Economic Growth, Public Health Expenditure and Air Pollution: A Panel Analysis of Indian States.

Abstract

This study investigates the relationship between fine particulate matter (PM2.5) air pollution and economic growth and labour productivity in India. Over the past decade, India has experienced rapid economic growth and wide-scale urbanization alongside a deterioration in air quality. Rising pollution levels may negatively affect the health of the workforce, consequently reducing the overall output and productivity of industries. Rise in illness incidences puts strain on the healthcare system, therefore prompting an increase in healthcare expenditure.

Using state-level data from 2014 to 2024, this paper examines the relationship between PM2.5 concentration and economic indicators, including Net State Domestic Product (NSDP) and the Index of Industrial Production (IIP). Using these economic indicators as proxies for industrial and state-level activity, this study aims to establish if higher pollution levels can be associated with slower or negative economic growth.

Introduction

Over the past decade, India has experienced rapid economic growth alongside deterioration in air quality. Fine particulate matter (PM2.5), a major component in air pollution, poses serious risks to the health of the population in many economically active regions of the country. At the same time, India has expanded its industrial output and infrastructure development and is continuously working towards more sustainable development techniques. However, this simultaneous rise in economic activity and environmental degradation can be a point of concern for long-term sustainability, particularly in regions with dense industrial activity and experiencing rapid urbanization. Rapid urbanization, increased energy consumption and the growth of the manufacturing industry have contributed significantly to rising pollution levels, especially in metropolitan cities, where economic growth and activity is more concentrated. This creates a situation in which the Government may divide priorities and resources, favoring economic growth or focusing on the preservation or restoration of the environment.

Exposure to PM2.5 can have adverse effects on labour productivity, through increased incidence of illness, higher healthcare costs, and—particularly in the tertiary sector—a reduction in effective working hours through temporary shutdowns and remote work. Prolonged exposure to air pollution can result in major human illnesses and consequently strain the active workforce, reducing economic efficiency and productivity. In response to these growing health and economic concerns, the Indian Government has increased its healthcare budget over time reflecting the rising economic costs associated with pollution-related production. This further strains economic activity as further resources are being diverted into resolving and mitigating health issues rather than enhancing economic output. Such an allocation of resources presents an opportunity cost to the economy, as these funds could have been allocated into education, infrastructure, or technological developments that can have positive effects on long-term economic efficiency and output, but are instead being used to treat health issues caused by air pollution.

This study examines whether PM2.5 air pollution significantly affects economic growth and labour productivity in India. Using state-level data from 2014-2024, the paper analyzes the relationship between PM2.5 concentration and proxies for economic indicators, such as real Net State Domestic Product (NSDP) and the Index of Industrial Production (IIP). NSDP reflects the overall economic output at state level, IIP serves as the indicator for industry-specific output, allowing for detailed analysis. By analyzing the relationship between air pollution concentration and proxies for economic indicators and focusing on this time period, the study aims to offer a relevant and comprehensive report of the economic implications of air pollution in India. Moreover, utilizing state-level data allows for identifying and comparing trends and variations throughout the years of pollution-related impacts on economic outcomes, providing for a more nuanced understanding of the relationship between pollution and economic output within a large and diverse economy like India. This investigation is important because the connection between air pollution and economic output explains valuable factors that should be discussed regarding economic growth.

Literature Review

A growing body of research has documented the detrimental effects of PM2.5 on human health and economic performance. In India, Behrer et al. (2021) show that long-term exposure to elevated PM2.5 levels is associated with lower labour productivity and reduced human capital formation. Similarly, Majumder et al. (2019) find that every 10% rise in PM2.5 concentration corresponds to a 14% decline in labour productivity in manufacturing industries. Agarwal and Narain (2018) further document increased morbidity and healthcare spending linked to poor air quality.

Internationally, Chay and Greenstone (2003) show that reductions in particulate air pollution improves worker productivity in the United States. Graff Zivin and Neidell (2012) find that local air pollution reduces productivity in the service sector and raises healthcare costs. In China, Ebenstein et al. (2017) demonstrate that decreases in PM2.5 following policy changes regarding pollution resulted in higher productivity and lower mortality.

Focusing on the broader impacts of air pollution, Chen et al. (2018) show that higher PM2.5 exposure significantly worsens mental health outcomes, highlighting an important channel through which air pollution can indirectly reduce labour productivity and economic performance. Zhang et al. (2019) link higher PM2.5 concentration with lower urban economic output and reduced consumption. Hanna and Oliva (2015) show that PM2.5 exposure increases labour supply constraints through health effects in Mexico. In addition, reports by global organisations such as the World Bank and OECD (2022-25) provide evidence that PM2.5 imposes significant costs on productivity, health expenditure, and long-term growth.

Literature Gap- Despite this literature, relatively few studies examine the relationship between PM2.5, labour productivity, and economic growth at the state level within large and diverse economies such as India over an extended period. This study aims to address this gap by focusing on India from 2014-15 to 2024-25.

Research Question

What is the relationship between PM2.5 air pollution, economic growth, and labour productivity across Indian states?

Objectives

Based on the research question this paper aims to explore:

- Examine the relationship between economic growth (NSDP) and PM2.5 air pollution levels
- Analyse the relationship between industrial productivity (proxied by wages) and pollution
- Evaluate the association between of government health expenditure PM2.5 air pollution levels
- Explore the correlation between PM2.5 air pollution levels and health expenditure

Methodology

The paper is based on secondary data sources. Data is collected from various official websites for the time period of 2014-15 to 2024-25. This study investigates the determinants of air pollution across Indian states using a balanced panel dataset covering 29 states for the period 2014–2015 to 2024–2025. The panel dataset contains 319 observations, allowing the analysis to capture both cross-sectional and time-series variations in air pollution levels. The dependent variable used in the analysis is PM2.5 concentration, which represents the level of fine particulate matter with a diameter of less than 2.5 micrometers. PM2.5 air pollution is widely recognized as one of the most harmful air pollutants due to its ability to penetrate deep into the respiratory system and cause severe health problems. According to the World Health Organization, exposure to high levels of PM2.5 air pollution is associated with respiratory diseases, cardiovascular illnesses, and premature mortality.

The key explanatory variables included in the study are economic growth, government health expenditure, industrial productivity, and rainfall. Economic growth is measured using the logarithm of Net State Domestic Product (lnNSDP), which captures the level of economic activity within each state. Government health expenditure is measured using the logarithm of public health spending (lnGovHealthExp) to reflect the level of government investment in healthcare infrastructure and public health services.

Industrial productivity is proxied by average wages, which reflect the level of industrial and labor market activity within each state. Higher wage levels often indicate increased industrial production and economic development. Wages are used as a proxy for industrial productivity due to the unavailability of consistent state-level productivity measures, and they reflect labour market conditions and industrial activity, which are closely linked to production levels. Rainfall is included as a meteorological control variable because precipitation can influence the dispersion and removal of particulate pollutants through atmospheric processes such as wet deposition.

To examine the relationship between economic growth, public health expenditure, industrial productivity, and air pollution, the study employs a panel regression model. Panel data analysis is particularly useful because it allows researchers to control for unobserved heterogeneity across states and capture temporal dynamics in the data.

The general empirical model used in the study can be expressed as:

$$PM2.5_{it} = \beta 0 + \beta 1(lnNSDPit) + \beta 2(lnGovHealthExp_{it}) + \beta 3(Wages_{it}) + \beta 4(Rainfall_{it}) +_{)} + u_i + \lambda_t + \epsilon_{it}$$

where:

- PM2.5it represents the PM2.5 concentration in state i at time t
- lnNSDPit represents the logarithm of Net State Domestic Product
- lnGovHealthExpit represents the logarithm of government health expenditure
- Wagesit represents average wages as a proxy for industrial productivity
- Rainfallit represents precipitation levels
- $\beta_{0=}$overall intercept
- i = state
- t = year
- u_i = state-specific fixed effect (e.g., governance quality, geography)
- λ_t =Time fixed effects
- ϵ_{it} = idiosyncratic error

The inclusion of state-specific effects allows the model to control for time-invariant characteristics such as geographic conditions, historical industrial structures, and institutional factors that may influence pollution levels across states.

Result & analysis

This study examines the determinants of air pollution across Indian states using a panel dataset covering the period 2014–2015 to 2024–2025. The empirical analysis uses a fixed-effects panel regression model with Driscoll–Kraay standard errors to account for potential heteroskedasticity, serial correlation, and cross-sectional dependence in the panel structure. The Driscoll–Kraay estimator provides strong inference even when cross-sectional units are interdependent, which is particularly relevant for environmental studies where pollution often spreads across regional areas (Driscoll & Kraay, 1998).

The dependent variable is PM2.5 concentration, which represents fine particulate matter widely recognized as a major environmental and public health hazard. Key variables include economic growth (log of Net State Domestic Product), government health expenditure (log), wages as a proxy for industrial productivity, and rainfall as a meteorological control variable.

The statistical results ($F = 152.41$, $p < 0.01$) confirm that the variables chosen explain why air pollution levels differ across Indian states. While the model accounts for about 16% of the year-to-year changes in PM2.5 levels within those states with an R^2 value of 0.1603, this level of impact is quite standard for environmental research. Air quality is incredibly complex, shaped by a massive web of shifting weather patterns, local geography, and evolving government policies that are difficult to capture in a single mathematical snapshot.

- **Impact on Economic Growth and Air Pollution**

The regression results show that economic growth (represented by NSDP) is positively and significantly associated with PM2.5 concentrations ($\beta = 6.568$, $p < 0.05$). This finding suggests that increases in state-level economic output are associated with higher levels of particulate pollution.

One possible explanation is that economic expansion in developing regions is often accompanied by rapid industrialization, increased energy consumption, infrastructure development, and growth in transportation, and is associated with higher emissions of pollutants. In many emerging economies, economic growth initially relies heavily on fossil fuels, which intensifies the pollution produced.

This result is consistent with the Environmental Kuznets Curve (EKC) framework proposed by Gene Grossman and Alan Krueger. The EKC hypothesis suggests that environmental degradation tends to increase during the early stages of economic development as production and consumption expand. However, after a certain income level is reached, environmental quality may improve as economies adopt more environmentally-friendly technologies, stronger environmental regulations, and more efficient production methods thanks to better access to technology.

The positive relationship observed in this study indicates that many Indian states may still be in the initial phase of the EKC, where the high economic growth directly corresponds with higher pollution levels. Similar findings have been reported in several empirical studies examining the growth–environment nexus in developing economies (Stern, 2004; Shahbaz et al., 2013).

- **Impact of Industrial Productivity on Pollution**

Wages, used as a proxy for industrial productivity and economic activity, is positively and significantly associated with PM2.5 concentrations ($\beta = 2.20 \times 10^{-6}$, $p < 0.01$). This indicates that higher wage levels are associated with increased air pollution.

Higher wages often reflect greater industrial production and labor demand, as industrial expansion is generally associated with increased energy consumption and greater use of fossil fuels, which is linked to higher emissions. As industrial productivity rises, pollution levels may increase unless cleaner technologies, more efficient production methods and environmental regulations are implemented.

Additionally, rising wages can stimulate higher household consumption and increased transportation, both of which contribute to higher emissions. Households often purchase more vehicles when they possess an increased purchasing power, consume a higher amount of electricity, and promote an expansion and improvement in urban infrastructure, all of which may increase air pollution.

This finding aligns with previous studies showing that industrialization and productivity growth are significant drivers of environmental degradation in developing economies (Stern, 2004). Without appropriate environmental policies, industrial growth can lead to detrimental ecological outcomes, including deteriorating air quality.

- **Impact of Government Health Expenditure on Air Pollution**

Government health expenditure (represented by Government health expenditure) shows a negative and significant relationship with PM2.5 concentrations ($\beta = -12.517$, $p < 0.01$). This result implies that higher public spending on healthcare is associated with a reduction in air pollution levels. This finding highlights the important role of public health investments in improving environmental outcomes. From a theoretical perspective, government expenditure on healthcare can influence pollution through several mechanisms.

Firstly, increased health spending often reflects greater commitment to public welfare and environmental protection. Governments facing rising pollution-related health risks may allocate more resources in order to control and reduce pollution through better environmental monitoring systems and regular interventions in the public health sector aimed at improving health services.

Secondly, higher healthcare expenditure can strengthen institutional capacity, enabling governments to implement stricter environmental regulations and enforce pollution standards more effectively. Environmental governance requires adequate public resources for monitoring emissions, conducting health surveillance, and implementing regulatory frameworks.

Higher healthcare spending also helps build stronger government institutions, giving them the resources they need to effectively enforce environmental laws and pollution standards. Effective environmental oversight requires ample funding for monitoring emissions, tracking public health trends, and maintaining regulatory systems.

Third, investments in public health infrastructure often raise public awareness about environmental risks. Greater awareness can lead to stronger demand for environmental regulation and policies that promote or enforce sustainable development.

The relationship between public health investment and environmental quality is also consistent with the health–environment feedback hypothesis, which suggests that governments respond to environmental health risks by increasing public spending to protect population health (Jerrett et al., 2005). Similarly, research has shown that improved healthcare systems and stronger institutional frameworks can facilitate environmental improvements by enhancing regulatory enforcement and environmental management.

Furthermore, strategic investments in public health can also shift the focus toward cleaner production and more sustainable practices, encouraging governments to prioritize prevention over simply treating the consequences of pollution. By moving away from a model that only reacts after environmental damage has occurred, public funding can be directed toward proactive measures like advanced pollution monitoring systems, comprehensive urban air quality programs, and the adoption of green technologies. This transition not only protects public health but also establishes a more resilient and sustainable regulatory framework.

Empirical studies have also highlighted the importance of government spending in improving the environment. For instance, Lopez, Galinato, and Islam (2011) found that public expenditure on environmental and social sectors can contribute to improved environmental quality by strengthening regulatory institutions and supporting environmental protection initiatives.

Therefore, the negative coefficient of government health expenditure observed in this study suggests that greater investment in healthcare can contribute not only to improved health outcomes but also to better environmental conditions.

- **Rainfall and Air Pollution**

Rainfall was included in the model as a meteorological control variable because precipitation can influence the dispersion and removal of particulate matter from the atmosphere. The regression results show that rainfall has a negative but statistically insignificant effect on PM2.5 concentrations.

Although rainfall can reduce airborne particulate matter through a process known as wet deposition, its long-term impact on pollution levels may be limited. Air pollution is influenced by several meteorological conditions, including wind patterns, atmospheric stability, and humidity. Therefore, rainfall may only have a temporary cleansing effect, which may not significantly affect long-term pollution trends across states.

Overall, the results suggest that economic growth and industrial productivity contribute to higher air pollution levels, while government healthcare expenditure plays a significant role in reducing pollution. These findings highlight the importance of integrating environmental considerations into economic development policies.

The results also emphasize the role of public sector investment and institutional capacity in addressing environmental challenges. Governments that invest more in healthcare and public welfare may also be more likely to implement effective environmental policies and pollution control measures.

For rapidly developing economies such as India, achieving sustainable development requires balancing economic growth with environmental protection. Policies promoting clean technologies, renewable energy adoption, advanced and efficient methods of production, and stronger environmental regulation are essential for reducing pollution while maintaining economic progress.

Table: Fixed Effects Regression Results (Driscoll–Kraay Standard Errors)

Variables	Coefficient	Std. Error	t-value	p-value
lnNSDP	6.568***	2.570	2.56	0.029
lnGovHealthExp	−12.517***	2.380	−5.26	0.000
Wages	2.20e-06***	2.24e-07	9.83	0.000
Rainfall	−0.000235	0.001652	−0.14	0.890
Constant	65.388***	11.375	5.75	0.000

Notes: ***p < 0.01, **p < 0.05, *p < 0.10.

To complement the panel regression analysis, the study examines the relationship between PM2.5 and government health expenditure using the Pearson correlation coefficient. The estimated correlation value of −0.02 indicates a negligible and statistically insignificant linear relationship between the two variables. This suggests that, at the aggregate level, variations in pollution do not exhibit any meaningful direct association with health expenditure. The near-zero correlation may arise due to lagged health responses to pollution exposure, differences in state-level institutional capacity, and the presence of omitted variables such as income levels and demographic structure. Therefore, simple bivariate correlation may not adequately capture the complex relationship between environmental degradation and public health spending.

Conclusion

This study investigates the determinants of PM2.5 air pollution across Indian states using a panel dataset covering the period 2014–2015 to 2024–2025. The empirical findings reveal that economic growth, measured by Net State Domestic Product, is positively associated with pollution levels, indicating that higher economic activity is associated with increased environmental degradation. This result suggests that many Indian states are still in the early phase of development, where growth is driven by energy-intensive industrialization.

Industrial productivity, proxied by wages, is also found to significantly increase pollution levels, reflecting the environmental costs of expanding industrial activity and rising consumption. In contrast, government health expenditure indicates a negative and significant relationship with PM2.5 concentration, suggesting that higher public investment in health is associated with improved environmental outcomes. This may reflect stronger institutional capacity, greater public awareness, and more effective policy implementation in states with higher levels of public spending.

Rainfall, while theoretically expected to reduce pollution through atmospheric cleansing, does not show a statistically significant impact in the long run.

Overall, the findings highlight the trade-off between economic growth and environmental sustainability in developing economies. The results suggest that without policy intervention, economic growth is associated with higher levels of environmental degradation. However, the results should be interpreted with caution, as the model does not fully establish cause-and-effect relationships. Therefore, a clear need for stronger policy frameworks that promote clean energy systems, stricter environmental regulations, and increased investment in public health and environmental infrastructure are essential to achieve sustainable and inclusive growth in India.

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