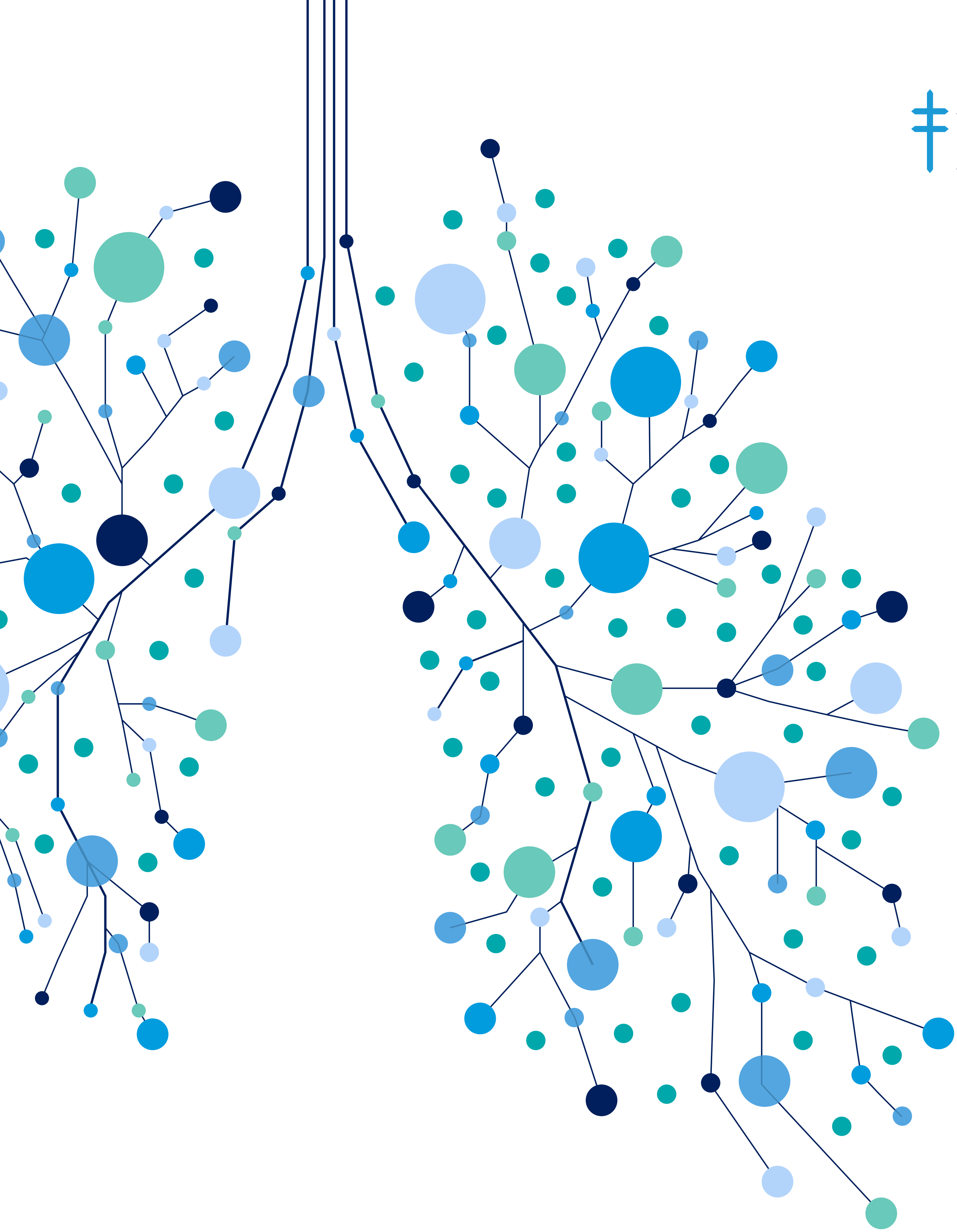


Something in the Air

Nitrogen Dioxide and Community Health

A “State of the Air” Supplemental Report

Index

Introduction

This report is the second installment in the "Something in the Air" series, which builds on the foundational insights from the American Lung Association's annual "State of the Air" report. The series explores new opportunities to enhance public access to air quality data, ensuring communities have a clearer picture of the air they breathe. The first report, "Bridging the Air Quality Data Gap with Satellite Technology," highlighted the power of satellite-derived data in improving the understanding of fine particle pollution in counties without regulatory monitors.

This second report focuses on nitrogen dioxide (NO_2), a widespread air pollutant that is under-researched, under-monitored and under-regulated. Leveraging satellite data and key findings, "Nitrogen Dioxide and Community Health" highlights adverse and underreported health impacts of NO_2, identifies localized pollution hotspots and emphasizes exposure risks—particularly in communities overburdened by pollution. The report provides actionable recommendations to advance air quality monitoring through emerging data systems, improve assessments of NO_2's role in air pollution and strengthen protections to safeguard public health.

For over two decades, the American Lung Association has been committed to informing decisionmakers and the public about nationwide air quality through our annual "State of the Air" report, which provides insights into the health impacts of fine particulate matter ($PM_{2.5}$) and ozone, two of the most dangerous and pervasive air pollutants. NO_2, though a prevalent and well-documented contributor to respiratory illness, has not received the same level of attention in public messaging and regulation. Closing this gap in awareness and regulatory focus on NO_2 is vital to addressing community-level exposure patterns, broadening the nation's perspective on air quality and establishing access to clean air protections for all.

NO_2 Formation, Sources and Health Effects

Formation

NO_2 is a gaseous air pollutant composed of one nitrogen atom and two oxygen atoms. It is the most prevalent form of a group of highly reactive gases including nitric oxide (NO), which are collectively known as nitrogen oxides (NO_x). NO_2 has a pungent odor, it is corrosive and acts as a highly reactive oxidant (U.S Environmental Protection Agency [EPA], 2011). It is one of six widespread air pollutants regulated under the National Ambient Air Quality Standards (NAAQS), which set limits on harmful pollutant concentrations in outdoor air.

NO_2's high reactivity and rapid atmospheric transformations cause its concentration levels to fluctuate significantly over short distances and time periods. Once emitted, NO_2 undergoes rapid chemical reactions, altering air composition and forming secondary pollutants. In the presence of volatile organic compounds (VOCs) and sunlight, NO_2 undergoes chemical reactions in the lower atmosphere, forming ozone, a major air pollutant. Additionally, NO_2 contributes to the formation of a type of fine particulate matter known as nitrate, another major pollutant causing respiratory disease. Due to these reactive properties, controlling NO_2 offers a potential triple benefit to health: reducing direct NO_2 exposure, lowering ozone formation and decreasing $PM_{2.5}$ levels. Although NO_2 is nearly invisible under typical conditions, it can be noticeable from afar, developing a reddish-brown tint at elevated concentrations. When combined with the light-scattering effects of fine particulate matter, this can contribute to the characteristic haze and smog seen in regions like California (California Air Resources Board, 2025).

Sources

- NO_2 is primarily produced when fossil fuels such as coal, oil, methane gas (commonly known as natural gas) and diesel burn at high temperatures, causing nitrogen and oxygen in the air to react.
- Trucks, buses and cars are the largest sources of NO_2 emissions, followed by diesel-powered non-road equipment, industrial processes such as oil and gas production, industrial boilers and other movable engines, power plants and combustion processes.
- NO_2 is a concern indoors, where appliances like gas stoves, wood-burning stoves, kerosene heaters, dryers and space heaters that burn methane or liquefied petroleum gas can generate substantial amounts of NO_2.
- Wildfires produce NO_2, as do some natural sources including lightning, leafy plants and soil microbes. NO_2 and other NOx also interact with water, oxygen and other chemicals in the atmosphere to form acid rain and regional haze that harm ecosystems and degrade visibility.

Health Impacts

NO_2 causes a range of harmful effects on the human body, acting mainly as an irritant affecting the mucosa of the eyes, nose, throat and respiratory tract. Individuals with asthma, chronic obstructive pulmonary disease (COPD), cardiovascular disease and diabetes face greater risks from NO_2 exposure, as studies show clear links between pollution and increased emergency room visits, respiratory distress and worsened chronic disease outcomes (EPA, 2008).

Health impacts depend on the concentration and duration of exposure, with higher concentrations typically found near busy roadways. Short-term exposure to NO_2, lasting from 30 minutes to 24 hours, poses significant health risks, particularly for communities already experiencing elevated pollution burdens. It has been scientifically linked to airway inflammation in healthy individuals and worsened respiratory symptoms in people with asthma. Even low-level NO_2 exposure may lead to decreased lung function in COPD patients, increased bronchial reactivity in people with asthma and a higher risk of respiratory infections, especially in young children.

"Elevated levels of NO_2" refers to concentrations that exceed ambient (typical) levels found in the air, reaching thresholds known to harm human health. Prolonged exposure can contribute to chronic respiratory conditions and an increased risk of cardiovascular disease. Short-term exposure to elevated levels can irritate the airways and worsen respiratory health, triggering symptoms such as coughing, wheezing and difficulty breathing. Chronic exposure, even at moderate levels, has been linked to higher rates of respiratory illness, long-term cardiopulmonary effects, premature death and increased hospitalizations. Additional health effects include pulmonary fibrosis, reduced lung function, increased risk of ear infections, weakened immune defense and fluid accumulation in the lungs. (EPA, 2024b).

A 2020 study identified a significant link between long-term NO_2 exposure and increased risks of both all-cause and respiratory-related mortality, particularly from COPD and acute lower respiratory infections (Atkinson et al., 2020). A 2022 review further associated elevated NO_2 levels— along with particulate matter and sulfur dioxide— to serious health effects, such as heart and lung damage, pregnancy complications, increased risk of kidney and neurological disorders, autoimmune diseases and cancer. Studies indicate that NO_2 levels are highest in urban areas with heavy traffic and industrial activity, increasing exposure risks for significant portions of the population. These areas frequently coincide with, or are situated in, low-income communities, exposing residents to greater air quality challenges. Prolonged NO_2 exposure in these communities increases respiratory illnesses and compounded health risks, worsening overall health outcomes. Children, the elderly, individuals with preexisting health conditions and outdoor workers are particularly vulnerable to NO_2 exposure (EPA, 2011). NO_2 remains an underexplored pollutant, with substantial gaps in monitoring and research that limit the understanding of its role in air pollution and its impact on health and the environment. Its presence in many areas is poorly tracked and inadequately addressed, reinforcing the call for stronger, evidence-based clean air protections.

Definitions:

Fenceline: A fenceline community lives immediately adjacent to highly polluting facilities and is directly affected by traffic and fuel sources.

Vulnerable: Groups that are high-risk for adverse health outcomes due to environmental harms, including socioeconomic challenges.

Marginalized: Groups systematically excluded from full participation in social, economic and political realms, resulting in limited access to resources and opportunities.

Low-income: U.S. Department of Housing and Urban Development (HUD) defines low-income families as those earning no more than 80% of the median family income for their area.

People of Color: The term "people of color" refers to individuals who identify as non-white.

Source: EPA, 2025.

NO_2 Monitoring and Regulation

Monitoring NO_2 Leaves Hotspots Under-measured

The placement of NO_2 monitors, guided by the NAAQS and implemented through Tribal and State Implementation Plans (TIPs/SIPs), is managed by the EPA, state, Tribal and local air agencies. These agencies oversee monitor placement, equipment maintenance and compliance with federal guidelines, with monitoring plans reviewed every five years (EPA, 2024a). Data from these monitors are submitted to EPA's Air Quality System (AQS), supporting regulatory assessments, public health decisions and policy adjustments.

Ambient NO_2 concentrations are measured using monitors strategically placed to track air quality, with 482 monitoring sites across the U.S. (2021–2023), operated by State, Local and Tribal air agencies with partial EPA funding (**Figure 1**). State and Local Air Monitoring Stations (SLAMS) represent 80% (249 sites) of these monitors and measure NO, NO_2 and NOx, providing essential data for NAAQS implementation (EPA, 2024c). Two key subsets of SLAMS sites include, 1] Photochemical Assessment Monitoring Stations (PAMS), which measure ozone precursors to support ozone regulation (but are not directly regulatory for NO_2 compliance) and 2] NCore sites, which serve as regulatory monitors supporting NO_2 NAAQS compliance and multi-pollutant monitoring (EPA, 2024c).

Tribal Air Monitoring Stations (TAMS) are operated by Tribal governments to monitor air quality on Tribal lands. Other monitoring networks include Special Purpose Monitors (SPMs), used for short-term studies and not typically for NAAQS compliance, and near-road monitors (73 operational sites). The near-road network was established in 2014 as a part of the 2010 NO_2 NAAQS review to expand measurements in metropolitan regions with populations over 1 million, where traffic-related NO_2 pollution is most concentrated (EPA, 2024c).

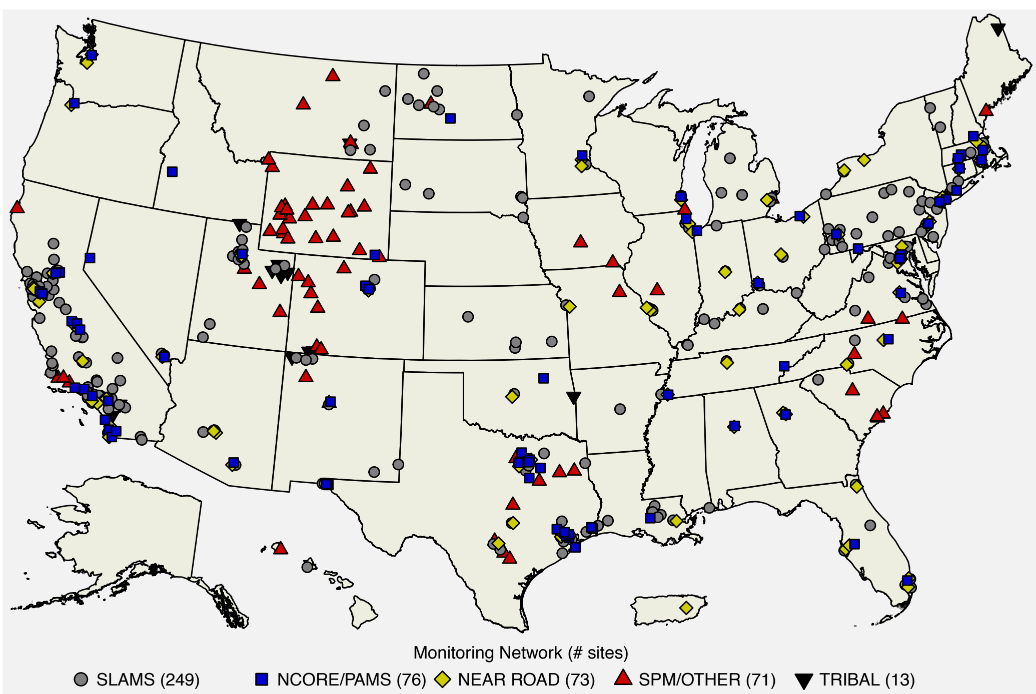


Figure 1: Map of U.S. NO_2 monitoring sites reporting data to the EPA during the 2021-2023 period (EPA, 2024c)

The NO_2 monitoring network is designed to assess compliance with the NAAQS, but several challenges limit its effectiveness. These include the limited placement and spatial coverage of the current network, the lack of near-road monitoring and focus on regulatory compliance rather than capturing localized, or small-scale, pollution variations. As previously noted, NO_2 is a short-lived pollutant that undergoes rapid atmospheric fluctuations, resulting in significant spatial and temporal variability in its concentration and interaction with other pollutants, which poses challenges for accurate measurement and assessment (National Aeronautics and Space Administration [NASA], 2023).

Evidence suggests that the current monitoring network often fails to detect localized NO_2 pollution clusters, leading to underreported levels in high-exposure areas along major roadways and industrial corridors, where concentrations can vary significantly within just a few city blocks. This issue is particularly pronounced near highways, emission hubs and dense urban areas, where peak pollution levels frequently go undetected by existing monitors. Studies reveal that NO_2 concentrations drop sharply with increasing distance from traffic, highlighting steep pollution gradients near roadways (EPA, 2008). Because the monitoring network relies on fixed-site monitors, pollution levels in unmonitored counties or rapidly changing urban environments may be underestimated.

Recognizing these monitoring gaps, the EPA revised the NO_2 NAAQS in 2010 and mandated the deployment of 40 NO_2 monitors in high-exposure areas to better assess risks for susceptible and vulnerable populations. These monitors were strategically placed in locations where emissions from motor vehicles, industrial facilities and area sources had the potential to exceed NAAQS levels (EPA, 2024a). Susceptible populations include individuals with asthma and communities disproportionately affected by NO_2 pollution, who face heightened health risks due to increased exposure. Despite these additional monitoring efforts, significant gaps remain, leaving many communities inadequately monitored.

Studies using satellite data and near-road monitors reveal elevated NO_2 levels that the broader regulatory network often fails to capture (Atkinson et al., 2020). These findings underscore the need for more comprehensive monitoring to detect within-city pollution variations and improve community-level exposure assessments. Addressing NO_2 monitoring gaps is critical, as current ground-based systems do not provide a complete picture of localized pollution hotspots. Strengthening NO_2 monitoring networks, expanding research accessibility and leveraging emerging technologies are essential steps for accurately assessing NO_2 levels. These efforts, combined with strategic interventions, are vital to reducing exposure disparities, protecting public health and addressing pollution-related health risks.

Regulation of NO_2 Inadequate to Protect Public Health

Over time, efforts to regulate NO_2 have expanded through targeted programs and policies that reduce emissions from key sources. The EPA implements initiatives such as the New Source Performance Standards (NSPS) and the National Emission Standards for Hazardous Air Pollutants (NESHAP) to target emissions from power plants and industrial facilities. Though these programs are not specific to NO_2, their implementation impacts ancillary reductions in NO_2 pollution, demonstrating the multi-pollutant benefits of stricter emissions controls (EPA, 2024e). Similarly, the Tier 3 Motor Vehicle Emission and Fuel Standards impose stricter tailpipe and evaporative emission limits on passenger cars, light-duty trucks, medium-duty passenger vehicles and some heavy-duty vehicles, playing a key role in limiting NO_2 pollution from one of its primary sources—transportation (EPA, 2014a). Although these policies have successfully lowered NO_2 emissions, their impact is only part of the equation.

Progress over the years

Data from NASA's Ozone Monitoring Instrument, which also detects other gases in the atmosphere (like NO_2), reveals a 20-50% decrease in NO_2 concentrations from 2005 to 2022 across the U.S., attributed to state and federal regulations aimed at reducing NO_x emissions from power plants and vehicles (NASA 2022).

How standards are determined and whether the current standards reflect real-world exposure risks are critical factors in ensuring effective public health protections. To mitigate risks to both public health and the environment, the EPA regulates NO_2 through the NAAQS, the primary regulatory framework to set limits on acceptable concentration levels. Under the Clean Air Act, these standards are required to be reviewed every five years to ensure they reflect the latest advancements in scientific understanding. When the NO_2 NAAQS were established in 1971, the EPA set an annual standard limiting the average NO_2 concentration in ambient air to 53 parts per billion (ppb), a threshold that has remained unchanged since its inception (EPA, 2011).

In 2010, the EPA introduced the 1-hour standard of 100 ppb to address short-term exposure risks and more effectively capture peak NO_2 pollution levels, particularly near major emission sources. In 2016, EPA released the "Integrated Science Assessment for Oxides of Nitrogen - Health Criteria" to evaluate the human health effects of nitrogen oxides and provide the scientific foundation for reviewing the primary NO_2 NAAQS (EPA, 2024a). This assessment strengthened the evidence linking both short-term and long-term NO_2 exposure to respiratory diseases, cardiovascular conditions and mortality; however, updates to the standards have not kept pace with advancing research.

1-Hour Standard (Primary): 100 ppb, based on the 98th percentile of 1-hour daily maximum concentrations, averaged over three years (primary standards protect human health).

Annual Standard (Primary & Secondary): 53 ppb, measured as an annual mean (secondary standards safeguard the environment & public welfare).

In 2018, following a comprehensive review of the available scientific evidence, the EPA decided to retain the existing NO_2 NAAQS. The history of NO_2 NAAQS reviews reflects a gradual regulatory approach but also underscores significant gaps in addressing its cumulative and localized impacts. EPA's 2022 NO_2 standards review, detailed in the Integrated Review Plan (IRP), assessed the latest health science and included a risk and exposure analysis to guide policy decisions on whether to retain or strengthen the standards. Various health organizations, including the American Lung Association, advocated for stronger regulations, continued public input, expanded monitoring and policy-relevant scientific research to address NO_2 pollution gaps (EPA, 2024b).

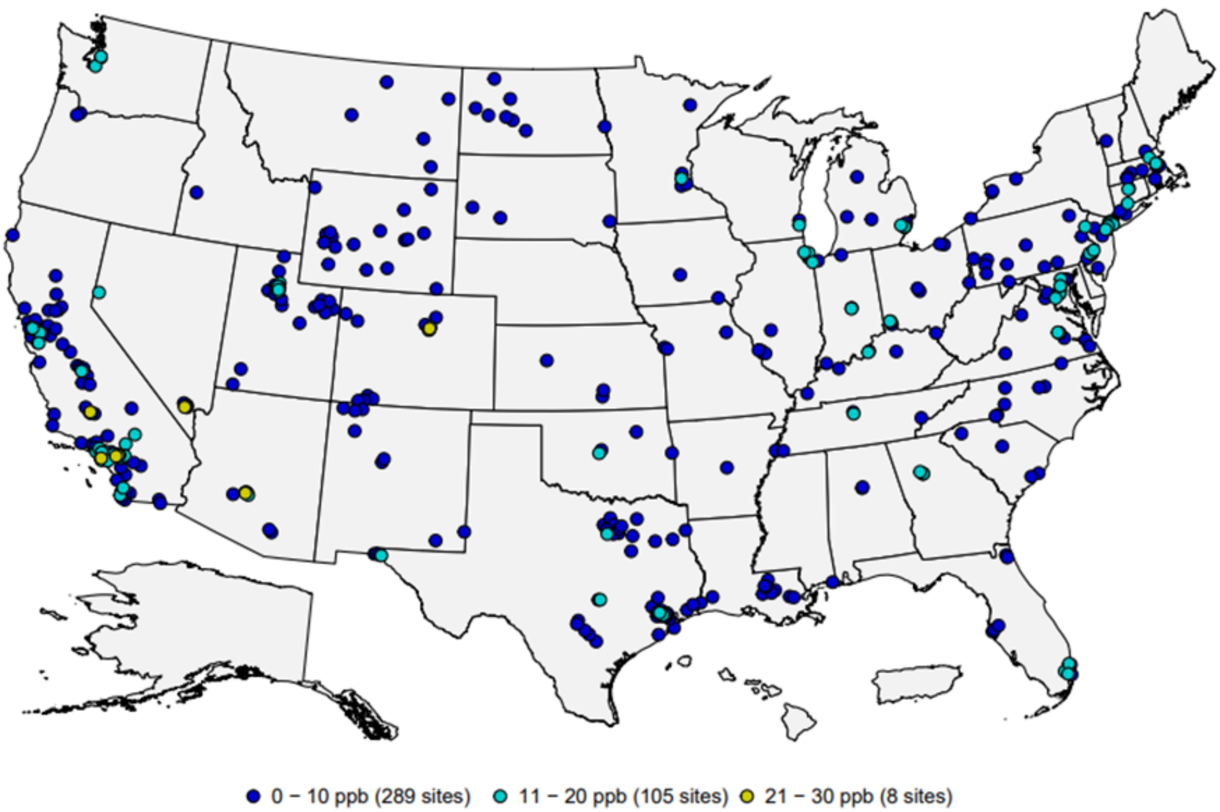


Figure 2: Annual NO_2 Design Values (DVs) at U.S. ambient air monitoring sites based on data from 2022 (EPA, 2023)

Examining recent air quality levels and monitoring coverage across the U.S., as illustrated in **Figure 2**, offers valuable insight into potential gaps in regulatory oversight. Despite growing evidence of NO_2's health impacts, the monitoring network suggests broad compliance with the annual 53 ppb standard, as most locations report concentrations well below this threshold—often cited as justification for maintaining the current NAAQS. Yet, this broad compliance does not account for several critical factors that influence NO_2 exposure and regulation, including,

- how decades of emission control strategies—such as vehicle regulations and industrial pollution reductions—have contributed to declining NO_2 levels at these monitored sites,
- the persistent challenge of limited monitoring, particularly near major emission sources,
- the difficulty in measuring NO_2 peaks due to its short-lived nature, and
- the health impacts associated with secondary pollutants formed from NO_2.

The sparse distribution of monitors does not fully account for capturing measurements in the most persistent pollution clusters, typically among fenceline communities. Without adequate localized data, critical exposure differences may go undetected, leaving these communities disproportionately affected by NO_2-related health risks (EPA, 2013). One of the primary challenges in regulating NO_2 pollution is that it remains under-researched, particularly regarding its impact on vulnerable communities and its contribution to secondary pollutant formation. These knowledge gaps hinder a full assessment of NO_2's health and environmental consequences, contributing to regulatory shortcomings.

This highlights the need for stronger protections, especially as Canada has set a precedent for stricter NO_2 regulation with their health-based standards. The Canadian Ambient Air Quality Standards (CAAQS) for NO_2 were set at 17.0 ppb in 2020 and will tighten to 12.0 ppb in 2025 (Canadian Council of Ministers of the Environment, 2024). This standard is significantly more protective than the U.S. limit, reflecting a precautionary approach that prioritizes minimizing NO_2 exposure to reduce associated risks. If the annual NO_2 NAAQS were as stringent as Canada's, approximately 25% of monitored U.S. counties, based on 2022 Design Values, would fail to meet the upcoming 12.0 ppb CAAQS standard set to take effect in 2025. These findings emphasize the need to assess whether current U.S. NO_2 standards adequately safeguard public health based on the latest scientific evidence, as the lack of comprehensive data continues to hinder effective regulation.

Disparities in the Burden of NO_2 Exposure

Marginalized communities experience disproportionately high rates of chronic illnesses such as cancer, heart disease and diabetes, driven by greater health needs and compounded by demographic, economic, social and environmental challenges. Low-income populations and communities of color are more likely to reside in areas with elevated levels of NO_2, ozone and particulate matter, contributing to a higher burden of comorbid respiratory illnesses and cardiovascular diseases (Health Effects Institute, 2023). These environmental exposures, when layered with factors such as poverty, inadequate healthcare access and other social stressors, contribute to worsening health outcomes.

A recent study on air pollution exposure disparities detailed that Black, Hispanic, Asian and multiracial populations in the U.S. are exposed to NO_2 levels 15–50% higher than the national average, whereas non-Hispanic white populations experience 5–15% lower levels (Kerr et al., 2023). These findings indicate that NO_2 pollution hotspots often align with broader environmental and health burdens, underscoring the need for interventions. Additionally, screening tool analyses show that communities facing economic and environmental hardships experience even greater NO_2 exposure disparities, with factors such as income, race and pollution burden contributing to heightened risks.

Despite technological advances, such as cleaner-burning fuels, low-emission engines and electric vehicles, traffic-related pollution continues to increase in many areas due to urbanization, population growth, economic expansion and land use policies that prioritize motor vehicle infrastructure over community health. While regulatory efforts have contributed to lowering emissions, they have not effectively reduced exposure disparities, as fenceline populations continue to bear the burden of these health effects.

The sparse distribution of NO_2 monitoring sites, primarily in urban and low-income communities near major roads and pollution sources, results in significant data gaps, restricting the ability to assess exposure differences across demographic groups.

A NASA-funded study used satellite data and additional resources to reveal that nearly 150,000 warehouses across the U.S. substantially contribute to elevated local NO_2 levels, with many located in vulnerable communities. The study found that areas near warehouses experience, on average, a 20% rise in NO_2 levels, primarily driven by truck traffic and high warehouse density (NASA, 2024). In addition, the sharp decline in human activity during the COVID-19 pandemic exposed NO_2 pollution variation across diverse communities. While public health safety precautions significantly limited population movement and reduced NO_2 levels in urban areas, they did not eliminate preexisting exposure disparities. Despite the overall decrease, communities with greater racial diversity and lower socioeconomic status continued to experience disproportionately higher NO_2 pollution compared to more affluent areas, underscoring the uneven distribution of air quality improvements. NO_2 levels in the least White census tracts were 1.5 times higher than those in the most White tracts, even after reductions (Kerr et al., 2023). Data further demonstrated that NO_2 levels in marginalized communities were nearly three times higher than in predominantly White areas. Despite a 50% decrease in passenger vehicle traffic, NO_2 disparities remained, highlighting the significant contribution of heavy-duty vehicles—such as those used in ground shipping, which increased during the COVID-19 pandemic—and the impact of roadway proximity in sustaining these exposure differences (Kerr et al., 2023).

According to the EPA, more than 45 million people in the U.S. live within 300 feet of major transportation infrastructure, including busy roads (2024d). This proximity significantly increases exposure to transportation-related air pollution. Near-road NO_2 concentrations can be two to three times higher than ambient levels, placing commuters, traffic workers and residents near highways at greater risk (EPA, 2008). Findings indicate that roadways significantly impact air quality within a few hundred meters—roughly 500 to 600 feet—downwind of heavily traveled roads or transportation corridors with high trucking and rail activity (EPA, 2014b). NO_2 levels near major traffic corridors can be up to twice as high as in residential or less-traveled areas, but concentrations decrease rapidly with distance from the source (EPA, 2011). This rapid dissipation limits monitoring coverage, preventing the collection of adequate data on pollution clusters in the most overburdened areas.

A cross-sectional study on racial and ethnic disparities in the distribution of EPA regulatory monitors analyzed data from 329 million people across 237,631 U.S. census block groups. The study found that monitoring data alone does not equitably represent air quality, as communities of color have significantly fewer NO_2 monitors, potentially leading to an underestimation of pollution exposure and associated health risks (Bastian et al., 2023).

The limited and scattered distribution of monitoring sites makes achieving continuous spatial coverage challenging. Using advanced technologies like satellite data provides a more detailed view of NO_2 levels at the community level. NASA stated, "satellite data has the potential to transform the measurement of certain environmental and climate factors...the consistency of NASA's NO_2 data for every corner of the U.S. makes it tremendously valuable for screening and mapping of disproportionate impacts in communities" (NASA, 2024).

Using Satellites to Capture NO_2 Exposure

Satellite data for NO_2 "have become one of the most widely used air quality metrics, especially as an indicator of nitrogen oxides" (Holloway et al., 2021). NO_2 data gathered from satellites are measured through a column of air, capturing the total amount of the gas from the Earth's surface to the upper atmosphere, unlike ground-based monitors that measure NO_2 at or near the surface. Using computer modeling to interpret column data helps estimate surface pollution, offering a more detailed perspective, especially in areas with limited monitoring coverage.

To better understand NO_2 pollution, satellite instruments like Tropospheric Emissions: Monitoring of Pollution (TEMPO) and the Tropospheric Monitoring Instrument (TROPOMI) provide complementary capabilities. TEMPO, positioned in a geostationary orbit, captures hourly daytime variations in NO_2 levels over North America, offering high-resolution data on the daily cycle of emissions (NASA, 2024). Meanwhile, TROPOMI measures air quality and atmospheric gases in the troposphere, which is the lowest layer of Earth's atmosphere where most weather and human activities occur. It uses spectrometry to analyze Earth's surface and atmosphere, identifying the absorption patterns of pollutants.

Ground-based monitors, while highly accurate, have limited spatial coverage due to their fixed locations and typically measure air quality within a few kilometers of their installation sites. In contrast, satellites offer higher-resolution data and broader coverage, allowing for the detection of detailed pollution patterns across vast regions. By imaging trace gas concentrations over the Earth's surface in a fine spatial grid, they provide a more comprehensive view of air quality variations. Data from satellites is processed using algorithms that account for factors such as cloud cover, surface reflectance and atmospheric scattering, enhancing the accuracy of NO_2 measurements (Holloway et al., 2021).

Satellites enable improved understanding of temporal and spatial pollution patterns, allowing satellite data to closely align with ground-level measurements and effectively capture localized pollution hotspots to inform targeted pollution control strategies (NASA, 2022). **Figure 3** visualizes county rankings for NO_2 across the U.S. based on satellite data from 2020–2022 *(see Methodology for data analysis conducted by the University of Wisconsin-Madison)*. Each pollution category represents a separate percentile range rather than a cumulative total. For example, the "dirtiest 2%" includes NO_2 values between the 98th and 99th percentile but does not include the "dirtiest 1%," which only includes values at or above the 99th percentile. Similarly, the "dirtiest 5%" covers values from the 95th to 98th percentile, meaning it excludes the dirtiest 2% and 1%, ensuring no overlap between categories.

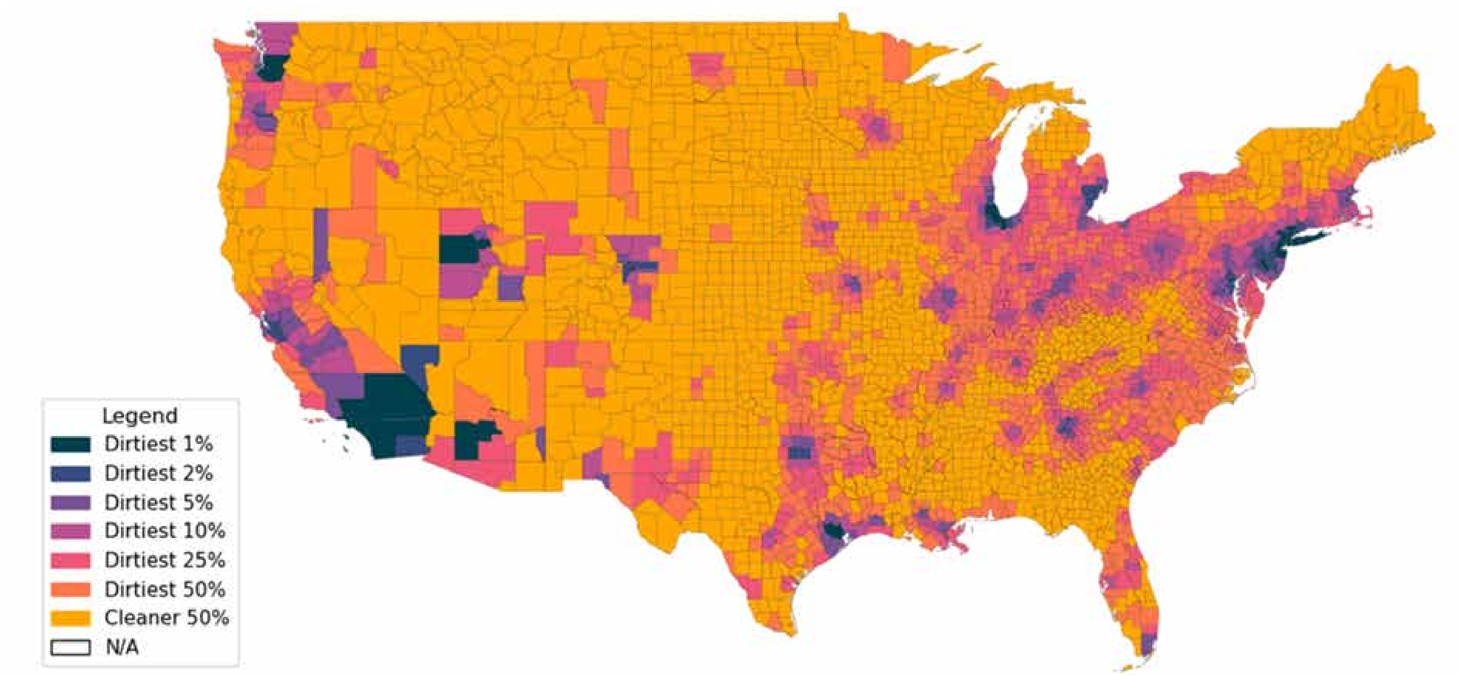


Figure 3: NO_2 Rankings by Satellite Values (2020–2022)

Higher NO_2 column values, represented by darker shades of blue, are primarily concentrated in urban areas. Satellite-derived rankings highlight the predominantly urban nature of NO_2 pollution, with the most affected regions closely tied to densely populated metropolitan areas. The map shows elevated NO_2 levels along coastal and urban corridors, particularly in California, Illinois, New York, New Jersey, Michigan and Washington. Among the 50 counties with the highest satellite-detected NO_2 concentrations, the total population exceeds 28 million, with a median county population of over 475,000.

This visual reinforces the connection between NO_2 pollution, urbanization and vehicle traffic in densely populated areas. However, the map also illustrates that NO_2 pollution is not solely confined to major cities; numerous communities across the Midwest, South and the Mountain West fall within the dirtiest 25% of counties. These areas, while less populated than coastal cities, still experience significant exposure, emphasizing the nationwide scope of the issue and the critical role of satellite data in identifying regions with limited monitoring coverage.

While county-level data reveals critical patterns and highlights regional disparities in NO_2 pollution, it often obscures the finer-scale variations that shape the lived experiences of affected populations. Within counties, NO_2 exposure can vary dramatically, with neighborhood-level differences driven by factors such as traffic density, industrial activity and demographic composition, all of which significantly influence public health outcomes. Research indicates that moving beyond broad county-level averages to more granular, small-scale data enables a more precise identification of localized pollution hotspots and disproportionately affected populations, providing actionable insights to address inequities.

For instance, a 2022 study on air pollution inequities found that relying on state and county data underestimated racial and ethnic exposure differences by approximately 20% compared to finer-scale analyses (Harris). Air pollution levels can vary significantly within communities, even at the neighborhood level emphasizing the need for more precise data to accurately identify pollution sources and who they impact. Because pollution does not exist in isolation, integrating transparent and quantifiable measures of cumulative impact—considering multiple pollutants and social stressors—alongside community vulnerability assessments can drive progress in addressing the under-researched, under-monitored and under-regulated implications of NO_2 across the U.S.

Satellite Data Reveal Intra-County Inequities

Analysis conducted by the Holloway Group at the University of Wisconsin-Madison demonstrates how satellite data identifies localized NO_2 pollution hotspots. These hotspots emerge at the intersection of emission sources, population demographics and air quality, exposing significant inequities in NO_2 exposure.

The convergence of these factors underscores how vulnerable populations bear a disproportionate pollution burden, shaped by broader systemic challenges. Many fenceline communities, predominantly composed of people of color and low-income populations, experience some of the earliest and most severe health impacts. Satellite data highlights intra-county variation in NO_2 exposure that traditional monitoring networks often do not detect. **Figure 4** further illustrates this variation, detailing the relative NO_2 exposure disparity in select counties.

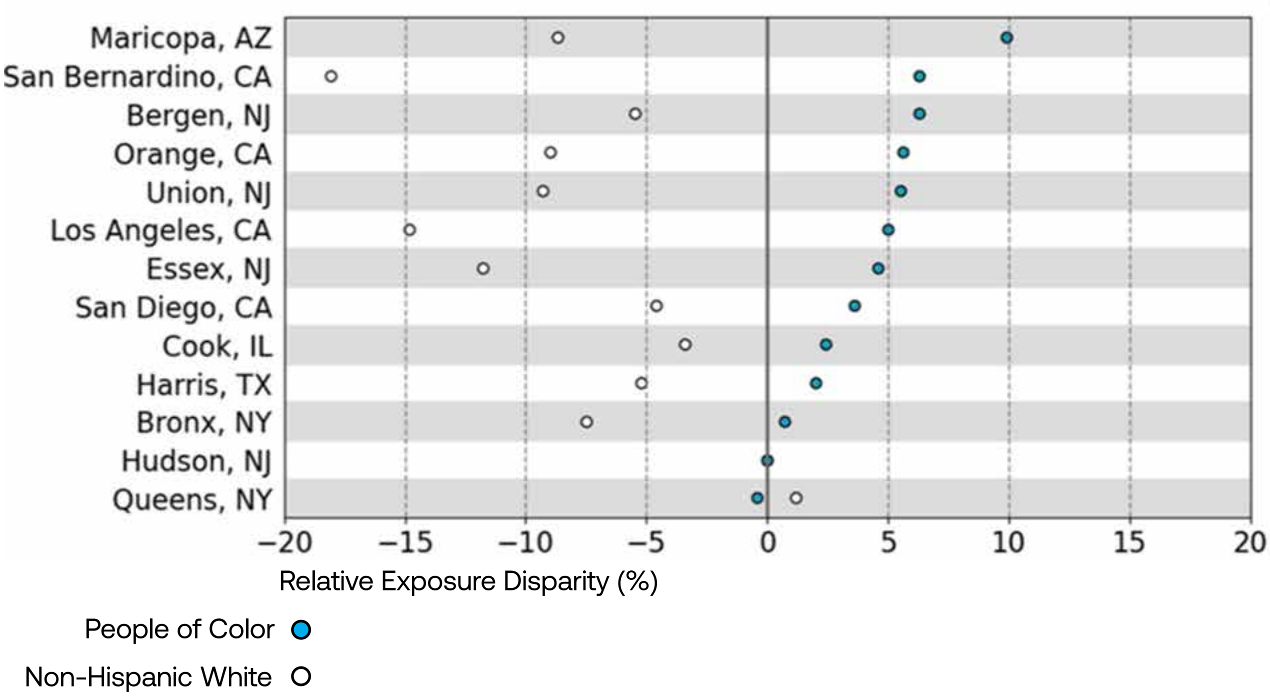


Figure 4: Relative NO_2 Exposure Disparities in select U.S. Counties

The horizontal axis shows NO_2 exposure levels, measured relative to each county's population average, ranging from lower to higher. Counties are ranked based on the degree of exposure disparity for people of color, denoted by the blue dot, compared to their non-Hispanic white counterparts, represented by the white dot. These 13 counties are among the 25 most polluted for NO_2, as measured by satellite data. Except for Essex County, NJ—where no ground-level monitors exist—each of these counties also ranks among the 25 most polluted for NO_2 based on regulatory monitoring data. The counties featured in Figure 4—Maricopa (AZ); Los Angeles, Orange, San Bernardino, and San Diego (CA); Cook (IL); Bergen, Essex, Hudson, and Union (NJ); Bronx and Queens (NY); and Harris (TX)—represent major metropolitan areas with high traffic density and, in some cases, industrial activity. These factors contribute to significant NO_2 pollution, impacting communities with a high percentage of people of color.

The integration of satellite and ground-based data consistently reveal NO_2 pollution patterns, underscoring the need for targeted interventions. By combining both measurement approaches, this analysis offers a more comprehensive understanding of pollution disparities, ensuring that satellite-identified hotspots are validated by on-the-ground monitoring, ultimately to enhance the reliability of findings. These results highlight areas of elevated public health risk, reinforcing the urgency of mitigation efforts.

To further examine the intersection of pollution exposure and demographic disparities, the maps in **Figure 5** illustrate how satellite-derived NO_2 concentrations align with demographic characteristics at the census tract level. By focusing on four counties with some of the highest relative NO_2 exposure disparities, these maps highlight the localized nature of pollution burdens and provide a clearer visualization of how exposure varies within communities. Maricopa County, AZ; Orange County, CA; Essex County, NJ; and Cook County, IL were selected as examples to illustrate how NO_2 pollution exposure varies within counties based on demographic differences. These disparities are evident across the selected counties, where communities face higher pollution burdens due to their proximity to major emission sources. This pattern underscores the link between increased vulnerability and health disparities in low-income populations.

Figures 5a–5d provide a side-by-side analysis of NO_2 pollution and demographic patterns, offering a closer look at how air pollution is unevenly distributed within each county. Each of the four county examples includes two maps displaying data by census tract: the left map uses a gradient from light yellow to deep red to represent increasing NO_2 concentrations, while the right map illustrates the percentage of the population who are people of color, using a gradient from pale green to dark blue.

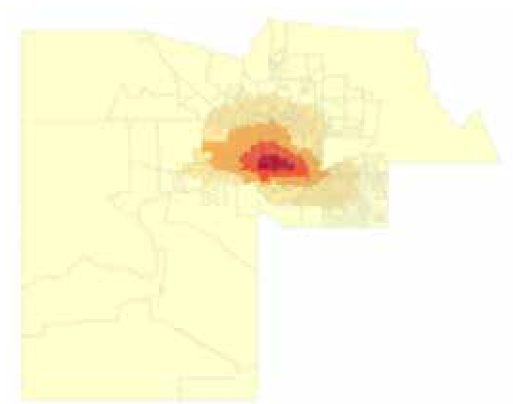
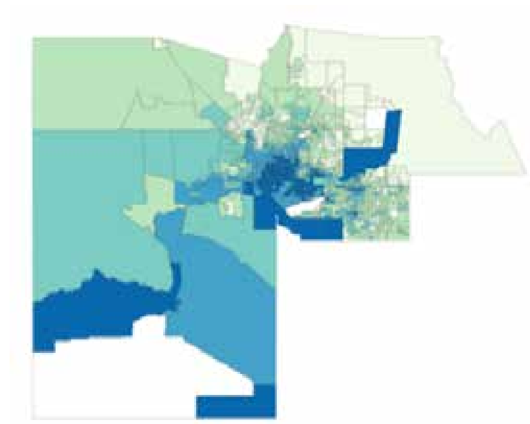
Pollution	Demographics
	
Census Tract Averaged NO_2 (10^{15} molecules/cm^2) ≤ 3 3 - 4 4 - 5 5 - 6 6 - 7 ≥ 7	% People of Color by Census Tract 0 - 20 % 20 - 40 % 40 - 60 % 60 - 80 % 80 - 100 % No Population

Figure 5a: Maricopa County, Arizona: Exposure Disparities

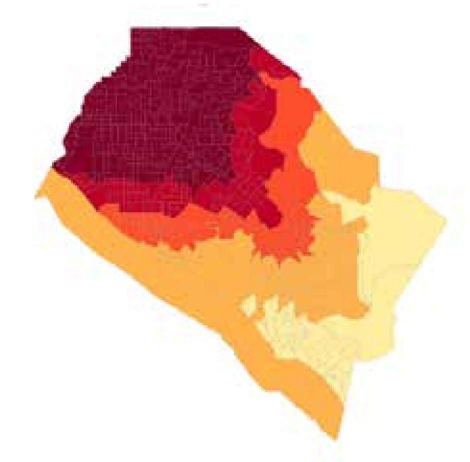
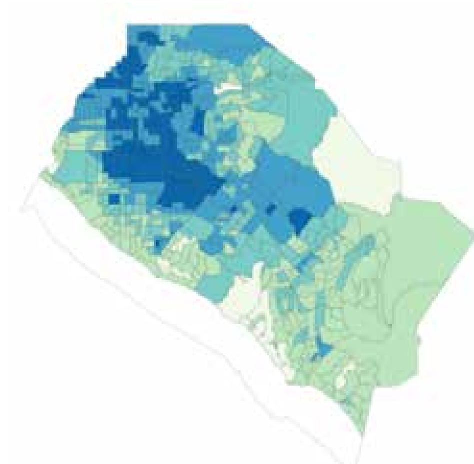
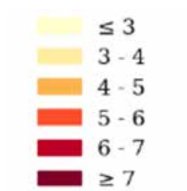
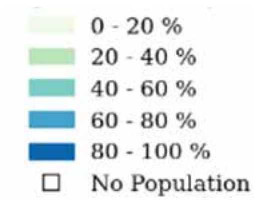
Pollution	Demographics
	
Census Tract Averaged NO_2 (10^{15} molecules/cm^2) 	% People of Color by Census Tract 

Figure 5b: Orange County, California: Exposure Disparities

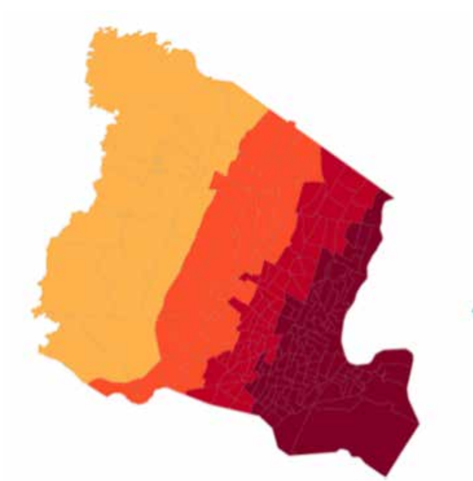
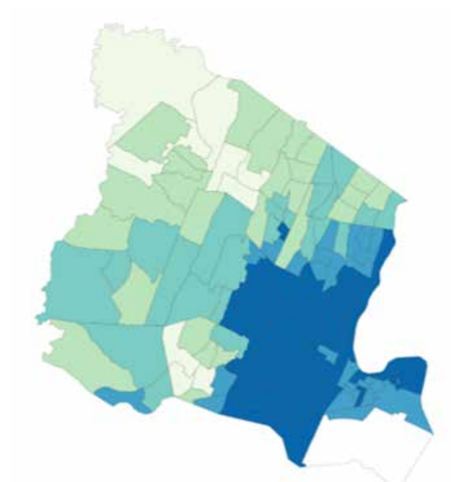
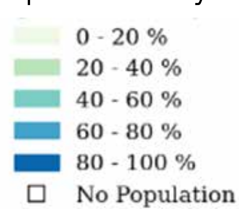
Pollution	Demographics
	
Census Tract Averaged NO_2 (10^{15} molecules/cm^2) 	% People of Color by Census Tract 

Figure 5c: Essex County, New Jersey: Exposure Disparities

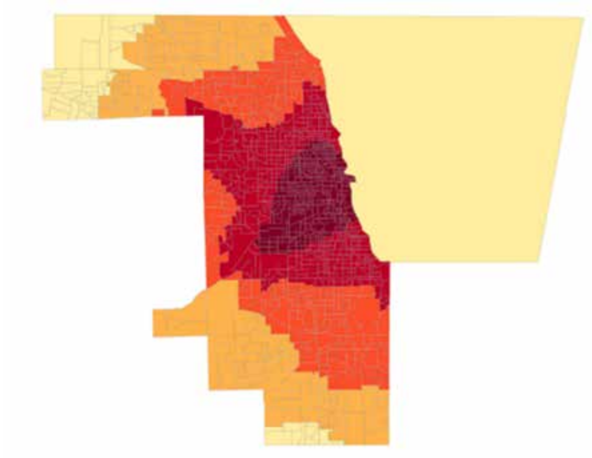
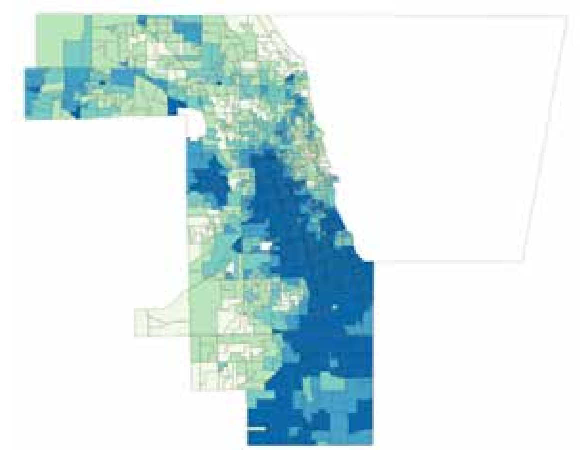
Pollution	Demographics
	
Census Tract Averaged NO_2 (10^{15} molecules/cm^2)	% People of Color by Census Tract
≤ 3 3 - 4 4 - 5 5 - 6 6 - 7 ≥ 7	0 - 20 % 20 - 40 % 40 - 60 % 60 - 80 % 80 - 100 % No Population

Figure 5d: Cook County, Illinois: Exposure Disparities

While NO_2 is often considered a regional issue, its effects vary significantly at the local level. Studies consistently show that White populations experience lower air pollution exposure, while people of color face disproportionately higher levels, even within the same county. By illustrating these patterns, the maps identify areas requiring targeted action to reduce pollution and reduce exposure disparities. Intra-county analysis using satellite data offers high-resolution insights that the existing monitoring network cannot fully capture.

Although the monitoring network indicates that NO_2 levels generally comply with the current NAAQS, a closer examination reveals significant variations in community-level air quality that often go undetected due to the limitations of traditional monitoring methods. As noted in prior studies, the existing network provides less coverage in high-exposure communities, potentially underestimating the true extent of NO_2 pollution. Satellite data identifies pollution clusters in areas with high populations of people of color, raising concerns about whether current air quality standards and monitoring practices sufficiently capture localized burdens, particularly in high-traffic urban corridors, industrial zones and other near-source regions. This raises a critical question: are current standards adequately protecting public health?

Recommendations for Action

Nitrogen dioxide remains an under-researched, under-monitored and under-regulated pollutant. Addressing these gaps requires a multi-faceted approach that strengthens research, expands monitoring, leverages satellite data and integrates cumulative risk assessments into the regulatory process—particularly in communities who remain overburdened by NO_2 exposure.

Persistent research gaps continue to limit a full understanding of NO_2's health impacts, particularly for vulnerable populations that include people of color and low-income communities. Scientific efforts should prioritize examining how multiple pollutants interact to better reflect real-world exposures. Additionally, advancing methodologies for assessing cumulative risks across pollutants and diverse populations can inform future regulatory and policy considerations. Researching the interplay between NO_2 and other pollutants at finer geographic scales, such as the intra-county level, is critical for strengthening future revisions to the NAAQS.

Ensuring adequate air quality monitoring in high-risk regions is essential. As a highly localized pollutant, NO_2 often goes undetected by traditional ambient air monitoring methods, which weakens the network's capability to generate data critical for fully protecting public health. More precise approaches are needed to identify pollution clusters and assess exposure where it is most severe. The strategy should focus on urban areas with high population densities and regions where these clusters are known to occur.

Strengthening the NO_2 monitoring infrastructure will generate more comprehensive data, better inform regulatory decisions, support stricter standards and improve public health protections for all. Continued federal investment in air monitoring remains critical to ensuring equitable and effective air quality management.

The current U.S. NO_2 standard (53 ppb annual) is far less stringent than Canada's current and future standards (17 ppb by 2020, 12 ppb by 2025) and the recommended World Health Organization (WHO) Global Air Quality Guideline standard (5.3 ppb annual average), which aims to safeguard public health (WHO, 2021). Strengthening the NO_2 NAAQS is essential to providing meaningful public health protections, as the current standard likely underestimates risks—particularly for populations facing disproportionate exposure.

To advance research, studies should further examine the cumulative health impacts of NO_2 alongside other criteria pollutants while incorporating localized case studies to better quantify real-world multipollutant exposures. Enhanced analytical tools can provide critical insights into how these pollutants interact, compounding health risks and reinforcing the need for stronger research and policy measures to address pollution challenges effectively.

Furthermore, regulatory frameworks should integrate cumulative risk assessments that consider a broad range of chemical pollutants—including gaseous and particulate contaminants—alongside non-chemical stressors such as socioeconomic disparities, climate-related factors and community vulnerabilities.

Conclusion

For more than 50 years, the implementation and enforcement of the Clean Air Act have led to significant reductions in emissions and improvements in air quality. Advancements in vehicle emission standards, cleaner-burning fuels and industrial controls have contributed to lower ambient NO_2 levels, which in turn has helped reduce ozone and particle pollution. These achievements have provided substantial public health benefits; however, not all communities have experienced them equally. Existing air quality standards do not fully address the inequitable distribution of pollution. Closing these gaps requires decisive action to ensure that all communities, especially those facing the greatest risks, receive the air quality protections they need. Addressing heightened NO_2 exposure demands a comprehensive approach that expands monitoring networks, advances research, integrates satellite technologies and strengthens air quality standards.

Satellites can play a valuable role in closing data gaps between monitored and unmonitored areas, offering high-resolution insights that reveal clusters of elevated pollution. By refining our ability to assess NO_2 distribution at finer scales and across smaller geographic areas, this technology enables more precise, data-driven interventions to alleviate pollution challenges in under-monitored and overburdened communities.

Stronger air quality standards and targeted pollution reduction efforts are essential to reducing disparities in air pollution-related health outcomes and ensuring comprehensive protections for all communities.

Coming Soon

Future installments in the Something in the Air series will spotlight solutions that harness emerging technologies—such as satellites and community sensors—to close air quality data gaps. Future case studies will showcase community-driven approaches to advocate for stronger air quality protections and ensure everyone has access to cleaner, healthier air.

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Appendix: Methodology and Acknowledgements

Methodology

About the Satellite Data:

The satellite data for this project was sourced from the TROPOspheric Monitoring Instrument mounted to the European Union's Copernicus Sentinel 5 Precursor mission satellite, launched in 2017. TROPOMI uses differential optical absorption spectroscopy (DOAS) to take measurements for multiple air pollutants, including nitrogen dioxide (NO_2). This means that the instrument measures how specific wavelengths of light are absorbed or scattered to estimate concentrations of trace gases and aerosols in the atmosphere. The data employed here is available from NASA in 5.5 km by 3.5 km swaths wherein the retrievals express the total tropospheric column value for nitrogen dioxide. TROPOMI provides observations of the nitrogen dioxide amounts from surface level through the troposphere. Notably, TROPOMI offers higher resolution data than previous missions observing nitrogen dioxide.

How the Data were Allocated to a Grid:

Using the Wisconsin Horizontal Interpolation Program for Satellites (WHIPS) which is an open-source program capable of allocating satellite data to a user-specified grid, we allocated the TROPOMI data to a grid with 1 km by 1 km grid cell sizes over the contiguous United States for the years 2020-2022. TROPOMI data has also been processed using WHIPS to a 1 km grid for 2020 over Alaska. As a result of processing with WHIPS, the satellite data has been allocated to a fixed grid in terms of average vertical tropospheric column density in units of 1015 molecules per centimeter squared. To note, during the allocation process the data with a quality flag below 0.75 was excluded to ensure accuracy and reliability in the final dataset.

How the Data were Allocated to the County (Max-In-County):

After processing the data to a grid and averaging over three years, the grid cells were converted to point data so that the value of the grid cell is attributed to the center point of the grid cell. Next, we spatially joined the satellite-derived data to the county boundaries as determined by the Census Bureau for 2020. By using grid cell centers, we avoid any grid cells being assigned to more than one county. Following the grouping by county boundaries, we selected the highest value within each county to represent the satellite-derived county DV. We call this the "Max in County" method.

How the Data were Allocated to Census Tracts:

After processing the TROPOMI satellite data with WHIPS and averaging over three years, we clipped the data to each specific county of study. Next, we converted the clipped data files for geospatial processing wherein we averaged the satellite data within census tract boundaries. This averaging was spatially weighted, meaning that if a grid cell intersected with census tract boundaries, the value of each grid cell is partially counted towards each census tract in proportion to the area included in each census tract.

About Equity Metric Calculations:

Combined with American Community Survey demographic data, we used the census tract averages to assess equity in terms of Population Weighted Concentrations (PWCs) and Relative Exposure Disparity in Percent.

Population Weighted Concentrations (PWC) are a measure of average exposure for both the total population and demographic subgroups, where i represents an individual census tract and n represents total census tracts within a county. The demographic population is multiplied by pollutant concentration at each census tract, summed and divided by the sum of the demographic population to yield the PWC for the county for the specified demographic group.

$$\text{Population Weighted Concentration (PWC)} = \frac{\sum_{i=1}^{n} (\text{Population}_i * \text{Concentration}_i)}{\sum_{i=1}^{n} \text{Population}_i}$$

Percent relative exposure disparity is a measure of how average exposure for a demographic subgroup varies from the total population exposure average. The total PWC for a county is subtracted from the PWC for a demographic subgroup within the same county, and then divided by the total PWC to find a percent difference in average exposure.

$$\text{Relative Exposure Disparity (\%)} = \frac{PWC_{\text{demographic group}} - PWC_{\text{total population}}}{PWC_{\text{total population}}} * 100\%$$

Using these equity metrics, we quantified intra-county inequitable exposure to nitrogen dioxide.

Figures

Figure 1:

The monitoring site locations and classifications were sourced from the EPA's Air Quality System (AQS), which aggregates air pollution data reported by state, local and tribal air agencies. The dataset includes regulatory and non-regulatory monitoring networks.

- The dataset was filtered to include only active monitors that reported NO_2 concentrations to the EPA between 2021 and 2023.
- Sites were classified based on their network type to distinguish regulatory from research-based monitors.
- The spatial distribution was analyzed to highlight areas with extensive monitoring coverage versus regions with limited NO_2 monitoring.

Figure 2:

NO_2 concentration data were obtained from EPA's AQS database. Annual NO_2 Design Values were calculated following EPA's regulatory methodology, which considers the highest 1-hour daily maximum concentrations, averaged over three years, for short-term exposure compliance.

- 0–10 ppb (289 sites) – Lowest NO_2 levels, predominantly in rural and less industrialized areas.
- 11–20 ppb (105 sites) – Moderate NO_2 levels, often found in urban settings and near industrial sources.
- 21–30 ppb (8 sites) – Highest NO_2 levels, typically located in major metropolitan areas with heavy traffic and industrial activity.

Figure 3:

TROPOMI NO_2 data, regridded to a 1 km × 1 km resolution using WHIPS, was averaged over the years 2020 to 2022 to create a multi-year average. Each grid cell was assigned point geometry, which was then spatially joined to county boundaries to determine county-level NO_2 values. The maximum NO_2 value within each county was extracted and assigned as the representative value for that county. Counties were then ranked based on their maximum NO_2 values and categorized into percentile-based pollution groups, where each group represents a specific percentile range.

The percentile range is as follows:

- **Dirtiest 1%:** Cells with NO_2 values at or above the 99th percentile (5.64 to 14.51 × 10^{15} molecules/cm^2).
- **Dirtiest 2%:** Cells between the 98th and 99th percentiles (4.59 to 5.60 × 10^{15} molecules/cm^2).
- **Dirtiest 5%:** Cells between the 95th and 98th percentiles (3.50 to 4.57 × 10^{15} molecules/cm^2).
- **Dirtiest 10%:** Cells between the 90th and 95th percentiles (2.86 to 3.48 × 10^{15} molecules/cm^2).
- **Dirtiest 25%:** Cells between the 75th and 90th percentiles (2.15 to 2.86 × 10^{15} molecules/cm^2).
- **Dirtiest 50%:** Cells between the 50th and 75th percentiles (1.71 to 2.15 × 10^{15} molecules/cm^2).
- **Cleaner 50%:** Cells with NO_2 values below the 50th percentile (0.58 to 1.71 × 10^{15} molecules/cm^2).

Figure 4:

Dot plot visualizing the relative exposure disparity in NO_2 concentrations among people of color (blue dots) and non-Hispanic white populations (white dots) across 13 U.S. counties. The horizontal axis represents the percentage difference in exposure compared to the county average, with negative values indicating lower-than-average exposure and positive values indicating higher-than-average exposure.

- The 13 counties are among the 25 most polluted counties for NO_2 as measured by both satellite data and by ground-level monitors, with the exception of Essex County, NJ which is unmonitored.
- Satellite-Derived NO_2 Concentrations (2020–2022): Satellite data from the TROPOMI instrument was processed to estimate average NO_2 exposure at the census tract level.
- Demographic Data: Census tract population demographics were obtained from the American Community Survey (ACS) to calculate population-weighted exposure levels for different racial and ethnic groups.
- (See Equity Metrics Calculations above)

Figure 5:

Visualized relative exposure disparities by census tract for Maricopa County, AZ; Orange County, CA; Essex County, NJ; and Cook County, IL. Overlaid NO_2 concentrations with demographic data to highlight intra-county pollution disparities.

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Something in the Air

Nitrogen Dioxide and Community Health

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