

Air Pollution in India: Analysis of SO₂, NO₂, PM₁₀, And PM_{2.5} Pollutants Across Diverse Regions

Dr. Chandrima Chakraborty^{1*}, Dipali Bera²

¹Associate Professor, Department of Economics, Vidyasagar University, India

²Ph.D. Research Scholar, Department of Economics, Vidyasagar University, India

*Corresponding author: Dr. Chandrima Chakraborty

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Abstract: Pollution is a major issue among the countries over the world. India is one of them. Out of the other pollutions, air pollution has the most powerful impact on our daily life as well as on environment. The present study tries to analyse the relative position and relative performance of the Indian states region wise for selected pollutants like SO₂, NO₂, PM₁₀ and PM_{2.5} separately. It also tries to evaluate the relative position on the basis of these above pollutants together for different regions separately. This paper considers the annual average value of all concentration of air Pollution during 2007 to 2023 for 16 major States in India. The findings suggest that North and South zone states show overall good performance and also some states from different zones are doing so well with respect to different pollutants over the years. This paper prescribes some policies for reducing the air Pollution and suggests to monitor the air quality by better machine system and using AI if possible. It also suggests that Government may create some strong rules and regulations on using Vehicles, burning fuels, throwing solid garbage etc for better public health and environment.

Keywords: Air Pollution, pollutants, Indian regions, SO₂, NO₂, PM₁₀, PM_{2.5}.

INTRODUCTION

The modern world is facing greatest challenges in pollution. The pollution occurs when harmful substances or different kinds of energy are induced into the environment. These substances are harming the balance of nature of Soil, Water and Air and also human health, plants, animals. Due to Industrialization, Globalization, Urbanization, the human activities are increasing. That's why a huge of amount of waste, Gases is released into nature.

Pollutants are the substances responsible for causing pollution. Pollutants are may be gas, liquid or may be solid and they may release from human or non-human activities. Other types of pollutants are may be biodegradable (like newspaper, food waste etc.) or non-biodegradable (plastic, metals, electronics).

This paper is focusing on Air pollution which has a bad impact on human life and Environment. Air pollution occurs when gases, smoke, dust, or chemicals are released into the atmosphere in large amounts. The main causes of Air pollution are human Activities, excess vehicles use. The SO₂, NO₂, CO₂ are released from vehicles. Other sources of air pollutants are fossil

fuel (coal, oil), burning garbage and agricultural waste, construction work and other mining activities. The particulate matters (PM₁₀ & PM_{2.5}) are released from these mining activities and construction sites. These pollutants are contributed to global warming, acid rain, and damage to the ozone layer.

Air pollution can be classified into four main types of air pollution. These are Primary, Secondary, Indoor and outdoor air pollution. The primary air pollution is caused by directly releasing pollutants like smoke from factories, SO₂, dust, PM, CO, NO_x, VOCs, and Lead. This pollutant causes asthma attacks, carcinogenic issues, neurological development of children, lung cancer. The secondary pollutants are formed through chemical reactions with primary pollutants. They impact our health, respiratory systems, lungs, the major secondary pollutants are O₃, smog, Acid rain, NO₂. The Indoor air pollution occurs when smoke from solid fuels, tobacco, mould, chemical fumes are released. The outdoor pollutants are released from vehicle emissions, industrial smoke, burning fossil fuels, power plants.

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To prevent the pollutions mainly air pollution, some air pollution acts and conferences are made in worldwide. These are as follows:

Clean Air Act (United States) was passed in 1970 and later amended in 1977 and 1990. It gives the authorization to U.S. Environmental protection agency to regulate air emissions from vehicles and industries and other sources. It was made for protecting the human health and improvisation the air quality. Air (Prevention and control of pollution) act, 1981-India was passed in 1981 to control, prevent and reduce air pollution in India. It also established the central and states pollution control board to regulate air quality. Environment protection act (1986) provides a framework for protecting and improving environmental quality, including air. It empowers the government to set standards for emissions and regulate industrial pollution. Earth Summit (1992) was Held in Rio de Janeiro which focused on environmental protection and Sustainable development as well as on air quality and climate change. Other conferences on air pollution are Paris Climate Conference (COP 21, 2015), World Environment Day, are Bharat State (BS) emission Standards, National Ambient Air Quality Standards (NAAQS), Montreal Protocol (1987) etc.

To reduce the air pollution and improve the human health, the various agencies and Government around the world are introducing some policies. These policies focus on controlling emissions from industries, vehicles, energy production, and waste management. Some policies are Banning crop and open waste burning, Monitoring air quality and issuing public advisories, Promoting renewable energy (solar, wind, hydro) etc.

The UNCED is given a definition on the concept of sustainable development. It explains sustainable development as a process that provides for the current generation who does compromise on the needs of future generations.

The next portion of the present paper is constructed as follows:

Section 2 discusses the literature review and the field of observation. In section 3, methodology and data source are presented. Results of the analysis are discussed in section 4 and some concluding remarks are made in section 5.

2. Survey of Literature and objectives of the Study

In this section survey of literature and the fields of observation are discussed. Subsection 2.1 discusses the literature survey and the scope of the study is presented in subsection 2.2.

2.1 Survey of Literature

The review of the literatures reveals that there many studies related to air pollution or particular one type of air pollution in India and around the globe. In this

connection mention should be made of the following names among others:

Lvovsky (1998) showed that India is one of the countries which appear to bear a very high level of pollution costs by international comparison. This study evaluates the effects of revelation to particulates on the mortality rate in India, and the issues of economic valuation of illness and early death due to air pollution in some developing countries. By illustrating a case study of Mumbai, the paper examined the relative effects of different sources of pollution on the appearance levels and health outcomes, and uses some dimensions and policies for a good health conditions. Dinda, & *et al.*, (2000) showed in their empirical study, an inverse (and sometimes U-shaped) relationship between per capita real income and environmental deterioration as opposed to the inverted U-shaped Environmental Kuznets Curve (EKC) found in many earlier studies. They observed the level of suspended Particulate Matter (SPM) in the atmosphere decrease as capital concentration increases. Per capita real income is also found to be inversely related to SPM partially, but the interaction effect of income per capita and capital-intensity on SPM is observed to be positive. Andreoni and Levinson (2001) suggested that the incomes of country are depended on some pollutants. This relationship has been shown by an inverse U-shaped 'environmental Kuznets Curve'. They present a significant model of the micro-foundations of this relationship, in which the curve depends on increasing returns in the technological link between consumption of a desired good and abatement of its undesirable byproduct. They conclude by presenting empirical support for increasing returns to minimize some common air pollutants. Bell, McDermott, Zeger (2004) examined that Ozone gas has a negative impact on health. For the harmful effect of Ozone gas, hospital admissions rates are increasing, and strengthening of breathing problems. They used time-series analysis to estimate the relations between day-to-day variation in ozone levels and mortality rates. Peng, Chang, and Bell (2008) tried to analyze that most of the health issues were caused by the particulate matter of 2.5(PM_{2.5}) μm or less in astrophysics indicators (PM_{2.5}). This study concerns about the health issues due to particular matter which value is greater than 2.5 μm and 10 μm or less in aerodynamic indicator (PM_{10-2.5}) is determined. Hutton (2011) measured that the total damage costs for atmospheric pollution to be US\$ 3.0 trillion or 5.6% of the Gross World Product (GWP) in 2010. The amount of losses is US\$ 430 for every person globally. Damage costs are distributed equally between indoor and outdoor air pollution worldwide; while around two-thirds of the compensations are to the populations of developing countries. A further decline from the current economic damage levels will require successful environmentally sustainable policies, but these strategies are not significant to reduce poverty in developing countries. Zvin and Neidell (2012) postulated that the effect of

pollution on productivity of the worker by relating exogenous daily variations in ozone layer with the productivity of farming workers as recorded under piece-rate contracts. They find that ozone levels are going below federal air quality standards which have a significant impact on labor productivity. Kankaria & *et al.*, (2014) studied on Indoor Air Pollution. They tried to analyse the impact of Indoor Air pollution in India on public health. Luo, Chen, and Zhang, *et al.*, (2014) tried to find the relation between the socioeconomic indicators such as Gross Regional Product per capita, the concentration of air pollutants (like PM₁₀, SO₂, NO₂), and the air pollution index (API) in 31 mainland China's provincial capitals during 2003 to 2012. The three major industries had a quadratic correlation with NO₂, but a negative correlation with PM₁₀ and SO₂. Li, Liu, and Salvo (2015) examined the fluctuations in level of per worker output over 15 months for a panel of 98 manufacturing workers at a plant located in north China's industrial city in Hebei province. The workers who work over 8 hours can earn an extra but very low amount of wage. Over 15 months, particulate matter 2.5 is measured at an outdoor air monitor located 2 km from the plant ranged between 10 and 773 micrograms per cubic meter ($\mu\text{g}/\text{m}^3$, 8-hour means) which variation is larger than observed value in the rich world today. Ravindra & (2016) focused on a case study on Indian scenario and presented the current scenario of air pollution in India with special reference to particulate matter. The study suggests that the development of air quality is needed and forecast the pollution level for health monitors for public. The study concludes that the using models and statistical tools are important to bridge the gap between policy and science. Ravishankara & *et al.*, (2020) studied on urban Outdoor Air Pollution in India. They use census data with satellite-derived demarcations to parse India's population into urban and nonurban regions and satellite-derived surface PM_{2.5} level to see the impacts on human in urban and non-urban areas. The study shows that with implications to monitoring, rules, physical condition, and guiding principle, outdoor air pollution is just as rigorous in nonurban regions as in the urban regions of India. Singh & *et al.*, (2021) try to determine the fundamental factors in high air pollution over India with implications for mitigation. They use most recent meteorological data from the European Centre for Medium-range Weather Forecasting. The study finds that Indo-Gangetic Plain (IGP) emerges as the most polluted region. Bera (2022) analysed the impact of Air pollution in some Indian states by comparing the rank positions between 2007 and 2020. Chakraborty & Bera (2022) try to analyse the relative position and relative performance of some sample states in India for SO₂, NO₂, P₁₀ and PM_{2.5} separately. They use simple mean and Rank correlation method to find the linear association between states. Iqbal, *et al.*, (2022) determine the particulate matter (PM₁₀) in terms of total suspended particles (TSP) in the marble factories and without marble factories areas. This study concludes that the areas of the marble factories

were more at risk to air pollution as the TSP concentration was higher than the optional TSP levels. Sharma & Mauzerall (2022) analyzed the data on Air pollution in India between 2015 and 2019. They present the first comprehensive analysis of government air quality for PM₁₀, PM_{2.5}, SO₂, NO₂ and O₃. They find that particulate pollution dominates the pollution mix across India with virtually all sites in northern India (divided at 23.5°N) exceeding the annual average PM₁₀ and PM_{2.5} residential national ambient air quality standards (NAAQS).

2.2. Objectives:

The major objectives of the present study are as follows:

- To analyse the relative position of the Indian states region wise for different pollutants separately
- To analyse the relative performance of Indian states region wise for different pollutants separately
- To analyse the relative performance for total pollutants for different regions separately

3. METHODOLOGY AND SOURCE OF THE DATA

In this section Methodology and source of the Data are discussed. Subsection 3.1 discusses the Methodology and Data source is presented in subsection 3.2.

3.1. Methodology

The present study tries to analyse the relative position and relative performance of the Indian states region wise by considering 16 major states in India over 18 years (2007-2023) for Air pollutants like SO₂, NO₂, PM₁₀ & PM 2.5. These 16 states are divided into four regions like Northern; Eastern/North East; Southern; Western/Central. The Northern States are Punjab, Rajasthan, Uttar Pradesh, Himachal Pradesh and Delhi. The Eastern States are Andhra Pradesh, Karnataka, Kerala and Tamil Nadu. The Southern States are Assam, Odisha and West Bengal. The Western and Central zone states are Gujarat, Madhya Pradesh, Maharashtra and Chhattisgarh.

To analyse the relative position of the Indian state's region wise for those pollutants separately, this study compares the annual average value of SO₂, NO₂, PM₁₀, PM_{2.5} in 2007 with the annual average value of same pollutants in 2023. Then position by ranking the states zone wise is shown in tables. Finally, to see the relationship between the two years of the zone wise states for different pollutants, the rank correlation is calculated.

To analyse the relative performance of the four regional states in India, the average of the annual average of the states for four pollutants is calculated from 2007 to 2023 separately and then compared with the Grand Mean. The relative performance of the states is good or

bad for that particular region is determined by less than or greater than GM value respectively.

As it is well known that pollution is a bad good, the state which has got minimum value of concentration is assigned rank 1 and vice-versa. While considering the change in rank, decreasing rank means that particular state's pollution decreases. Say, from rank A to B, where $B < A$. and that have increasing rank if the state rank has change from A to B, where $B > A$.

3.2. Data Source:

All the data used are obtained from National ambient air pollution, Air Quality Index and World monitoring data.

4. RESULTS AND DISCUSSION

This analysis shows how much the selected states are affected by the pollutants like SO₂, NO₂, PM₁₀, PM_{2.5}.

Table 1: Rank of the Indian States during 2007 and 2023 (for SO₂)

States	2007	2023	Rank
	NORTH		
Punjab	14	12	Decrease
Rajasthan	10	10	Unchanged
U. P.	11	15	Increase
Delhi	4	1	Decrease
H. P.	1	2	Increase
	EAST/NORTH EAST		
Assam	3	5	Increase
Odisha	2	9	Increase
W. B.	9	8	Decrease
	SOUTH		
A.p.	8	6	Decrease
Karnataka	7	14	Increase
Kerala	5	3	Decrease
Tamilnadu	12	13	Increase
	WEST/ CENTRAL		
Gujarat	15	7	Decrease
M. P.	16	11	Decrease
Chhattisgarh	6	4	Decrease
Maharashtra	13	16	Increase

The above table shows the rank of the selected Indian states by comparing SO₂ Annual average data for 2007 and 2023. The table shows that the ranks of Punjab and Delhi decreased and Uttar Pradesh and Himachal Pradesh increased and for Rajasthan is unchanged, which are situated in the North zone of India. The ranks of Assam and Odisha increased and West Bengal

decreased, which are in Eastern/ North Eastern zone in India. By comparing the southern zone of India, it shows that the ranks of Karnataka and Tamil Nadu increased and Andhra Pradesh and Kerala decreased. Also, this comparison shows that in the West/ Central zone of India, the ranks of Gujarat, Madhya Pradesh and Chhattisgarh decreased and Maharashtra increased.

Table 2: Rank of the Indian States during 2007 and 2023 (for NO₂)

States	2007	2023	Rank
	NORTH		
Punjab	14	12	Decrease
Rajasthan	10	14	Increase
U. P.	15	13	Decrease
Delhi	7	1	Decrease
H. P.	1	2	Increase
	EAST/NORTH EAST		
Assam	2	4	Increase
Odisha	5	8	Increase
W. B.	16	15	Decrease
	SOUTH		
A.p.	12	7	Decrease
Karnataka	6	9	Increase

Kerala	3	3	Unchanged
Tamilnadu	13	11	Decrease
WEST/ CENTRAL			
Gujarat	9	5	Decrease
M. P.	8	10	Increase
Chhattisgarh	4	6	Increase
Maharashtra	11	16	Increase

The above table shows the rank of the selected Indian states by comparing NO₂ Annual average data for 2007 and 2023. By comparing the Northern zone states, it shows that the ranks of Punjab, Uttar Pradesh, and Delhi decreased and Rajasthan and Himachal Pradesh increased. By comparing the East/ North Eastern states with the GM, the ranks of Assam & Odisha increased and

for West Bengal it decreased. In Southern zone of India, the ranks of Andhra Pradesh & Tamil Nadu decreased and Kerala remained unchanged, and Karnataka increased. Also, by comparing the West/ Central states, it shows that the ranks of Maharashtra, M.P & Chhattisgarh increased and for Gujarat it increased.

Table 3: Rank of the Indian States during 2007 and 2023 (for PM10)

States	2007	2023	Rank
	NORTH		
Punjab	8	15	Increase
Rajasthan	4	16	Increase
U. P.	3	13	Increase
Delhi	6	1	Decrease
H. P.	16	4	Decrease
EAST/NORTH EAST			
Assam	2	5	Increase
Odisha	10	11	Increase
W. B.	9	14	Increase
SOUTH			
A.p.	5	7	Decrease
Karnataka	11	9	Decrease
Kerala	14	3	Decrease
Tamilnadu	15	8	Decrease
WEST/ CENTRAL			
Gujrat	12	6	Decrease
M. P.	1	10	Increase
Chhattisgarh	13	2	Decrease
Maharashtra	7	12	Increase

The above table shows the rank of the selected Indian states by comparing PM₁₀ Annual average data for 2007 and 2023. By comparing the Northern zone states, it shows that the ranks of the Himachal Pradesh & Delhi decreased and Rajasthan, Uttar Pradesh and Punjab increased. By comparing the East/ North Eastern states

with the GM, the ranks of Assam & Odisha and West Bengal increased. In Southern zone of India, the ranks of Andhra Pradesh, Kerala, Karnataka & Tamil Nadu are decrease. Also, by comparing the West/ Central states, it shows that the ranks of Maharashtra & M.P increased and Gujarat & Chhattisgarh decreased.

Table 4: Rank of the Indian States during 2007 and 2023 (for PM2.5)

States	2007	2023	Rank
	NORTH		
Punjab	1	8	Increase
Rajasthan	3	15	Increase
U. P.	16	13	Decrease
Delhi	15	1	Decrease
H. P.	2	4	Increase
EAST/NORTH EAST			
Assam	8	7	Increase
Odisha	4	12	Increase
W. B.	11	16	Increase

	SOUTH		
A.p.	12	5	Decrease
Karnataka	6	10	Increase
Kerala	9	2	Decrease
Tamil Nadu	13	9	Decrease
	WEST/ CENTRAL		
Gujrat	14	6	Decrease
M. P.	5	11	Increase
Chhattisgarh	10	3	Decrease
Maharashtra	7	14	Increase

The above table shows the rank of the selected Indian states by comparing PM2.5 Annual average data for 2007 and 2023. By comparing the Northern zone states, it shows that the ranks of Uttar Pradesh & Delhi are decreased and for Rajasthan, Himachal Pradesh and Punjab it increased. By comparing the East/ North Eastern states with the GM, the ranks of Assam & Odisha and West Bengal increased. In Southern zone of India, the ranks of Andhra Pradesh, Kerala & Tamil Nadu decreased and Karnataka decreased. Also, by comparing the West/ Central states, it shows that the ranks of

Maharashtra & M.P increased and Gujarat & Chhattisgarh decreased.

The rank correlation of the all states of the four regions in India is -0.2058 which means that there is a negative relationship between the ranks of the data in two years (2007 & 2023).

5. Result of analysis of the relative performance in region wise of the sample states considering different air pollutants:

Table 5: Relative performance of the sample states considering different air pollutants

SO2	NORTH		EAST		SOUTH		WEST	
	Punjab	Bad	Assam	Good	A.p.	Good	Gujarat	Bad
	Rajasthan	Good	Odisha	Good	Karnataka	Good	M. P.	Bad
	U. P.	Bad	W. B.	Bad	Kerala	Good	Chhattisgarh	Good
	Delhi	Good			Tamil Nadu	Bad	Maharashtra	Bad
	H.p.	Good						
	North		East		South		West	
NO2	Punjab	Bad	Assam	Good	A.p.	Bad	Gujarat	Good
	Rajasthan	Bad	Odisha	Good	Karnataka	Good	M. P.	Bad
	U. P.	Bad	W. B.	Bad	Kerala	Good	Chhattisgarh	Good
	Delhi	Good			Tamil Nadu	Good	Maharashtra	Bad
	H.p.	Good						
	North		East		South		West	
PM10	Punjab	Bad	Assam	Good	A.p.	Good	Gujarat	Good
	Rajasthan	Bad	Odisha	Good	Karnataka	Good	M. P.	Bad
	U. P.	Bad	W. B.	Bad	Kerala	Good	Chhattisgarh	Good
	Delhi	Good			Tamil Nadu	Good	Maharashtra	Good
	H.p.	Good						
	North		East		South		West	
PM2.5	Punjab	Good	Assam	Good	A.p.	Bad	Gujarat	Bad
	Rajasthan	Good	Odisha	Bad	Karnataka	Bad	M. P.	Bad
	U. P.	Bad	W. B.	Good	Kerala	Good	Chhattisgarh	Good
	Delhi	Good			Tamil Nadu	Good	Maharashtra	Good
	H.p.	Good						

By comparing the average of SO2 annual average value of the sample Zonal states in India with Grand Mean (GM), the result shows that the average values of the Rajasthan, Delhi, H.P. are lower than but Punjab & UP are greater than GM, which are in North zone of India. In East/North East zone states like Assam & Odisha have less value than GM but West Bengal has greater value than GM. In South zone, the average values of AP, Karnataka, Kerala are less than and of Tamil Nadu

is greater than GM value. In West region of the India, Gujarat, MP and Maharashtra have large average value than but Chhattisgarh has less value than GM.

By comparing the average of NO2 annual average value of the sample Zonal states in India with Grand Mean (GM), the result shows that the average values of the Northern States like Delhi & HP are less than Grand Average but Rajasthan, Punjab & UP are

less. In Eastern zone of India, the average values of Assam & Odisha are lower than but WB is more than GM. In Southern Zone, the average values of Karnataka, Kerala & Tamil Nadu are less than but of AP is greater than GM. In Western zone the values of Gujarat & Chhattisgarh are less than but MP and Maharashtra are greater than GM.

By comparing the average of PM10 annual average value of the sample Zonal states in India with Grand Mean (GM), the result shows that the average values of the Northern States like Punjab, Rajasthan & UP have more than average value but Delhi & HP have greater than average value. In Eastern Zone, Assam & Odisha have less than average value but WB has larger than GM. In Southern zone all states have less than GM value. In Western zone, the average values of Gujarat, Chhattisgarh & Maharashtra are less than but MP is greater than GM.

By comparing the average of PM2.5 annual average value of the sample Zonal states in India with Grand Mean (GM), the result shows that in Northern zone, out of five states four have less average value than GM but only UP has greater than GM. In east zone, Assam & WB have less than but Odisha has greater average value than average of all states. In South region, the average values of AP & Karnataka are greater than but of Kerala & Tamil Nadu are less than GM. In the West/Central Zone, Gujarat & MP have greater than but Chhattisgarh & Maharashtra have less average value than GM.

The above table represents that the relative performance of the zonal states in India by comparing the average values of different pollutant with Grand Average.

SUMMARY AND CONCLUSION

The present study tries to analyze the level of air pollution overtime in the major polluting states of India in zone wise. In doing so, it attempts to identify the relative performance of states in zone wise as well as the relative position of the different regions in India in terms of four air pollutants such as SO₂, NO₂, PM10 and PM2.5.

From the above analysis it can be concluded that there is clear evidence of inter region disparity among the Indian states in terms of the relative performance as well as the relative position of the different regional States in India.

By comparing the four zones in India for SO₂, the North & South zone have good performance than others. For NO₂ & PM 10, only South region is doing well than other zones. For PM2.5, Northern zone States have good performance.

Regarding the relative performance of the India's four regions, it is found that, by comparing all the air pollutants in North Zone, Uttar Pradesh has bad performance during 2007 to 2023 and Punjab is only doing well performance in PM2.5 otherwise it has bad performance in other three air pollutants, Rajasthan has good performance in SO₂ & PM₂, and Delhi & Himachal Pradesh are doing well in all air pollutants. In Eastern Zone, Assam & Odisha are doing good and WB is doing bad in SO₂, NO₂, PM10 but in PM2.5 Assam & WB are doing well but Odisha has bad performance. In Southern Zone, Andhra Pradesh is doing well only in SO₂ & PM10, Karnataka is doing bad only in PM2.5 otherwise it has good performance over the years. Kerala is a good performer in all pollutants and Tamil Nadu has only worse performance in SO₂ other it is also doing well.

In western/ Central Zone, Chhattisgarh is doing well in all air pollutants over the years. Gujarat is doing well in only NO₂ & PM10; Maharashtra is doing well only in PM10 & Pm2.5. But Madhya Pradesh is a bad performer in all pollutants.

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