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The Impact of Urban Air Pollution on Public Health and Environmental Inequality: Evidence from Major U.S. Cities

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Abstract: Exposure to air pollution and the associated health burdens in major U.S. cities present a differentiated structure that cannot be explained by a single income gradient. Nationwide, approximately 170,000 deaths per year are attributed to NO_2 exposure, with non-Hispanic Black populations experiencing about 47% higher attributable mortality rates than the national average. Paradoxically, NO_2 concentrations are higher in high-income counties, and racial disparities in exposure persist within every income group, indicating that class and race are not interchangeable explanatory variables. Data from the 2024 Air Quality Report further quantify this rupture: people of color represent 41.6% of the U.S. population but account for 52% of residents in counties failing at least one air quality metric; in counties failing all three metrics, they represent 63%. This distribution pattern is not a product of pollution randomly settling, but rather the ongoing operation in contemporary urban fabrics of spatial hierarchies encoded by 20th-century redlining policies. Longitudinal studies in Boston, Nashville, and Detroit find that historically redlined census tracts still have higher proportions of Black residents, higher poverty rates, and greater social vulnerability indices; NO_2 exposure disparities persist in Boston and have even widened in Nashville. This article focuses on major U.S. cities to examine the group distribution characteristics of health burdens from urban air pollution, trace the historical and structural mechanisms of environmental inequality, and assess the capabilities and limitations of current exposure assessment methods and policy instruments in identifying and rectifying these inequalities.

U.S. urban air quality has substantially improved over the past half-century, but these improvements have not been equitably distributed among social groups. An analysis in the Detroit urban area shows that current exposure levels of PM2.5, ozone, SO_2, and NO_2 cause more than 100,000 disability-adjusted life years lost annually and about $6.5 billion in monetized health impacts, with PM2.5 and ozone driving 660 premature deaths each year; NO_2 exposure contributes to 46% of asthma hospitalizations linked to air pollution [1]. These aggregate figures do not directly point to inequality, but when stratified by race and income, a stable pattern emerges: minority groups and low-income communities bear systemic excess burdens that cannot be simply attributed to the intuitive notion that “the poor live in more polluted areas.” High-income counties exhibit higher NO_2

concentrations than low-income counties, yet minorities within high-income counties still endure greater exposure and vulnerability, contradicting the intuition that the poor solely reside in polluted places [2]. Urban air pollution inequality is embedded in spatial and social structures more complex than income alone.

Existing research has amassed substantial evidence at the levels of single pollutants, single cities, or single health endpoints, but few have integrated these dispersed findings into an analysis of the production mechanism of urban environmental inequality. The analysis proceeds along three interrelated levels: the distribution patterns of health burdens by race and class; the historical spatial mechanisms forming and maintaining these patterns, particularly the long-term legacy of redlining policies; and the structural limitations of current exposure assessment paradigms and policy interventions in capturing and correcting inequalities [3]. Data from major cities including Los Angeles, Houston, Chicago, Boston, Detroit, and New York alternate throughout to portray a picture of both national contours and local heterogeneity.

1. Group Differentiation of Urban Air Pollution Health Burdens

(1) Racial and Income Differences in Exposure Levels

The health hazards of urban air pollution do not impact all residents equally. Nationwide TROPOMI NO_2 inversion analysis reveals widespread racial, ethnic, and income disparities, which become even more pronounced on the worst pollution days, indicating that vulnerable groups face steeper incremental exposures when air quality deteriorates. Low-income census tracts inhabited by non-white and Hispanic residents exhibit NO_2 concentrations 37% ± 6% higher than high-income white tracts; by race alone, NO_2 disparities range from 11% to 32%, and by poverty status from 15% to 28%. Analysis in Los Angeles County also shows that low-income communities of color have significantly higher asthma emergency visit rates, with PM2.5 contributing to neighborhood asthma risk. Chicago data demonstrate a different spatial logic: Hispanic/Latino populations make up 50% of the population in the most PM2.5-polluted areas but only 30% of the city's population, although differences in PM2.5 concentrations among racial groups in Chicago are not as large as in Los Angeles or Phoenix [4]. This indicates exposure inequality can be realized either through concentration differences or through the spatial concentration of vulnerable populations in moderately polluted areas.

(2) Differentiation in Susceptibility and Health Outcomes

The second dimension of differentiation is susceptibility, i.e., group differences in the probability of adverse health outcomes at the same exposure level. An analysis of NO_2-attributable mortality considering both exposure and susceptibility shows that among most causes of death, minorities have higher relative risks than other groups, with the magnitude of excess risk varying by cause of death and income tier; in low-income counties, non-Hispanic Blacks bear the greatest overall mortality burden, whereas in high-income counties, the most affected racial-ethnic group varies by county [5]. This finding has important methodological implications: "minorities" is not a homogeneous category uniformly bearing pollution burdens everywhere; local racial composition, industrial layout, and residential segregation patterns collectively shape specific inequality forms. Environmental inequality research on cancer risk also supports this, demonstrating nationwide that in census tracts with the highest estimated cancer risk, Black and Hispanic residents constitute a much larger share than White residents, with the correlation between racial composition and inequality stronger than that with income or education level; however, these racial differences are not uniformly present in rural and suburban areas, where predominantly White communities bear higher cancer risk burdens. In other words, urban environmental inequality has a particular structure not readily generalizable by the simplistic narrative of "minorities suffer more."

(3) Differentiation by Emission Source Type and Burden Allocation

Detroit studies integrate exposure, susceptibility, and baseline health rates into a burden attribution framework, showing how different emission sources bear health costs differently. Industrial and traffic emissions are primary sources of health burden inequality; the excess burden borne by Hispanic/Latino groups is mainly due to industrial emissions, whereas traffic emissions predominantly drive the excess burden for low-income groups. Evidence from Houston echoes this: communities around the Valero refinery are 86% people of color and 21% below the poverty line, enduring a "double jeopardy" of health impacts from toxic air pollution and safety threats compared to predominantly White, affluent neighborhoods in West Houston. The core lesson is that inequality cannot be simply reduced to spatial distribution of a single pollutant—different emission sources, pollutants, and vulnerability dimensions intertwine within urban space, creating highly contextualized burden allocations [6].

2. Historical Roots and Spatial Mechanisms of Environmental Inequality

(1) The Spatial Legacy of Redlining Policies

Attributing contemporary urban air pollution inequalities entirely to current market processes or individual residential choices overlooks a decisively consequential historical level. In the 1930s, the Home Owners' Loan Corporation (HOLC) used racial composition as a key criterion to rank urban communities into four grades—best, still desirable, definitely declining, and hazardous—with the latter marked in red, hence "redlining." This federal-level mapping did not merely reflect existing residential conditions but linked mortgage qualification to neighborhood racial composition, systematically depriving redlined communities of the ability to accumulate housing wealth and improve built environments, thus cementing spatial hierarchies [7].

Although the 1968 Fair Housing Act legally prohibited such discrimination, its spatial consequences persist in forms of neighborhood segregation, homeownership gaps, resource scarcity, and concentrated environmental burdens. A longitudinal analysis of Boston, Nashville, and Detroit assigns precise quantified evidence to this legacy: from 2000 to 2016, these cities' redlined areas consistently show higher proportions of Black residents, poverty rates, lower incomes and housing values, and greater social vulnerability indices. Air quality generally improved during this period; however, NO_2 exposure disparity trajectories vary across cities—Boston's redline-associated disparities persist, Nashville's have expanded, while in Detroit, by 2016, NO_2 levels across historical redline zones have largely converged. Detroit's exception is theoretically valuable, showing the redlining spatial imprint is not immutable; post-industrial economic decline, deindustrialization, and population loss can, in some cases, decouple pollution and historic hierarchy. Yet Boston and Nashville's persistence suggest that without targeted intervention, historic spatial inequities self-reproduce [8]. Research in New York City supplements this image from birth outcome perspectives: residing in historically redlined or ungraded census tracts correlates with elevated prenatal PM2.5 exposure and reduced birthweight z-scores, associations remaining significant even after adjusting for individual and tract-level race, ethnicity, and income.

(2) Reproduction Mechanisms in Contemporary Land Use and Housing Markets

Redlining policies do not exist in isolation as institutional devices; they operate cumulatively with contemporary land use decisions, industrial siting and zoning, transportation infrastructure layouts, and spatial variations in law enforcement intensity to form an additive environmental inequality production system. In Chicago, this system operates such that the population composition in most polluted areas is predominantly Latino, not because Latino families chose these areas but because affordable housing availability, discriminatory real estate practices, and industrial zoning converge spatially, rendering these communities the actual housing market options accessible to low-income

people of color. Houston's lack of zoning regulation allows industrial facilities to embed closer to residential areas, and the Texas Supreme Court's invalidation of local air quality ordinances further undermines urban-level spatial constraints on emission sources. Environmental inequality is not a natural byproduct of pollutant physical dispersion patterns but is jointly produced by historical institutional layers, contemporary governance structures, and housing market dynamics as a spatial order [9].

(3) Inter-City Differences and Institutional Conditions

Comparisons across three cities reveal that local institutional conditions modulate the strength of historical legacies. Detroit's convergence trajectory links to the city's large-scale population loss and industrial contraction; the spatial distribution of pollution sources has been reorganized by dramatic economic restructuring, partly decoupling historical redlining grades from contemporary emissions patterns. Nashville's widening disparities correlate with land use decisions during economic growth periods; rapidly increasing housing demand coupled with relatively relaxed environmental reviews resulted in historically disadvantaged areas bearing new transportation and construction emissions. Boston's persistence reflects another relatively common pattern: historic redlined neighborhoods have long been designated as low-income rental housing markets; aging building stock and proximity to major roadways maintain higher exposure levels in these communities despite overall regional air quality improvements. These differences show that the long-term effects of redlining are not immutable constants but variables modulated by subsequent land use regimes, economic development trajectories, and environmental enforcement capacity [10].

3. Blind Spots in Exposure Assessment and Limits of Policy Intervention

(1) Limitations of the Residential Location Paradigm and Mobility Exposure

Because urban air pollution health inequality is largely driven by historic spatial hierarchies and structural vulnerabilities, policies and evaluative tools aimed at rectifying these inequities must be capable of identifying such mechanisms. Yet prevailing exposure assessment paradigms and regulatory frameworks exhibit systematic blind spots for this task. Traditional exposure estimates are residence-based, assuming individuals spend most of their day within their census tract or surrounding residence area, simplifying exposure as a static spatial attribute. Boston research directly challenges this assumption: integrating 155,000 smartphone GPS travel trajectories with high-resolution PM2.5 monitoring data leads to the conclusion that mobility-based exposure estimates average 0.10 μg/m³ higher than residence-based estimates on weekdays, rising to 0.45 μg/m³ on heavily polluted days [11]. More notably, this underestimation is uneven across groups; employed persons, high-income individuals, and Whites experience considerably larger exposure increments during peak commuting periods, up to 0.30 μg/m³. This finding does not negate residential exposure inequality but reveals a more complex picture: urban air pollution inequality operates along both residential and daily activity spatial axes; focusing on only one systematically misrepresents inequality's form and magnitude.

(2) Differential Effects of Regulatory Interventions

Policy interventions reveal differentiated effects, showing inequality does not naturally disappear with overall air quality improvements. A nationwide census tract-level analysis of cancer risks from 2011 to 2019 found racial disparities peaked in 2011 then narrowed, interpreted as evidence that toxic air pollutant control measures are effective; however, disparities borne by low-income communities remained stable throughout without comparable convergence.

In other words, overall gains produced by regulation yielded partial equalization along racial dimensions but stagnation in income dimensions. One possible explanation for this asymmetry is that technical controls targeting a specific pollutant or source type are relatively easier to implement,

whereas exposure pathways highly coupled with poverty and residential segregation—such as indoor-outdoor infiltration in aging housing, persistent emissions along traffic corridors, lack of air conditioning and filtration in housing stocks—are not encompassed by traditional air quality regulatory scopes. Chicago simulation studies also found a paradox: emission reductions focused solely in high-pollution areas led to the largest exposure declines for Hispanic/Latino populations (17%-19%) but the smallest declines for Blacks (8%-9%), thus enlarging relative exposure and mortality inequalities. Without forecasting group distribution effects, targeted governance designs may simultaneously improve totals but exacerbate relative inequities.

(3) Capacities and Boundaries of Local Policy Innovations

The timeline for integrating environmental justice considerations into PM2.5 regulation at the federal level itself warrants scrutiny. A review of the PM2.5 regulatory process since 1997 shows systemic environmental justice consideration emerged only after 2012 and that 2024 policy adjustments still do not fully incorporate child health effects into environmental justice frameworks. New York State's cumulative impact law effective December 2024 addresses overlapping environmental burdens during permitting and review stages; California's CalEnviroScreen synthesizes pollution, population vulnerability, and socioeconomic stress into a spatial screening index used to direct regulatory resources and community investments. These local innovations conceptually acknowledge the multifaceted nature of environmental inequality; however, their efficacy depends on two conditions: first, whether data infrastructures can capture mobility and cumulative exposure with adequate spatial and temporal resolution; second, whether regulatory authority can cover emission pathways beyond traditional stationary source permitting frameworks. Houston illustrates that when local spatial constraints are limited by state-level legal structures, urban willingness to correct inequality often lacks policy leverage to reach the spatial roots of emissions.

4. Conclusion

Understanding urban air pollution in major U.S. cities as an environmental inequality issue entails acknowledging that the pollution distribution itself expresses social structure. The counterintuitive finding that NO_2 concentrations are higher in high-income counties, the persistence of racial disparities within income groups, and exposure inequality differentiation between residential and mobility spaces collectively reject simplistic linear narratives attributing inequality solely to poverty causing exposure. The spatial hierarchy encoded by redlining policies retains explanatory power over NO_2 exposure disparities against the backdrop of overall air quality improvements, its intensity varying by city but signifying a historical institutional inertia exceeding normal policy cycles. Current evaluation systems and regulatory modes that rely on residence-based metrics and pollutant totals possess structural deficiencies in identifying these mechanisms. Boston's mobility data and Chicago's targeted governance simulations show that focusing solely on pollution distribution without considering spatial dynamics of exposure and group distribution effects leads to policies that succeed in improving totals but produce unintended fairness outcomes. To genuinely address the coupling between public health and environmental inequality, urban air pollution governance must shift evaluation tools, regulatory targets, and investment decisions from "where pollution is" to "how burdens are distributed, who bears them, and by what spatial mechanisms they are produced."

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