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# Impact of COVID-19 Lockdowns from 2019 to 2021 on Air Pollution and Ischemic Heart Disease

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## ABSTRACT

Background: The COVID-19 lockdown led to reduced human activities and emissions, improving urban air quality. Studies have linked air pollution to increased risk of cardiovascular disease (CVD). Epidemiological studies have shown an association of ambient air with increased risk of cardiovascular disease mortality and morbidity. This study examines the effect of reduced vehicle movement and improved air quality on ischemic heart disease (IHD) emergency department (ED) visits in Tbilisi, Georgia.

Objectives: To assess the short-term effects of exposure to fine particulate matter ($PM_{2.5}$, $PM_{10}$), nitrogen dioxide ($NO_2$), sulfur dioxide ($SO_2$), and carbon monoxide (CO) on IHD (ICD10 codes: I20, I21) during the 2020 lockdown, compared with the same periods in 2019 and 2021.

Methods: This retrospective study analyzed ED visits for IHD (ICD-10 codes: I20, I21) and ambient air pollution data in Tbilisi, Georgia. The lockdown period (March 21-May 22, 2020) was compared to the same periods in 2019 and 2021 using a 7-day moving average and t-tests to assess mean differences.

Results: A total of 5,694 IHD cases were recorded across all years - 42.8% in 2019, 26.2% in 2020, and 31% in 2021. In 2020, compared to 2019, there were significant reductions in CO and $SO_2$ levels and in 7-day average hospital admissions (mean difference 15.49, 95% CI (13.41-17.58)). In 2021, air pollution levels and hospital admissions increased compared to 2020.

Conclusions: The decline in CO and $SO_2$ during the 2020 lockdown coincided with a reduction in IHD admissions, although the difference was not statistically significant. In 2021, pollution levels and admissions rose, suggesting a link between air quality and cardiovascular health, highlighting the potential public health benefits of improved air quality.

Keywords: Air pollution; COVID-19 lockdown; health risks; ischemic heart disease; Tbilisi.

## BACKGROUND

Air pollution is a leading environmental health risk, responsible for an estimated 6.7 million premature deaths annually.[1] Major anthropogenic sources, such as road traffic, fossil-fuel combustion, and household activities, contribute substantially to outdoor air pollution in urban settings.

Both short- and long-term exposure to fine particulate matter ($PM_{2.5}$) are associated with adverse health outcomes, including respiratory and cardiovascular morbidity, increased hospitalizations, and elevated mortality risk,[2-4] with long-term exposure linked to a 10-11% increase in cardiovascular deaths[5,6] and short-term exposure associated with a 0.84% rise in acute events.[7] Exposure has also been implicated in myocardial infarction, stroke, hypertension, and atherosclerosis.[8]

Since December 2019, the SARS-CoV-2 virus has spread all over the world, has infected more than 760 million people, and killed more than 6.9 million people worldwide.[9] On March 11, 2020, the WHO declared COVID-19 a pandemic,[10] and since then, it has caused enormous economic, public health, and social damage worldwide.[11,12] In response, the government enacted wide-ranging public health measures, including lockdowns, travel bans, social distancing, bans on public gatherings, and institutional closures, that significantly reduced human mobility and industrial activity. These interventions contributed to short-term improvements in air quality in many urban centers.[13-15]

Several cities worldwide experienced significant reductions in major pollutants during lockdowns. For example, $PM_{2.5}$ decreased by approximately 12% across the most polluted cities worldwide, with the largest reductions in the capitals of America, Africa, and Asia.[16] In major cities like New York City and Delhi, $PM_{2.5}$ levels dropped by 35-40%,[17] while in Mexico City, CO concentration decreased by 40% and $NO_2$ concentration in London by 49%.[18] However, these improvements were temporary, as air pollution levels rebounded once restrictions were lifted. In Georgia, the government declared a national emergency on March 21, 2020, instituting mobility restrictions, closing institutions, and enforcing remote work and public health campaigns.[19] These actions played a crucial role in curbing the spread of the virus and safeguarding public health, and they also impacted air quality by reducing unnecessary energy consumption and transportation. However, the health implications of this temporary improvement in air quality remain underexplored.

This study investigates changes in ambient air pollution levels and potential short-term impacts on ischemic heart disease hospitalizations during the COVID-19 lockdown in Tbilisi. Specifically, we compare air pollution concentrations and emergency department visits for IHD (ICD10: I20, I21) during the lockdown period (March 21-May 22, 2020) with the


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same timeframes in 2019 and 2021. The study aims to answer two questions: (i) To what extent did outdoor air pollution decline in Tbilisi during the 2020 lockdown compared to adjacent years? (ii) Was this reduction in air pollution associated with a decrease in hospitalizations for ischemic heart disease?

## METHODS

### Selection of study area

This retrospective study focuses on Tbilisi, Georgia's capital. High pollution levels, mainly from traffic congestion and industrial emissions, pose a major concern, especially in urban centers like Tbilisi, where the impact is more severe than in suburban areas.[20] The largest city, accommodating over 30% of the country's population. It is in the southeastern part of the country, nestled in a valley along the Mtkvari River. City experiences a humid subtropical climate with continental influences, characterized by hot, dry summers and mild winters with occasional snowfall.[21] The city's geography contributes to the accumulation of air pollution, particularly in colder months. Its geographical position and weather patterns make it an important area for studying variations in air quality and their potential impact on public health.

Tbilisi was selected based on its air quality monitoring network, large population, and strict COVID-19 lockdown measures. The lockdown period (March 21-May 22, 2020) led to substantial reductions in mobility and industrial activity, providing a natural experiment for assessing air pollution and health outcomes.

### Study period

We examined daily air pollution levels and emergency department (ED) visits for ischemic heart disease (ICD-10: I20, I25) between March 21 and May 22 over three consecutive years: 2019 (pre-lockdown period), 2020 (lockdown period), and 2021 (post-lockdown period). The year 2020 was defined as the exposure year of interest, while 2019 and 2021 served as comparison periods.

### Air quality data

Air quality data were obtained from the Air Quality Portal (https://air.gov.ge/en/), the official website of the National Environmental Agency of Georgia, which publishes data from all nationwide monitoring stations. Tbilisi air quality data included daily average concentrations of ambient particulate matter ($PM_{2.5}$, $PM_{10}$), nitrogen dioxide, ozone, sulfur dioxide, and Carbon monoxide from automatic monitoring stations. There are four automatic air quality monitoring stations in Tbilisi, all classified as traffic-oriented due to their proximity to major roads and high vehicular density. While these stations effectively capture traffic-related emissions, they may overestimate localized pollutant concentrations and may not accurately reflect ambient exposure for the general population. To minimize this potential bias, data for the present study were obtained from the Varketili station, located in a predominantly residential area with comparatively moderate vehicular flow. This site was selected for its capacity to provide a more representative measure of background urban air quality and to reduce the influence of transient roadside pollution peaks, thereby offering a more stable indicator of population-level exposure.

### Health data

We obtained patient-level Emergency Department visit data on ischemic heart disease from the National Center for Disease Control and the Public Health of Georgia. ED visits were included if they met the following criteria: 1) diagnosis with ICD-10 codes I20 or I25; 2) admission between March 21 and May 22 in 2019, 2020, or 2021; and 3) residence in Tbilisi. Exclusion included incomplete records. A total of 5,694 eligible ED visits were analyzed.

### Statistical analysis

The year 2020, which corresponds to the COVID-19 lockdown period in Georgia, was treated as the reference year for all comparisons. Environmental exposure data and hospital admission counts from 2019 and 2021 were compared to the corresponding period in 2020 (March 21-May 22) to assess both pre- and post-lockdown trends.

We first conducted descriptive statistical analyses to summarize the distribution of key variables. For each air pollutant ($PM_{2.5}$, $PM_{10}$, $NO_2$, $SO_2$, and CO), we calculated daily mean concentrations, standard deviations (SD), and medians with interquartile ranges (IQR). Similarly, the distribution of emergency department (ED) visits for ischemic heart disease (IHD) was summarized using frequency counts and proportions. All analyses were stratified by year to allow temporal comparisons.

To examine the short-term impacts of the lockdown, we conducted an episode analysis, comparing the number of IHD-related ED visits during the 2020 lockdown with those in the same calendar period in 2019 and 2021. A 7-day moving average was applied to smooth daily fluctuations in both hospital admission and pollutant concentration data. Differences in mean pollutant levels and hospital admissions across years were tested using independent two-sample t-tests.

To explore the association between changes in environmental exposure and hospital admissions, we calculated daily differences in pollutant concentrations and 7-day average IHD admissions for two comparisons: 2019 vs. 2020 and 2020 vs. 2021. Each air pollutant was modeled as a continuous independent variable (entered linearly) in univariate linear regression models, with the 7-day moving average of hospital admissions as the dependent variable. The resulting coefficients represent the estimated change in average daily IHD admissions associated with a one-unit increase in each pollutant (ppm). All statistical analyses were conducted using STATA software. A p-value of $<0.05$ was considered statistically significant.


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## RESULTS

### Description of hospitalized cases

The data included 5,694 individuals, of whom 57% (n=3,263) were male, and 43% (n=2,431) were female. The mean age was 65 years (SD 12). The highest admission rate was observed in 2019 at 42.8% (n=2,434), which dropped to 26.2% (n=1,495) in 2020 before rising again to 31.0% (n=1,765) in 2021. Overall, 90.4% (n=5,147) of hospitalizations were urgent, while 9.6% (n=547) were planned. Notably, planned hospitalizations decreased from 10.52% (n=256) in 2019 to 7.49% (n=112) in 2020, then increased to 10.14% (n=179) in 2021. Conversely, urgent hospitalizations rose from 89.48% (n=2,178) in 2019 to 92.51% (n=1,383) in 2020, then decreased to 89.86% (n=1,586) in 2021 (Tab.1).

TABLE 1. Distribution of sex, age, and hospital admission with ischemic heart diseases by year

| | **Total** | **2019 (March 21st - May 22nd)** | **2020 (March 21st - May 22nd)** | **2021 (March 21st - May 22nd)** |
|---|---|---|---|---|
| Frequency of admissions n (%) | 5,694 (100%) | 2,434 (42.8 %) | 1,495 (26.2 %) | 1,765 (31.0 %) |
| Mean age (Sd) | 65.0 (12.1) | 64.9 (12.3) | 64.7 (12.2) | 65.3 (11.7) |
| Male, n (%) | 3,263 (57.31%) | 1,372 (56.37%) | 875 (58.53%) | 1,016 (57.56%) |
| Female, n (%) | 2,431 (42.69%) | 1,062 (43.63%) | 620 (41.47%) | 749 (42.44%) |
| Urgent hospitalization, n (%) | 5,147 (90.39%) | 2,178 (89.48%) | 1,383 (92.51%) | 1,586 (89.86%) |
| Planned hospitalization n (%) | 547 (9.61%) | 256 (10.52%) | 112 (7.49%) | 179 (10.14%) |
| I20.0. Unstable angina, n (%) | 3,703 (65.03%) | 1,656 (68.04%) | 919 (61.47%) | 1,128 (63.91%) |
| I20.8. Other forms f angina pectoris, n (%) | 395 (6.94%) | 177 (7.27%) | 78 (5.22%) | 140 (7.93%) |
| I21.0. Acute transmural myocardial infarction of anterior wall, n (%) | 286 (5.02%) | 106 (4.35%) | 88 (5.89%) | 92 (5.21%) |
| I21.1. Acute transmural myocardial infarction of inferior wall, n (%) | 259 (4.55%) | 101 (4.15%) | 72 (4.82%) | 86 (4.87%) |
| I21.4. Acute subendocardial myocardial infarction, n (%) | 805 (14.14%) | 308 (12.65%) | 235 (15.72%) | 262 (14.84%) |

The most common cause of admission was unstable angina, accounting for 65% (n=3,703) of cases, followed by acute sub-endocardial myocardial infarction at 14.1% (n=805) and other forms of angina pectoris at 6.9% (n=395). All other causes of admission were 5% or less (Tab.1). 7-day-average hospital admissions decreased significantly in 2020 and increased again in 2021 (Tab.2).

TABLE 2. Changes in mean daily air pollutant concentrations (2019-2021)

| | **2020 vs 2019** | | | **2021 vs 2020** | | |
|---|---|---|---|---|---|---|
| | **Mean diff.** | **95%CI of difference** | **P value** | **Mean diff.** | **95% CI of difference** | **P value** |
| $NO_2$, µg/m³ | -0.15↑ | (-0.69) - 0.40 | 0.594 | 3.61 | 3.21 - 4.02 | <0.001↓ |
| $SO_2$, µg/m³ | 2.00↓ | 1.1 - 2.9 | <0.001 | -0.78 | (-1.31) - (-0.25) | 0.004↑ |
| $PM_{2.5}$, µg/m³ | 0.79↓ | (-1.15) - 2.72 | 0.422 | -2.89 | (-4.85) - (-0.92) | 0.004↑ |
| $PM_{10}$, µg/m³ | 3.48↓ | (-1.2) - 8.2 | 0.147 | -9.17 | (-14.11) - (-4.22) | <0.001↑ |
| CO, µg/m³ | 0.21↓ | 0.14 - 0.28 | <0.001 | -0.11 | (-0.16) - (0.06) | <0.001↑ |
| 7-day average admissions | 15.49↓ | 13.41 - 17.58 | <0.001 | (-4.8) | (-6.67) - (-2.99) | <0.001↑ |

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### Description of air pollution

The mean air concentrations of $SO_2$, $PM_{2.5}$, $PM_{10}$, and CO followed similar patterns: decreasing in 2020 compared to 2019, then increasing again in 2021. Notably, $NO_2$ levels did not follow this trend and did not decrease in 2020; however, they decreased sharply in 2021 from 4.5 µg/m³ to 0.9 µg/m³. The fluctuation in mean air pollutant concentrations from 2019 to 2021 was statistically significant only for $SO_2$ and CO. For the other pollutants, statistically significant changes were observed only between 2020 and 2021 (Tab.2 and Tab.3).

TABLE 3. Daily concentration (µg/m³) of air pollutants (2019-2021)

| | 2019 (March 21st - May 22nd) | | | | 2020 (March 21st - May 22nd) | | | | 2021 (March 21st - May 22nd) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Min | Max | Mean (Sd) | Median | Min | Max | Mean (Sd) | Median | Min | Max | Mean (Sd) | Median |
| $NO_2$, µg/m³ | 2.1 | 8.9 | 4.4 (1.4) | 4.3 | 2.1 | 8.0 | 4.5 (1.6) | 4.2 | 0.4 | 1.5 | 0.9 (0.2) | 0.9 |
| $SO_2$, µg/m³ | 3.3 | 17.5 | 7.0 (3.1) | 6.2 | 2.5 | 9.2 | 5.0 (1.6) | 4.8 | 3.0 | 12.4 | 5.8 (1.3) | 5.9 |
| $PM_{2.5}$, µg/m³ | 3.4 | 22.4 | 12.5 (5.2) | 12.5 | 3.3 | 30.1 | 11.7 (5.3) | 10.9 | 5.2 | 30.5 | 14.6 (5.5) | 13.8 |
| $PM_{10}$, µg/m³ | 9.0 | 60.8 | 26.6 (12.0) | 26.6 | 5.0 | 84.4 | 23.2 (13.6) | 19.6 | 11.0 | 90.9 | 32.3 (13.8) | 30.0 |
| CO, µg/m³ | 0.3 | 1.3 | 0.6 (0.3) | 0.6 | 0.2 | 0.8 | 0.4 (0.1) | 0.4 | 0.2 | 1.1 | 0.5 (0.2) | 0.5 |

### Univariable analysis

Univariable analysis revealed statistically significant associations between carbon monoxide (CO) and nitrogen dioxide ($NO_2$) concentrations with hospital admissions. Specifically, a one-unit increase in CO concentration was associated with an increase of 12.54 hospital admissions (95% CI: 6.95-18.14). Similarly, a one-unit increase in $NO_2$ concentration was associated with an increase of 0.63 hospital admissions (95% CI: 0.05-1.22).

### Changes from 2019 to 2020

Our analysis indicated that decreases in $PM_{2.5}$, $PM_{10}$, or CO concentrations from 2019 to 2020 did not correspond with a reduction in 7-day average hospital admissions. However, reductions in $NO_2$ and $SO_2$ concentrations during the same period showed a borderline significant association with decreases in the 7-day average of hospital admissions (Tab.4).

TABLE 4. Univariable analysis of 7-day average hospital admission and air pollution changes (2019 vs. 2020)

| | Coefficient | p-value | 95% CI |
|---|---|---|---|
| $NO_2$ | 0.67 | 0.07 | (-0.06)-1.41 |
| $SO_2$ | -0.40 | 0.08 | (-0.85)-0.54 |
| $PM_{2.5}$ | 0.04 | 0.66 | (-0.15)-0.25 |
| $PM_{10}$ | 0.03 | 0.48 | (-0.05)-0.12 |
| CO | 1.02 | 0.76 | (-4.77)-(6.81) |

*Note: Results are based on univariable linear regression models, with each air pollutant entered as a continuous predictor and 7-day average hospital admissions as the dependent variable.*

### Changes from 2020 to 2021

Conversely, the increases in CO and $NO_2$ concentrations from 2020 to 2021 were significantly associated with increases in 7-day average hospital admissions, by 15.28 and 1.39 admissions, respectively. Notably, a one-unit increase in $SO_2$ concentration during this period was negatively associated with hospital admissions, leading to a decrease of 0.81 admissions (Tab.5). The table values represent 5,448 of 5,694 total IHD admissions; rare diagnostic codes were excluded for conciseness.

TABLE 5. Univariable analysis of 7-day average hospital admission and air pollution changes (2020 vs 2021)

| | Coefficient | p-value | 95% CI |
|---|---|---|---|
| $NO_2$ | 1.39 | 0.01 | 0.31-2.47 |
| $SO_2$ | -0.81 | 0.02 | (-1.48)-(0.12) |
| $PM_{2.5}$ | 0.17 | 0.13 | (-0.05)-0.39 |
| $PM_{10}$ | 0.06 | 0.14 | (-0.02)-0.15 |
| CO | 15.28 | 0.00 | (6.45)-24.1 |

*Note: Results are based on univariable linear regression models, with each air pollutant entered as a continuous predictor and 7-day average hospital admissions as the dependent variable.*

## DISCUSSION

Our findings indicate that lockdown measures during the COVID-19 pandemic led to a significant reduction in ambient air pollution levels, particularly for $CO_2$ and $SO_2$, coinciding with a decline in ischemic heart disease (IHD) hospital admissions in Tbilisi. However, as normal activities resumed in 2021, air pollutant concentrations increased alongside a rise in IHD-related hospitalizations. Notably, while air pollution levels decreased in 2020, these reductions were not statistically associated with reductions in hospital admissions. Conversely, in 2021, increases in CO and $NO_2$ concentrations were significantly associated with higher admission rates, underscoring the adverse health implications of post-lockdown deterioration in air quality.

A significant reduction in hospital admissions for IHD was observed during the 2020 lockdown compared with 2019. While this decline paralleled improvements in air quality, particularly for CO and $SO_2$, the statistical analysis did not establish a robust association between these reductions and hospital admissions. In contrast, when air pollution levels increased in 2021, hospitalizations also rose, with CO and $NO_2$ concentrations showing significant positive associations with


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admissions. These findings suggest that while short-term improvements in air quality may not always yield immediate and measurable health benefits, deteriorating air quality, especially increased exposure to CO and $NO_2$, has a more direct and pronounced impact on cardiovascular health.

Our results align with global studies reporting improvements in air quality during COVID-19 lockdowns. Research conducted in major metropolitan areas such as New York, Delhi, and Beijing reported notable reductions in $PM_{2.5}$ levels (ranging from 30% to 40%), aligning with our observation in Tbilisi.[15,22,23] Additionally, previous studies have demonstrated that long-term exposure to fine particulate matter increases the risk of myocardial infarction and stroke.[24] While our findings suggest an association between fluctuations in air pollution and variations in IHD admissions, the relationship appears more complex, particularly regarding the effects of short-term reductions in pollution.

A meta-analysis by Niu et al. (2021) highlighted that temporary reductions in $PM_{2.5}$ and $NO_2$ levels were associated with decreased emergency hospital visits for cardiovascular diseases.[25] Our study partially supports these findings, as we observed a decline in IHD admissions during the lockdown period. However, the lack of a statistically significant association between reduced pollution levels and fewer admissions suggests that additional factors, such as healthcare access or behavioral changes during the pandemic, may have influenced hospitalization rates.

Notably, our findings differ from those of other studies regarding $NO_2$ concentrations. While many studies reported significant reductions in $NO_2$ levels during lockdowns, our analysis showed that $NO_2$ levels in Tbilisi remained relatively stable in 2020, then declined sharply in 2021. This discrepancy may be attributed to local variations in emission sources and meteorological conditions affecting pollutant dispersion. Research indicates that $NO_2$ reductions during lockdowns were more pronounced in areas with strict traffic restrictions, whereas cities with persistent industrial emissions experienced less dramatic declines.[26] This may explain why $NO_2$ levels in Tbilisi did not decrease substantially during the lockdown period.

Our findings contribute to the growing body of literature highlighting the health risks associated with air pollution, particularly in urban areas where traffic and industrial emissions are primary sources. While many studies emphasize the long-term effects of air pollution exposure, our results underscore the immediate consequences of deteriorating air quality. The strong association between increasing CO and $NO_2$ concentrations and rising IHD admissions suggests that these pollutants play a critical role in triggering acute cardiovascular events. Policymakers should prioritize sustained improvements in air quality through stricter emissions controls, particularly for pollutants such as CO and $NO_2$, which have been shown to have clear adverse effects on cardiovascular health.

Several limitations should be considered when interpreting these findings. First, this study is ecological in nature, meaning it relies on population-level data rather than individual exposure records. Consequently, we cannot establish a direct causal relationship between air pollution levels and hospital admissions. Future studies incorporating individual-level exposure assessments and personal health data could provide more precise estimates of these associations.

Additionally, changes in healthcare-seeking behavior during the pandemic may have influenced hospital admission rates independently of variations in air quality. Some individuals may have postponed seeking medical care due to lockdown restrictions, which could partially explain the decrease in hospitalizations observed in 2020. Further research is needed to assess the extent to which healthcare accessibility during public health crises affects hospitalization trends.

Furthermore, while our study focused on key pollutants ($NO_2$, $SO_2$, $PM_{2.5}$, $PM_{10}$, and CO), future research could expand the scope to include additional air pollutants, such as volatile organic compounds (VOCs) and ozone ($O_3$), to gain a more comprehensive understanding of the impact of air pollution on cardiovascular health.

Long-term studies are necessary to evaluate whether changes observed during the pandemic have had lasting effects on cardiovascular health outcomes. Investigating air pollution trends beyond 2021 could provide further insights into whether sustained reductions in pollution lead to measurable improvements in public health. Comparative studies across cities with similar lockdown measures could also help distinguish local from global pollution trends and their health implications.

## CONCLUSIONS

Our findings indicate that while hospital admissions significantly declined in 2020, coinciding with a reduction in air pollution levels, this decline was not statistically associated with decreases in $PM_{2.5}$, $PM_{10}$, or CO concentrations. However, reductions in $NO_2$ and $SO_2$ levels were associated with lower hospital admissions, though the association was borderline significant, suggesting a potential but inconclusive link.

Conversely, as air pollution levels increased again in 2021, hospital admissions also rose. Notably, increases in CO and $NO_2$ concentrations were significantly associated with higher admission rates, reinforcing the established relationship between air quality deterioration and adverse cardiovascular health outcomes. Interestingly, a rise in $SO_2$ levels during this period was inversely associated with hospital admissions, warranting further investigation into its potential mitigating effects or confounding factors.

These findings suggest that while short-term reductions in air pollution may not always yield immediate, measurable declines in hospitalizations, increases in specific pollutants, particularly CO and $NO_2$, are strongly and statistically significantly associated with elevated hospital admissions.


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Future research should examine the long-term health implications of fluctuations in pollution and identify critical exposure thresholds beyond which improvements in air quality may yield tangible health benefits. A deeper understanding of these dynamics is essential for informing public health policies to mitigate cardiovascular risks associated with air pollution.

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