PM<sub>2.5</sub>), nitrogen dioxide (NO<sub>2</sub>), and ozone, as well as fossil-fuel carbon dioxide (FFCO<sub>2</sub>), in over 13,000 cities. This study leverages recently updated global datasets to develop [Urban Air Quality Explorer](#), a multi-pollutant database for all urban areas worldwide that enables analysis of temporal trends and inter-city comparisons.

## Findings

From 2005 and 2019, there were significant increases in ozone (+6%) and small, non-significant changes in PM<sub>2.5</sub>, NO<sub>2</sub>, and FFCO<sub>2</sub> emissions. High-income countries with strong mitigation policies experienced decreases in all pollutants, while regions with rapid economic growth had overall increases. Over 50% of urban areas showed positive correlations for all pollutant pairs, though results varied by global region.

**Global Urban Air Pollution Overview:** Global urban air pollution, on average, exceeds the World Health Organization's (WHO) global air quality guidelines (AQG), evidence-based recommended targets on individual air

## Key Findings

- 1 **Trends vary significantly across regions** and cities, suggesting that there is no one solution for all urban areas.
- 2 **High-income countries showed significant decreases in air pollutants**, likely due to comprehensive air quality regulations and climate action.
- 3 Rapidly developing regions like South Asia and Sub-Saharan Africa **saw large increases in air pollutants**, suggesting need for solutions that can couple economic development with pollutant controls.
- 4 Positive correlations between trends in PM<sub>2.5</sub>, NO<sub>2</sub>, O<sub>3</sub>, and FFCO<sub>2</sub> in many urban areas suggest that these **pollutants often share emissions sources and could be addressed by integrated mitigation strategies**.

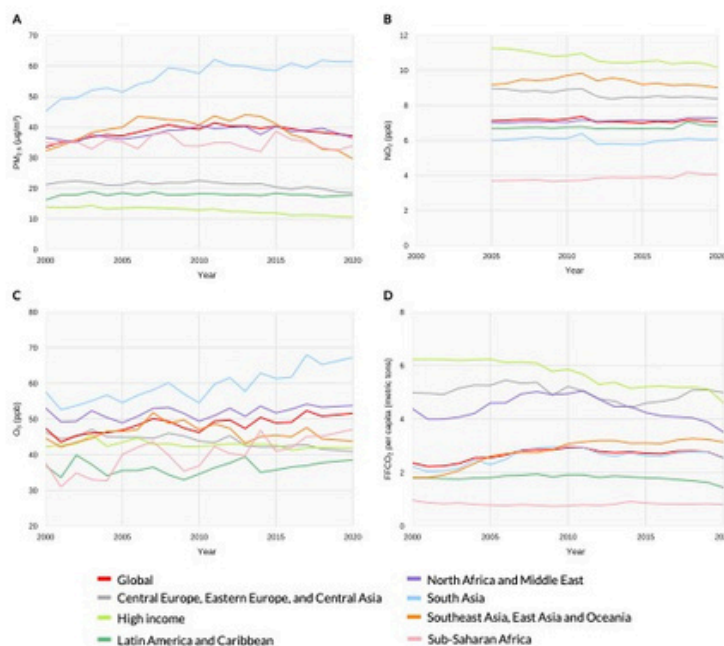
pollutants for governments to apply to achieve air quality that protects public health. In 2019, average pollutant levels (calculated as the global mean of average concentrations across all urban areas) exceeded the AQG as follows:

- Average urban PM<sub>2.5</sub> was **7.5 times higher** than the WHO AQG.
- Average urban ozone was **67% higher** than the WHO AQG.
- Average urban NO<sub>2</sub> was **34% higher** than the AQG.

In addition, the global median of FFCO<sub>2</sub> per capita across all urban areas was 2.8 metric tons.

**Temporal Trends:** Trends from 2005-2019 differed across pollutants. Globally, there were significant increases in ozone (+6%), small, non-significant changes in NO<sub>2</sub> (-1%) and FFCO<sub>2</sub> emissions (+4%), and no change in PM<sub>2.5</sub> (+0%), but these trends varied by region. High-income countries with strong mitigation policies experienced decreases in all pollutants, while developing regions with rapid economic growth like South Asia and Sub-Saharan Africa had overall increases.

**Fig. 1. Time-series of population-weighted annual average PM<sub>2.5</sub>, NO<sub>2</sub>, and ozone concentrations, and FFCO<sub>2</sub> per capita.**



(A) Population-weighted annual average PM<sub>2.5</sub> (µg/m<sup>3</sup>, regional mean); n = 13,185. (B) Population-weighted annual average NO<sub>2</sub> (ppb, regional mean); n = 12,981. (C) Population-weighted OSDMA8 (O<sub>3</sub>) (ppb, regional mean); n = 12,941. (D) FFCO<sub>2</sub> per capita (metric tons, regional median); n = 13,182.

**Correlations:** Across a majority of cities, the four pollutants were positively correlated with one another, reflecting that these pollutants and/or their precursors tend to be co-emitted. However, some regions showed variation in correlations. In Latin America, the Caribbean, and parts of the Middle East and North Africa, the trends in different pollutants were not always correlated. These areas had just as many—or even more—cities where pollutant levels moved in opposite directions, rather than together.

## Methods

The research team calculated PM<sub>2.5</sub>, NO<sub>2</sub>, and ozone concentrations and FFCO<sub>2</sub> emissions per capita in 13,189 urban areas worldwide from 2005 to 2019, leveraging recently-developed global datasets that predict surface-level pollutant and emissions using a mix of global land-use information and satellite measurements of air pollution.

Explore more detailed findings at [Urban Air Quality Explorer](#), an interactive multi-pollutant database for 13,189 urban areas worldwide. For more detailed findings and references, see full study at [Communications Earth & Environment](#). For more information, contact Susan Anenberg at [sanenberg@gwu.edu](mailto:sanenberg@gwu.edu).

## Takeaways

Air pollution and climate change are urgent global concerns, particularly for cities, which both contribute heavily to GHG and air pollutant emissions, and often face a higher burden of air pollution- and climate-related health effects. This research provides valuable findings and tools for cities looking to address GHG and air pollutant emissions.

- Positive correlations between trends in the pollutants in many urban areas suggest that these pollutants often share emissions sources and could be addressed by integrated mitigation strategies.
- Trends vary significantly across regions and cities, which stresses the need to understand local and regional drivers of air pollution and GHG emissions to inform region-specific strategies.
- High-income countries showed significant decreases in air pollutants, likely due to comprehensive air quality regulations and climate action, while rapidly developing regions saw large increases in air pollutants, suggesting a need for solutions that can couple economic development with pollutant controls.
- Satellite remote sensing and other global land-use information, which leverage full geospatial coverage, high spatial resolution, and a lengthened temporal record, are valuable for tracking these pollutants in urban areas across the globe, even in areas where there are no ground monitors.
- Cities and other stakeholders across the globe can use datasets like the Urban Air Quality Explorer to track cities' progress toward air quality goals like the WHO Air Quality Guidelines and individual GHG targets.

### Urban Air Quality Explorer

