Asian Journal of Water, Environment and Pollution. Vol. 22, No. 3 (2025), pp. 198-210.
doi: 10.36922/AJWEP025130088

ORIGINAL RESEARCH ARTICLE

The effects of urbanization on air pollution and public health in Vietnam: An empirical analysis

Duy Hung Bui[1] and Xuan-Hoa Nghiem[2]*

[1]Faculty of Economics, Banking Academy of Vietnam, Dong Da District, Hanoi, Vietnam
[2]Faculty of Economics and Management, International School, Vietnam National University, Hanoi, Vietnam
***Corresponding author:** Xuan-Hoa Nghiem (hoanx@vnu.edu.vn)

Received: March 25, 2025; Revised: May 29, 2025; Accepted: June 3, 2025; Published online: June 20, 2025

Abstract: Vietnam's rapid urbanization presents a critical challenge at the intersection of economic development and environmental health. This study examines the causal relationships between urbanization, air pollution, and public health outcomes across Vietnam's major urban centers. Using a comprehensive panel dataset spanning 2013 – 2022 for 10 Vietnamese cities, we employed instrumental variable (IV) techniques to address endogeneity concerns and establish robust causal inference. Our findings revealed that urbanization significantly exacerbates fine particulate matter ($PM_{2.5}$) air pollution levels, with each percentage point increase in urbanization rate associated with a 0.54 μg/m^3 rise in $PM_{2.5}$ concentration. Across IV analysis using industrial output share as an instrument, we demonstrated that $PM_{2.5}$ pollution substantially impacts respiratory health outcomes, with each 1 μg/m^3 increase leading to approximately 2.5 additional respiratory disease cases per 1,000 population. Environmental policies implemented across Vietnamese cities since 2017 have achieved modest but measurable success in mitigating pollution levels. These results underscore the urgent necessity for integrated sustainable urban planning and robust environmental governance to safeguard public health in Vietnam's rapidly transforming urban landscape.

Keywords: Urbanization; Air pollution; Public health; Instrumental variables; Vietnam; Environmental policy; $PM_{2.5}$; Respiratory disease

1. Introduction

The 21st century has witnessed unprecedented urbanization, particularly across developing nations where this demographic transformation represents both opportunity and challenge. Vietnam exemplifies this global trend, experiencing annual urban population growth of approximately 3% as the country undergoes rapid economic transformation. While urbanization drives economic development and poverty reduction, it simultaneously generates significant environmental and public health pressures, most notably through the deterioration of air quality.

Vietnam's urban air quality crisis has reached alarming proportions. Major cities, such as Hanoi and Ho Chi Minh City consistently rank among the world's most polluted urban centers. In 2023, Hanoi occupied the eighth position globally for air pollution severity; while Vietnam's national average $PM_{2.5}$ concentration reached 27.2 μg/m^3 in 2022 – nearly six times the World Health Organization's recommended guideline of 5 μg/m^3. According to WHO estimates, air pollution contributes to tens of thousands of pre-mature deaths annually across Vietnam, representing a substantial and growing public health burden.

Fine particulate matter ($PM_{2.5}$) emerges as the most concerning pollutant due to its widespread presence and established links to respiratory and cardiovascular diseases. In addition, nitrogen dioxide (NO_2) from vehicle emissions and power generation, along with sulfur dioxide (SO_2) from coal combustion and industrial processes, compound the urban health crisis. These pollutants frequently co-occur with $PM_{2.5}$, creating synergistic effects that amplify overall health risks.

The present research investigated the causal pathways linking urbanization, air pollution, and public health outcomes in Vietnam's major cities, advancing the existing literature through several key contributions. First, we provided country-specific empirical evidence from Vietnam, a rapidly developing Southeast Asian economy that has received limited attention in environmental health research despite its substantial pollution challenges. Second, by implementing instrumental variable (IV) methodologies, we moved beyond correlational analysis to establish robust causal relationships between urbanization processes, pollution levels, and health outcomes. Third, we evaluated the effectiveness of policy interventions, specifically Vietnam's National Action Plan on Air Quality Management launched in 2016 and subsequent municipal-level measures, in reducing pollution exposure and associated health risks.

Our findings offered crucial insights for policymakers not only in Vietnam but across developing countries grappling with the complex challenge of balancing urban growth with environmental protection. The analysis revealed both the magnitude of the present crisis and the potential for effective policy intervention to mitigate adverse health outcomes.

The paper proceeds as follows: Section 2 reviews relevant literature on urbanization-pollution-health relationships globally and in Vietnam; section 3 describes our data sources and econometric methodology; section 4 presents empirical results; section 5 discusses findings and policy implications; and section 6 concludes with recommendations for sustainable urban development.

2. Literature review

2.1. Global evidence on urbanization and air pollution

International research consistently demonstrates that rapid urban growth tends to elevate ambient pollution levels in the absence of strong environmental controls. This relationship has been documented across diverse geographic and economic contexts, though the magnitude and mechanisms vary considerably.

Chinese studies provide particularly relevant insights given similarities in development patterns. Wang *et al.*[1] analyzed data from 30 Chinese provinces between 2000 and 2016, finding that urbanization significantly increased $PM_{2.5}$ concentrations, with industrial structural changes mediating much of this effect. Their results suggested that every 10% increase in urbanization corresponds to approximately 5 – 8% higher $PM_{2.5}$ levels, though this relationship varies by region and development stage. A number of other studies in China also yielded the same results.[2-4] Additional investigations have also confirmed the importance of climate-resilient cities and urban planning in reducing air pollution in China.[5,6]

Similar patterns also emerge across other rapidly developing economies. In India, Mathew *et al.*[7] observed strong correlations between urban expansion and deteriorating air quality, particularly elevated particulate matter concentrations. Megacities, such as Dhaka, Bangladesh, and Jakarta, Indonesia exemplify this global challenge, ranking among the world's most polluted urban areas due to unconstrained urban growth combined with surging vehicle traffic and industrial emissions. On a larger scale, Bakry *et al.*[8] as well as Nghiem *et al.*[9] confirmed the benefits of information and communication technology (ICT) in improving environmental quality. Going into the underlying causes of emission, Bakry *et al.*[10] discovered that ICT adoption leads to reduced energy consumption, which, in turn, lowers emissions.

African urbanization presents an even more stark example of this challenge. Recent estimates suggested that over 80% of urban residents across Africa breathe air that has exceeded the WHO guidelines, indicating that pollution levels are directly linked to rapid, often unplanned, urban expansion. This pattern highlights how urbanization without adequate environmental planning consistently causes severe air quality degradation.

A comprehensive meta-analysis by Seto and Shepherd[11] examining 152 studies across 47 countries found that, on average, a 1% increase in urban population associates with approximately 0.5% higher $PM_{2.5}$ concentrations globally. However, they emphasize that this relationship depends critically on a city's development stage, infrastructure quality, and policy environment. In higher-income cities, advanced technology and pollution controls can substantially offset the negative effects of urban growth. Cui *et al.*,[12] Guo *et al.*,[13] and Nasreen *et al.*,[14] affirmed the decreasing (inhibiting) impact of different factors (the Russia-Ukraine war, financial development) on improving environmental quality in general, respectively. In another study, Bakry *et al.*[15] confirmed the reducing impact of digital finance on emission in a group of developing countries.

This variation points to the existence of an environmental Kuznets curve for air pollution, where pollution initially worsens with urbanization and industrialization but can improve beyond certain income thresholds as cleaner technologies become affordable and environmental regulations strengthen. Dong *et al.*,[16] using panel data from 126 countries, identified this inverted-U relationship between urbanization and $PM_{2.5}$, with urban agglomeration effects and technological progress helping reduce pollution at later development stages.

Several mechanisms explain how urbanization drives pollution increases. Urban concentration of people and economic activity intensifies energy consumption, vehicle use, and industrial output – all generating substantial emissions. Guan *et al.*[17] highlighted how urbanization typically increases fossil fuel consumption for electricity, heating, and industry, while simultaneously expanding transportation emissions as rural populations migrate to cities.

Importantly, urban form matters significantly for pollution outcomes. Chen *et al.*[18] demonstrated that densely populated, well-planned cities with mixed land use can achieve lower per capita emissions than sprawling, low-density urban areas. This suggests that compact growth combined with public transit can mitigate pollution, whereas urban sprawl tends to increase vehicle dependence and energy consumption.

2.2. Air pollution and public health

The health impacts of air pollution have been extensively documented through epidemiological research worldwide, with $PM_{2.5}$ showing particularly strong associations with adverse health outcomes across all age groups and health conditions.

A comprehensive review of 263 studies by Zhang *et al.*[19] confirmed robust associations between $PM_{2.5}$ exposure and increased risks of respiratory diseases, cardiovascular disorders, and pre-mature mortality. Pope III *et al.*[20] estimated that every 10 $\mu g/m^3$ increase in long-term $PM_{2.5}$ exposure associates with approximately 6% higher all-cause mortality globally, though this relationship appears non-linear with steeper slopes at higher pollution levels.

Health effects span both acute and chronic domains. Acute impacts include eye, nose, and throat irritation, asthma exacerbation, and increased hospital admissions for respiratory and cardiac conditions. Chronic outcomes encompass asthma development, chronic obstructive pulmonary disease, lung cancer, stroke, and heart disease, in addition to emerging evidence of impacts on neurological and reproductive health.

In developing countries where pollution levels frequently exceed WHO guidelines by substantial margins, the health burden becomes particularly severe. Apte *et al.*[21] found that health impacts per unit of pollution exposure were greater in highly polluted environments, suggesting non-linear dose-response relationships that amplify risks in contexts, such as Vietnam. The same research, focusing specifically on low- and middle-income countries, also identified stronger associations between air pollution and adverse health outcomes compared to high-income countries, potentially reflecting higher baseline pollution levels, greater population vulnerability, and limited healthcare access.[21]

Beyond $PM_{2.5}$, other urban pollutants pose significant health risks. Nitrogen dioxide (NO_2), primarily from vehicle engines and power generation, irritates lungs, aggravates asthma, and increases respiratory infection risk. Chronic NO_2 exposure associates with reduced lung function and contributes to secondary pollutant formation including ozone and nitrate particles. Epidemiological studies link long-term NO_2 exposure to elevated all-cause, cardiovascular, and respiratory mortality risks.

Sulfur dioxide (SO_2) from coal burning and industrial processes triggers bronchoconstriction and asthma attacks even at relatively low concentrations. Short-term SO_2 spikes correlate with increased hospital visits for respiratory and cardiac issues, while long-term exposure contributes to chronic respiratory illness and secondary particulate formation.

These pollutants often co-occur and may act synergistically. NO_2 and SO_2 can exacerbate $PM_{2.5}$ effects by injuring respiratory tissues and reducing physiological defenses. Ozone (O_3), a secondary pollutant forming from nitrogen oxides and volatile organic compounds under sunlight, causes respiratory inflammation and reduced lung function in urban areas.

2.3. Research on Vietnam

Research on air pollution and health in Vietnam has expanded considerably in recent years, though it remains limited compared to studies in China or India. Early Vietnamese studies were primarily descriptive, documenting pollution levels and basic health correlations.

Phung *et al.*[22] examined air pollution and hospital admissions in Ho Chi Minh City from 2010 to 2013, finding significant correlations between daily PM_{10} levels and respiratory hospital admissions. Hien *et al.*[23] analyzed air quality in Hanoi from 2016 to 2018, identifying traffic emissions and coal combustion as primary sources of particulate pollution. Nhung *et al.*[24] found that annual $PM_{2.5}$ concentrations in all studied provinces exceeded the limits set by the WHO Air Quality Guidelines and the Vietnamese Emission Standards (QCVN). These studies confirmed that Vietnam's urban pollution levels have frequently exceeded national standards and generated conspicuous short-term health impacts.

Several studies have linked Vietnam's rapid development to environmental degradation. By using satellite imagery, Nguyen *et al.*[25] documented the rapid expansion of built-up urban areas in major Vietnamese cities, which were accompanied by rising air pollutant concentrations. Tran and Nguyen[26] found that economic growth and industrialization were driving both urbanization and environmental decline, including higher emissions and water pollution, across Vietnam's cities.

More recent research has begun employing more sophisticated analytical methods. Vu *et al.*[27] investigated ambient air pollution impacts on hospital admissions for respiratory diseases among children in Hanoi, finding that days with higher $PM_{2.5}$ and NO_2 levels corresponded to increased pediatric hospitalizations for respiratory issues, even after controlling for weather and seasonal factors. While informative, such time-series analyses still face challenges in establishing causality due to potential confounding factors.

However, most Vietnam-specific studies to date have been correlational or descriptive, with few employing advanced causal inference methods. This represents a significant gap given the policy importance of understanding causal relationships between urbanization, pollution, and health outcomes in Vietnam's rapidly changing urban landscape.

2.4. Methodological approaches

Identifying causal relationships between urbanization, air pollution, and health outcomes presents substantial methodological challenges due to potential endogeneity, reverse causality, and omitted variable bias. Researchers have developed various approaches to address these analytical challenges.

Panel data methods have proven valuable for controlling time-invariant unobservable factors. Zhou *et al.*[28] employed fixed-effect models with city-level panel data in China to estimate urbanization impacts on $PM_{2.5}$ levels while controlling for economic factors and policy interventions. Difference-in-differences approaches have been used to evaluate specific policy impacts; for example, Greenstone and Hanna[29] applied this method to assess air pollution regulation effectiveness in India.

IV techniques have emerged as particularly valuable for establishing causality, though finding suitable instruments remains challenging. Appropriate instruments must influence the endogenous variable (*e.g.*, air pollution) while affecting the outcome (*e.g.*, health) only through the endogenous variable. Deryugina *et al.*[30] used wind direction as an instrument for air pollution to estimate causal effects on mortality in the United States, while Liu *et al.*[31] employed rainfall as an instrument for air pollution in studying recreational behavior impacts in Paris.

Our study addresses the methodological gap in Vietnam-specific research by applying panel data econometric techniques with city fixed effects and IVs to establish more robust causal links between urbanization, pollution, and health outcomes. By analyzing multiple cities over a decade, we can control for unobservable city-specific factors and common temporal shocks while leveraging industrial composition as an instrument for pollution levels.

3. Data and methodology

3.1. Data sources and description

In this study, we constructed a comprehensive panel dataset encompassing ten major Vietnamese cities observed annually from 2013 to 2022. The selected cities – Hanoi, Ho Chi Minh City, Haiphong, Da Nang, Can Tho, Bien Hoa, Hue, Nha Trang, Buon Ma Thuot, and Vinh – represent Vietnam's key urban centers across northern, central, and southern regions. This selection provides geographic diversity despite constraints in obtaining selected data, particularly for consistent air quality monitoring and health outcome reporting.

These cities collectively house over 30% of Vietnam's urban population and represent diverse economic profiles, from major metropolitan centers to secondary industrial cities. This diversity proves crucial for identifying causal relationships, as it provides variation in urbanization patterns, industrial composition, and policy implementation timelines.

Our dataset integrates multiple data sources to capture urbanization metrics, air pollution indicators, health outcomes, and control variables. Urbanization and economic indicators were sourced from Vietnam's General Statistics Office, which provides annual city-level data on population, urbanization rates, population density, and economic output by sector.

Air pollution data were compiled from monitoring stations operated by the Vietnam Environment Administration, supplemented with satellite-derived estimates for cities with limited ground monitoring coverage. We focused primarily on $PM_{2.5}$ concentrations as our main pollution indicator, while also collecting data on PM_{10}, NO_2, SO_2, and Air Quality Index (IQAir;[32] IQAir[33]) measures where available.

Health outcome data were obtained from the Ministry of Health and provincial health departments. Our primary health indicator is respiratory disease rates per 1,000 population, calculated from hospitalization and outpatient visit records. We also collected mortality rate data, though this proved less consistently available across all cities and years.

Control variables include GDP per capita, industrial output shares, weather variables (temperature, humidity, precipitation), and policy implementation indicators. The policy variable captures the implementation of Vietnam's National Action Plan on Air Quality Management and subsequent city-level environmental measures, coded as a binary indicator taking the value 1 for cities implementing substantial air quality policies after 2017.

The descriptive statistics reveal substantial variation across cities and time periods. $PM_{2.5}$ concentrations range from 23.4 $\mu g/m^3$ to 48.3 $\mu g/m^3$, with a mean of 33.45 $\mu g/m^3$ – well above WHO guidelines. Urbanization rates vary from 51.8% to 91.0%, reflecting differences between established metropolitan areas and emerging secondary cities. Respiratory disease rates show considerable variation, ranging from 116.9 to 178.7/1,000 population, suggesting significant differences in health outcomes across urban areas.

3.2. Econometric framework

To address our research questions systematically, we employed a two-stage analytical approach. First, we examine the effect of urbanization on air pollution using panel data methods. Second, we assessed the causal impact of air pollution on public health outcomes using IV techniques to address endogeneity concerns.

3.2.1. Urbanization and air pollution

We began by estimating the relationship between urbanization and air pollution using the following specification:

$$PM2.5_{it} = \beta_0 + \beta_1 UrbanizationRate_{it} + \beta_2 X_{it} + \alpha_i + \gamma_t + \varepsilon_{it} \quad \text{(I)}$$

where $PM2.5_{it}$ represents the concentration of fine particulate matter in the city *i* at time *t*; $\text{UrbanizationRate}_{it}$ is the percentage of the population living in urban areas; X_{it} is a vector of control variables including GDP per capita and policy implementation indicators; α_i represents city fixed effects; γ_t represents year fixed effects; and ε_I denotes error term. We estimated this model using both ordinary least squares (OLS) with robust standard errors and fixed-effect specifications to account for unobserved time-invariant heterogeneity across cities.

3.2.2. Air pollution and health outcomes

Our second analysis examined the causal effect of air pollution on health outcomes. The primary challenge here was that pollution levels may be endogenous in the health outcome equation. Unobserved factors, such as healthcare quality, population health behaviors, or local economic conditions could influence both pollution and health outcomes, biasing OLS estimates.

To address endogeneity, we employed an IV approach using two-stage least squares (2SLS). We instrument for $PM_{2.5}$ using the industrial share of gross domestic product (GDP) in each city. The rationale is that cities with higher industrial output shares generate more emissions and thus higher pollution levels, but conditional on overall economic development and other controls, industrial composition should not directly affect health outcomes except through pollution exposure.

Our structural equation (second stage) is:

$$\text{HealthOutcome}_{it} = \alpha_0 + \alpha_1 \widehat{PM2.5_{it}} + \alpha_2 X_{it} + \mu_i + \partial_t + \varepsilon_{it} \quad \text{(II)}$$

Where $HealthOutcome_{it}$ represents respiratory disease rates; $\widehat{PM2.5_{it}}$ is the instrumented value of $PM_{2.5}$ concentration; X_{it} is a vector of control variables; μ_i represents city fixed effects; ∂_t represents year fixed effects; and ε_{it} is the error term.

The first-stage equation is:

$$PM2.5_{it} = \gamma_0 + \gamma_1 IndustryShare_{it} + \gamma_2 X_{it} + \theta_i + \lambda_t + \Omega_{it} \quad \text{(III)}$$

 doi: 10.36922/AJWEP025130088

Where $IndustryShare_{it}$ represents the percentage contribution of industrial activities to the city's GDP.

The validity of our IV approach depends on two key assumptions: relevance and the exclusion restriction. The relevance condition requires that industrial share significantly affects $PM_{2.5}$ levels, which we test through first-stage F-statistics. The exclusion restriction requires that industrial share affects health outcomes only through $PM_{2.5}$, not through other channels.

We provide theoretical justification for the exclusion restriction by arguing that, conditional on overall economic development (GDP per capita), city and year fixed effects, and other controls, the specific composition of economic output between industry and services should not directly influence respiratory health outcomes. Industrial composition primarily affects health through pollution emissions, rather than through income, employment, or other pathways that we control for in our specification.

4. Results

4.1. Urbanization and air pollution

Table 1 presents the descriptive statistics of the variables included in the model and Table 2 presents regression results for the effect of urbanization on PM2.5 concentrations across different model specifications. The results consistently demonstrate a positive and statistically significant relationship between urbanization rates and $PM_{2.5}$ levels across all specifications.

Column 1 shows a simple OLS regression without controls or fixed effects, yielding a coefficient of 0.542, indicating that each percentage point increase in

Table 1. Descriptive statistics for key variables

Variable	Mean	Standard deviation	Min	Max
$PM_{2.5}$ (μg/m^3)	33.45	6.58	23.4	48.3
Urbanization rate (%)	70.18	11.82	51.8	91.0
Respiratory disease rate (per 1000)	145.28	16.97	116.9	178.7
Population (thousands)	2722.0	3141.8	350	8950
Population density (persons/km^2)	2648.7	1579.3	945	6121
GDP per capita (million VND)	82.63	15.21	65.0	124.3
Industrial output (trillion VND)	485.15	324.72	290	1342
Industry share (%)	27.85	9.36	15.0	46.2
Policy implementation (binary)	0.38	0.49	0	1

Abbreviations: GDP: Gross domestic product; $PM_{2.5}$: Fine particulate matter.

Table 2. Effect of urbanization on $PM_{2.5}$ levels

Variable	(1) OLS	(2) OLS with controls	(3) FE	(4) FE with controls
Urbanization rate	0.542***	0.496***	0.384***	0.357***
	(0.032)	(0.041)	(0.048)	(0.052)
GDP per capita		0.076*		0.103**
		(0.041)		(0.045)
Policy implementation		−1.623**		−1.495**
		(0.724)		(0.638)
Constant	−4.526	−7.842	6.872	1.953
	(3.481)	(4.135)	(5.237)	(4.926)
Year fixed effects	No	Yes	No	Yes
City fixed effects	No	No	Yes	Yes
Observations	100	100	100	100
R-squared	0.741	0.762	0.824	0.847

Notes: Robust standard errors in parentheses. *p<0.1, **p<0.05, ***p<0.01.
Abbreviations: FE: Fixed effects; GDP: Gross domestic product; OLS: Ordinary least squares.

urbanization rate associates with a 0.542 μg/m^3 increase in $PM_{2.5}$ Column 2 adds basic controls and year fixed effects, slightly reducing the coefficient to 0.496 but maintaining high statistical significance.

Most importantly, columns 3 and 4 present fixed-effect specifications that control for unobserved time-invariant city characteristics. In our preferred specification with fixed effects and full controls (column 4), a 1%point increase in urbanization rate associates with a 0.357 μg/m^3 increase in $PM_{2.5}$ concentration. This estimate is somewhat lower than the OLS results, suggesting that unobserved city characteristics were creating some upward bias in the simple correlation.

The fixed-effect estimate represents the within-city relationship over time – as individual cities become more urbanized, their pollution levels increase by approximately 0.36 μg/m^3 per percentage point of urbanization. Given that our sample cities experienced urbanization increases ranging from 5 to 15% points over the study period, this implies pollution increases of 2 – 5 μg/m^3 attributable to urbanization alone.

Control variables provide additional insights into pollution determinants. GDP per capita enters with a positive coefficient (0.103, significant at 5%), indicating that economic growth, holding urbanization constant, associates with higher $PM_{2.5}$ levels. This finding is consistent with Vietnam remaining on the ascending portion of the environmental Kuznets curve, where industrialization and increased consumption outpace environmental improvements.

The policy implementation variable shows a negative coefficient (−1.495, significant at 5%), suggesting that cities implementing air quality measures after 2017 experienced $PM_{2.5}$ reductions of approximately 1.5 μg/m^3 relative to cities without such policies. While statistically significant, this reduction represents only about 4 – 5% of average $PM_{2.5}$ levels, indicating modest policy effectiveness to date.

We also examined urbanization effects on other pollutants where data permitted. For the subset of five cities with consistent NO_2 monitoring, urbanization showed a positive and significant association (approximately 0.15 ppb increase per percentage point of urbanization, $p<0.05$). Similarly, urbanization demonstrated positive associations with SO_2 levels, though estimates were less precise due to inconsistent monitoring coverage.

4.2. Air pollution and health outcomes

Table 3 presents results from our IV analysis of $PM_{2.5}$ effects on respiratory disease rates, comparing OLS

Table 3. Effect of $PM_{2.5}$ on respiratory disease rates (IV estimation)

Variable	(1) OLS	(2) First stage	(3) 2SLS	(4) FE-IV
$PM_{2.5}$	2.980***		2.567***	2.315***
	(0.092)		(0.203)	(0.271)
Industry share		0.378***		
		(0.035)		
Urbanization rate	0.124*	0.312***	0.057	0.042
	(0.068)	(0.051)	(0.074)	(0.083)
GDP per capita	0.103*	0.097**	0.068	0.052
	(0.058)	(0.044)	(0.063)	(0.068)
Policy implementation	−0.742	−1.547**	−0.125	−0.095
	(0.821)	(0.631)	(0.889)	(0.912)
Constant	32.158***	−5.924	41.376***	48.243***
	(5.793)	(4.024)	(6.875)	(7.321)
Year fixed effects	Yes	Yes	Yes	Yes
City fixed effects	No	No	No	Yes
Observations	100	100	100	100
R-squared	0.914	0.839	0.918	0.934
First-stage F-statistic			117.83	92.47

Notes: Robust standard errors in parentheses. *p <0.1, **p <0.05, ***p <0.01.
Abbreviations: FE: Fixed effects; GDP: Gross domestic product; IV: Instrumental variable; OLS: Ordinary least squares; 2SLS: Two-stage least squares.

estimates with IV results and showing first-stage diagnostics.

The first-stage results (column 2) confirm that our instrument – industrial output share – strongly predicts $PM_{2.5}$ levels. The coefficient of 0.378 indicates that each percentage point increase in the industry's GDP share raises $PM_{2.5}$ by 0.378 μg/m^3 on average. The first-stage F-statistics (117.83 and 92.47 in columns 3 and 4) substantially exceed the conventional threshold of 10, indicating our instrument is not weak.

Comparing OLS and IV estimates reveals important insights about potential bias in simple correlations. The OLS estimate (column 1) suggests that each 1 μg/m^3 increase in $PM_{2.5}$ associates with 2.98 additional respiratory disease cases per 1,000 population – a substantial effect representing approximately 2% of the mean respiratory disease rate.

However, the IV estimates provide more credible causal identification. In our preferred fixed-effect IV specification (column 4), the coefficient is 2.315, indicating that each 1 μg/m^3 increase in $PM_{2.5}$ causally generates approximately 2.3 additional respiratory disease cases per 1,000 population. This estimate is somewhat lower than the OLS result, suggesting that simple correlations may overstate pollution's health impact due to omitted variable bias.

The IV estimate implies substantial health impacts from present pollution levels. Considering that $PM_{2.5}$ concentrations vary by about 25 μg/m^3 between the cleanest and most polluted cities in our sample, this variation could account for approximately 58 additional respiratory disease cases per 1,000 population – representing nearly 40% of the mean respiratory disease rate.

To put this in perspective, if Vietnam's most polluted cities reduced $PM_{2.5}$ concentrations by 10 μg/m^3 (a substantial but achievable reduction), this would prevent approximately 23 respiratory disease cases per 1,000 population annually – equivalent to roughly 15% fewer respiratory illnesses.

The policy implementation variable becomes statistically insignificant in the IV specifications, suggesting that environmental policies primarily affect health through pollution reduction rather than through direct pathways. This supports our identification strategy and implies that the health benefits of environmental policies operate primarily through their impact on air quality.

5. Discussion

5.1. Interpretation of key findings

Our results provide compelling evidence of a causal chain linking urbanization to air pollution and subsequently to public health outcomes in Vietnam's cities. The positive effect of urbanization on $PM_{2.5}$ levels aligns with extensive research on urban environmental challenges in rapidly developing countries, while the magnitude we identified proves consistent with findings from comparable Asian contexts.

The urbanization coefficient of approximately 0.36 μg/m^3 per percentage point increase represents a substantial relationship. As Vietnamese cities continue urbanizing at 3% annually, this implies $PM_{2.5}$ increases of roughly 1 μg/m^3 per year solely from urbanization processes without policy interventions. Over a decade, this cumulative effect could raise pollution levels by 10 – 12 μg/m^3, representing a 25 – 30% increase from present levels.

This finding proves consistent with studies from China, where Wang *et al.*[1] reported that provinces with 10% higher urbanization exhibited 5 – 8% higher $PM_{2.5}$ concentrations. Our fixed-effect estimates suggest comparable magnitudes: a 10% urbanization increase in Vietnamese cities correlates with approximately 3.6 μg/m^3 higher $PM_{2.5}$, representing roughly 10% of baseline levels.

The causal pathway from urbanization to pollution operates through multiple mechanisms. Urban concentration intensifies energy consumption for residential, commercial, and industrial uses, predominantly from fossil fuel sources in Vietnam's present energy mix. Simultaneously, urbanization dramatically increases vehicle usage as cities expand and rural populations migrate to urban areas. Vietnam's rapid motorization, particularly motorcycle adoption, has created dense traffic flows with limited emission controls.

Industrial concentration represents another crucial mechanism. As cities develop, they attract manufacturing and processing industries seeking infrastructure, labor, and market access. Without stringent environmental regulations, these industries contribute substantially to urban pollution through emissions from production processes, power generation, and freight transportation.

Our health impact estimates prove substantial and policy-relevant. The IV coefficient of 2.315 additional respiratory cases per 1,000 population per μg/m^3 of $PM_{2.5}$ implies that present pollution levels generate significant health burdens across Vietnamese cities. This estimate aligns with international evidence from developing countries, where pollution-health relationships often prove more severe than in developed nations due to higher baseline exposure, greater population vulnerability, and limited healthcare access.

The fact that IV estimates are somewhat lower than OLS results (2.315 vs. 2.98) suggests that simple correlations may overstate pollution's health impact due to confounding factors. Cities with higher pollution levels might also have other characteristics – such as industrial composition, population density, or healthcare infrastructure – that independently affect health outcomes. Our IV approach helps isolate pollution's causal impact by leveraging variation in industrial composition that affects pollution but not health through other channels.

These health impacts translate into substantial economic and social costs. Respiratory disease episodes generate direct medical costs, productivity losses from work absences, and reduced quality of life. For Vietnam's urban population of approximately 35 million, even small changes in disease rates imply thousands of additional cases annually, representing significant burdens on healthcare systems and economic productivity.

The policy analysis yields mixed but informative results. Environmental policies implemented since 2017 achieved statistically significant but modest pollution reductions of approximately 1.5 $\mu g/m^3$. While this represents progress, it falls far short of the reductions needed to meet air quality standards. Vietnam's cities still exceed national ambient air quality standards (25 $\mu g/m^3$ annual average for $PM_{2.5}$) by substantial margins, and remain far above WHO guidelines (5 $\mu g/m^3$).

However, the fact that policies generated measurable improvements demonstrates that interventions can succeed even in rapidly growing economies. This finding provides hope that scaled-up and strengthened policies could achieve more substantial improvements. International experience, particularly from China's aggressive pollution control efforts in the 2010s, demonstrates that rapid air quality improvements are possible with sufficient political commitment and policy implementation.

5.2. Policy implications

Our findings carry important implications for policymakers in Vietnam and other rapidly urbanizing developing countries. The established causal chain from urbanization through pollution to health outcomes underscores the urgent need for integrated urban planning that considers environmental and health consequences alongside economic development.

5.2.1. Sustainable urban planning integration

The strong urbanization-pollution relationship highlights the critical importance of environmental considerations in urban planning processes. Vietnam's continued rapid urbanization – projected to reach 50% of the total population by 2030 – makes the integration of urban planning into sustainability policies essential. Cities should prioritize compact, transit-oriented development over sprawling, car-dependent growth patterns.

5.2.2. Transportation sector transformation

Given transportation's substantial contribution to urban air pollution, particularly NO_2 and $PM_{2.5}$ from vehicle exhaust, transforming Vietnam's transportation system represents a critical policy priority. This transformation should encompass both regulatory and investment approaches.

Vehicle emission standards require immediate strengthening and enforcement. Vietnam should accelerate the adoption of Euro 5 and eventually Euro 6 fuel and vehicle standards, following successful implementations in European and other Asian countries. Stricter inspection and maintenance programs can ensure existing vehicles meet emission requirements.

Electric vehicle promotion offers longer-term pollution reduction potential. Vietnam's government has announced targets for electric vehicle adoption, but implementation requires supportive infrastructure including charging networks, financial incentives for consumers, and regulatory frameworks to encourage domestic manufacturing.

5.2.3. Industrial emission control

Our IV analysis demonstrates that industrial composition significantly affects urban air quality, suggesting that industrial emission control represents a crucial policy lever. This requires both regulatory strengthening and economic incentives for cleaner production.

Emission standards for industrial facilities need regular updating and rigorous enforcement. Vietnam should consider adopting international best practice standards for major industrial sources, including power plants, cement factories, steel mills, and chemical facilities. Regular monitoring and meaningful penalties for violations are essential for effective implementation.

Economic incentives can complement regulatory approaches. Pollution pricing through taxes or cap-and-trade systems can provide market-based incentives for emission reductions while generating revenue for environmental improvements. Several Vietnamese provinces have experimented with environmental taxes, and expanding these approaches could prove effective.

Industrial zoning policies should consider cumulative environmental impacts and proximity to population centers. Concentrating heavy industries in designated zones with appropriate pollution controls can reduce urban exposure while enabling economic development. The adoption and implementation of air-infiltration systems are also strongly recommended as these measures have proved effective and beneficial in mitigating air pollution and improving people's health and quality of life.[3,4,34,35]

5.2.4. Healthcare system adaptation

While addressing pollution sources remains the primary priority, strengthening healthcare systems to better manage pollution-related health impacts provides important interim protection. This is particularly crucial given that substantial air quality improvements will require years to achieve.

Healthcare providers in Vietnamese cities should receive training in recognizing and managing pollution-related health conditions, particularly respiratory diseases that spike during high pollution episodes. Emergency departments and respiratory clinics should prepare for increased patient loads during pollution episodes.

5.2.5. Regional and international cooperation

Air pollution often crosses administrative boundaries, making regional cooperation essential for effective management. Vietnam should strengthen coordination with neighboring countries on transboundary pollution issues, particularly seasonal agricultural burning that affects regional air quality.

Within Vietnam, cities and surrounding provinces should coordinate on pollution control since urban air quality is affected by emissions from broader metropolitan regions. Joint planning for industrial development, transportation systems, and pollution monitoring can improve effectiveness while reducing costs.

International cooperation can provide technical assistance, funding, and technology transfer for pollution control. Vietnam should actively engage with international organizations and developed countries that have successfully addressed similar air quality challenges.

5.2.6. Economic co-benefits and climate integration

Many air pollution control measures provide climate change mitigation co-benefits, enabling Vietnam to address both local air quality and global climate commitments simultaneously. This integration can unlock additional funding sources and international support.

Renewable energy development reduces both air pollution and greenhouse gas emissions. Vietnam's substantial solar and wind potential could provide cleaner electricity while reducing coal dependence, which contributes significantly to urban air pollution.

Energy efficiency improvements in buildings, industry, and transportation reduce both air pollution and carbon emissions while providing economic benefits through reduced energy costs. Comprehensive energy efficiency programs can achieve multiple policy objectives simultaneously.

6. Conclusion, policy implications/ recommendations, limitations, and future research directions

This study provided rigorous empirical evidence of the causal relationships linking urbanization, air pollution, and public health outcomes in Vietnam's major cities. Across panel data analysis spanning 2013 – 2022 and employing IV techniques, we demonstrated that urbanization significantly increases $PM_{2.5}$ pollution levels, which in turn substantially impact respiratory health outcomes.

Our key findings established that each percentage point increase in urbanization rate raises $PM_{2.5}$ concentrations by approximately 0.36 $\mu g/m^3$, while each $\mu g/m^3$ increase in $PM_{2.5}$ causally generates roughly 2.3 additional respiratory disease cases per 1,000 population. These quantitative relationships underscore the magnitude of Vietnam's environmental health challenge: continued rapid urbanization without effective policy intervention will likely generate substantial increases in pollution-related health burdens.

The analysis also revealed that environmental policies implemented since 2017 achieved modest but measurable pollution reductions of approximately 1.5 $\mu g/m^3$. While this indicates that policy interventions can succeed even in rapidly growing economies, the scale of improvement remains insufficient to meet air quality standards or protect public health adequately.

For Vietnam, these findings highlighted both urgent challenges and important opportunities. The country's continued rapid urbanization – projected to house over half the population in cities by 2030 – makes immediate action essential. Without integrated sustainable urban planning and strengthened environmental policies, pollution levels, and associated health impacts will likely continue increasing substantially.

Our results also demonstrated that policy interventions can effectively reduce pollution even in rapidly developing contexts. This finding, combined with international experience from countries, such as China that achieved dramatic air quality improvements through determined policy implementation, suggested that Vietnam can successfully address its air quality challenges with sufficient political commitment and appropriate policy design.

The policy implications extend beyond pollution control to encompass comprehensive urban development strategies. Sustainable urban planning that promotes compact, transit-oriented development; transportation systems that reduce vehicle dependence; industrial policies that minimize emissions; and healthcare systems adapted to protect vulnerable populations all represent essential components of an effective response.

Critically, addressing air pollution provides substantial co-benefits for climate change mitigation, as many pollution sources also generate greenhouse gases. This alignment enables Vietnam to pursue local air quality improvements and global climate commitments simultaneously, potentially unlocking additional resources and international support for environmental improvements.

Our findings also contribute to the broader global understanding of urbanization-environment-health relationships in developing countries. The quantitative estimates of these relationships in Vietnam's context provide valuable benchmarks for policy evaluation and international comparisons, while our methodological approach demonstrates how causal inference techniques can generate more robust evidence for policy design.

International experience demonstrates that this challenge is surmountable. Countries from the United Kingdom to Japan and China have successfully reduced urban air pollution while maintaining economic growth, though the health and economic costs of delayed action proved substantial. Vietnam has the opportunity to learn from these experiences and implement effective policies earlier in its development process, potentially avoiding the severe pollution episodes that other countries experienced.

In conclusion, our analysis provided clear evidence that Vietnam faces a critical choice in managing its urban development trajectory. The causal pathways from urbanization through pollution to health impacts are well-established and quantitatively significant. The effectiveness of policy interventions is demonstrated but requires substantial scaling up. The co-benefits with climate action provide additional motivation and potential resources for implementation. Most importantly, the health and well-being of millions of Vietnamese urban residents depend on the policy choices made in the coming years.

The transition to sustainable urban development will require sustained political commitment, substantial financial resources, and effective institutional coordination. However, the alternative – continued deterioration of urban air quality with mounting health and economic costs – represents a far more challenging long-term scenario. By acting decisively now, Vietnam can achieve the dual objectives of economic development and environmental protection, creating healthier and more prosperous cities for future generations.

Acknowledgments

None.

Funding

The authors gratefully acknowledge the financial support from the Banking Academy of Vietnam.

Conflict of interest

The authors declare they have no competing interests

Author contributions

Conceptualization: All authors
Formal analysis: All authors
Investigation: All authors
Methodology: Bui Duy Hung
Writing – original draft: All authors
Writing – review & editing: All authors

Availability of data

Data are available from the corresponding author upon reasonable request.

References

1. Wang Q, Kwan MP, Zhou K, Fan J, Wang Y, Zhan D. The impacts of urbanization on fine particulate matter ($PM_{2.5}$) concentrations: Empirical evidence from 135 countries worldwide. *Environ Pollut.* 2019;247:989-998. doi: 10.1016/j.envpol.2019.01.086
2. Zhan C, Xie M, Lu H, *et al*. Impacts of urbanization on air quality and the related health risks in a city with complex terrain. *Atmos Chem Phys.* 2023;23(1):771-786.

doi: 10.5194/acp-23-771-2023

3. Zhang S, Liu H, Tang N, Ge J, Yu J, Ding B. Direct electronetting of high-performance membranes based on self-assembled 2D nanoarchitectured networks. *Nat Commun.* 2019;10:1458. doi: 10.1038/s41467-019-09444-y
4. Zhang Y, Han Y, Ji X, *et al*. Continuous air purification by aqueous interface filtration and absorption. *Nature.* 2022;610(7930):74-80. doi: 10.1038/s41586-022-05124-y
5. Wen H, Hu K, Nghiem XH, Acheampong AO. Urban climate adaptability and green total-factor productivity: Evidence from double dual machine learning and differences-in-differences techniques. *J Environ Manag*. 2024a;350:119588. doi: 10.1016/j.jenvman.2023.119588
6. Wen H, Yu H, Nghiem XH. Impact of Urban sprawl on carbon emission efficiency: Evidence from China. *Urban Clim*. 2024b;55:101986. doi: 10.1016/j.uclim.2024.101986
7. Mathew J, Goyal R, Taneja KK, Arora N. Air pollution and respiratory health of school children in industrial, commercial and residential areas of Delhi. *Air Qual Atmos Health.* 2015;8(4):421-427. doi: 10.1007/s11869-014-0299-y
8. Bakry W, Mallik G, Nghiem XH, Sinha A, Vo XV. Is green finance really "green"? Examining the long-run relationship between green finance, renewable energy and environmental performance in developing countries. *Renew Energy*. 2023a;208:341-355. doi: 10.1016/j.renene.2023.03.020
9. Nghiem XH, Bakry W, Al-Malkawi HAN, Farouk S. Does technological progress make OECD countries greener? New evidence from panel CS-ARDL. *Manag Environ Qual Int J*. 2023;34(6):1555-1579. doi: 10.1108/MEQ-11-2022-0296
10. Bakry W, Nghiem XH, Farouk S, Vo XV. Does it hurt or help? Revisiting the effects of ICT on economic growth and energy consumption: A nonlinear panel ARDL approach. *Econ Anal Policy*. 2023b;78:597-617. doi: 10.1016/j.eap.2023.03.026
11. Seto KC, Shepherd JM. Global urban land-use trends and climate impacts. *Curr Opin Environ Sustain.* 2009;1(1):89-95. doi: 10.1016/j.cosust.2009.07.012
12. Cui L, Yue S, Nghiem XH, Duan M. Exploring the risk and economic vulnerability of global energy supply chain interruption in the context of Russo-Ukrainian war. *Resour Policy*. 2023;81:103373. doi: 10.1016/j.resourpol.2023.103373
13. Guo B, Guo Q, Amri F, Abbas S, Nghiem XH. Powering environmental sustainability through renewable energy and natural resources: A dynamic ARDL simulation approach. *Environ Sci Pollut Res*. 2023;30:90906-90923. doi: 10.1007/s11356-023-28643-1
14. Nasreen S, Khan FI, Nghiem XH. The effects of financial development and technological progress on environmental sustainability: Novel evidence from Asian countries. *Environ Sci Pollut Res*. 2023;30:53712-53724. doi: 10.1007/s11356-023-26139-6
15. Bakry W, Nghiem XH, Bhatti MI, Al-Mohamad S, Cui L. Digital finance and sustainable development: Evidence from developing nations. *Sci Prog*. 2024;107:2024;107(3). doi: 10.1177/00368504241278823
16. Dong Q, Lin Y, Huang J, Chen Z. Has urbanization accelerated $PM_{2.5}$ emissions? An empirical analysis with cross-country data. *China Econ Rev.* 2020;59:101381. doi: 10.1016/j.chieco.2019.101381
17. Guan D, Meng J, Reiner DM, *et al*. Structural decline in China's CO_2 emissions through transitions in industry and energy systems. *Nat Geosci.* 2018;11(8):551-555. doi: 10.1038/s41561-018-0161-1
18. Chen G, Li S, Zhang Y, *et al*. Effects of ambient PM_1 air pollution on daily emergency hospital visits in China: An epidemiological study. *Lancet Planet Health.* 2017;1(6):e221-e229. doi: 10.1016/S2542-5196(17)30100-6
19. Zhang L, Yang Y, Li Y, *et al*. Short-term and long-term effects of $PM_{2.5}$ on acute nasopharyngitis in 10 communities of Guangdong, China. *Sci Total Environ.* 2019;688:136-142. doi: 10.1016/j.scitotenv.2019.05.470
20. Pope CA 3rd, Coleman N, Pond ZA, Burnett RT. Fine particulate air pollution and human mortality: 25+ years of cohort studies. *Environ Res.* 2020;183:108924. doi: 10.1016/j.envres.2019.108924
21. Apte JS, Brauer M, Cohen AJ, Ezzati M, Pope CA 3rd. Ambient $PM_{2.5}$ reduces global and regional life expectancy. *Environ Sci Technol Lett*. 2018;5(9):546-551. doi: 10.1021/acs.estlett.8b00360
22. Phung D, Hien TT, Linh HN, *et al*. Air pollution and risk of respiratory and cardiovascular hospitalizations in the most populous city in Vietnam. *Sci Total Environ.* 2016;557:322-330. doi: 10.1016/j.scitotenv.2016.03.070
23. Hien PD, Men NT, Tan PM, Hangartner M. Impact of urban expansion on the air pollution landscape: A case study of Hanoi, Vietnam. *Sci Total Environ.* 2020;702:134635. doi: 10.1016/j.scitotenv.2019.134635
24. Nhung NTT, Duc VT, Ngoc VD, *et al*. Mortality benefits of reduction fine particulate matter in Vietnam, 2019. *Front Public Health.* 2022;10:1056370. doi: 10.3389/fpubh.2022.1056370
25. Nguyen TT, Ngo HH, Guo W, *et al*. Implementation of a specific Urban water management - sponge City. *Sci Total Environ.* 2019;652:147-162. doi: 10.1016/j.scitotenv.2018.10.168
26. Tran TT, Nguyen HD. Urbanization, economic

development, and environmental change in Vietnam. *J Econ Dev.* 2015;40(3):1-25.
27. Vu T, Nguyen TTN, Pham MH. Effect of ambient air pollution on hospital admissions for respiratory diseases among children in Hanoi, Vietnam. *Environ Res.* 2023;216:114655.
28. Zhou L, Chen X, Tian X. The impact of fine particulate matter ($PM_{2.5}$) on China's agricultural production from 2001 to 2010. *J Clean Prod.* 2018;178:133-141. doi: 10.1016/j.jclepro.2017.12.204
29. Greenstone M, Hanna R. Environmental regulations, air and water pollution, and infant mortality in India. *Am Econ Rev*. 2014;104(10):3038-3072. doi: 10.1257/aer.104.10.3038
30. Deryugina T, Heutel G, Miller NH, Molitor D, Reif J. The mortality and medical costs of air pollution: Evidence from changes in wind direction. *Am Econ Rev.* 2019;109(12):4178-4219. doi: 10.1257/aer.20180279
31. Liu K, Zhang H, Bo Y, *et al*. Ambient air pollution and Children's health: An umbrella review. *Atmos Pollut Res.* 2024;15:102108. doi: 10.1016/j.apr.2024.102108
32. IQAir. *World Air Quality Report 2020*. Switzerland: IQAir AG; 2021.
33. IQAir. *World Air Quality Report 2022*. Switzerland: IQAir AG; 2023.
34. Liu Y, Zhou B, Wang J, Zhao B. Health benefits and cost of using air purifiers to reduce exposure to ambient fine particulate pollution in China. *J Hazard Mater*. 2021;414:125540. doi: 10.1016/j.jhazmat.2021.125540
35. Balyan P, Ghosh C, Sharma AK, Banerjee BD. Health effects of air pollution among residents of Delhi: A systematic review. *Int J Health Sci Res*. 2018;8(1):273-282.