Research Article

A Decadal Trend Analysis of Air Pollutants in The Capital of Uttar Pradesh: A Study of Lucknow City

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Abstract

Introduction: India is one of the highly polluted country in world in term of air pollution and population. Also due to migration, urbanization and lack of awareness among the masses, India faces the severe air pollution crises.

Material and Method: The data is taken from CPCB, UPPCB & NAMP. For $PM_{2,5}$,PM_{10},NO_2 and SO_2 annual average mean value is calculated for this study by taking the monthly average of the years. Least square is used for calculating the annual trend value and also R-squared evaluates the scatter of the data points around the fitted Line or coefficient of determination.

Result: This paper aim to analysis the trend of air pollutant $PM_{2,5}$,PM_{10},NO_2 and SO_2 in Lucknow from 2015-2025 and implication for health and Economy in Lucknow City .The result of analysis indicates high level of pollutant, which is above the permissible limits of National Ambient Air Quality Standards (NAAQS) .Linear trend shows a positive slope of 1.438 and R^2 is 0.66794 is the coefficient of determination, which means 66.94% of the variation is explained by linear trend and rest 33.06% is due to lack data of particulate matter especially $PM_{2.5}$ since 2015-2023.Also lack of Particulate matter, Sulphur dioxide and Nitrogen dioxide data in month of May in two location Hazratganj and Mahanagar of Lucknow was not available. The data of PM $_{2.5}$ from 2015 to 2023 is not available, And only three location data is available in 2024 out of five monitoring sites i.e. Hazratganj, Mahanagar ,Ansal TC and Gomtinagar ,Aliganj,Talkatora .

Conclusion: Health and economy both are going to suffer due to high level of air pollutants, driving social, medical and economy cost.

Key Words: Air Pollutants, $PM_{2,5}$,PM_{10},NO_2 and SO_2 ,National Ambient Air Quality(NAMP), Central Pollution Control Board (CPCB), Uttar Pradesh Pollution Control Board (UPPCB)

INTRODUCTION

Most of India's people approximately 1.4 billion are effected by poor levels of atmospheric pollutant particulate matter, especially (PM2.5), the most harmful pollutant to human health emitting from many ways . The overall impact on health are leading to loss of productivity, economic losses and jobs. Tackling air pollution is complex, with emissions from multiple sources and neighboring states requiring coordinated, long-term action. The solution lies in managing pollution across an entire air shed not city by city built on rigorous modelling and multi-sector coordination. (1)

In advanced countries, ambient air quality has improved. However, there is evidence that exposure to air pollution even at the Levels still leads to adverse health effects. In developing countries like India, due to atmospheric pollutants from transportation and industrial emissions has increased because of energy demands. Especially, ambient particulate matter is the important air pollutant in India. Most of the cities in India, particulate levels of pollutants in the atmosphere have been found too high ,which is above the maximum limit. In the recent decades, a primary concern has been laid on the health impact of the air pollutants. Epidemiological and toxicological studies have well established that the human mortality and morbidity rate have risen. Several studies have investigated on air pollutants across the globe. (2).The trends of air quality in major states of North India, highlighting the sources of pollution and the challenges faced in mitigating air pollution. The impact of agricultural activities, particularly crop residue burning, on air quality in North India, providing insights into the seasonal variations and spatial distribution of pollutants. Focusing on health impacts, the study concluded by the Global Burden of Disease 2017, find the effects of air pollution on deaths, disease burden, and life expectancy in various district of India, including those in South India. While specific literature on air pollution in Northeast India may be limited compared to other regions. (3).In a developing countries , due to the severe problem related to high level of population ,without control expanding of urbanization with the development of industrialization. Which result in worst air quality, mostly in countries with lack of resources socially imbalance and also the absence of knowledge on sustainable management about the environment. (4)

As per TERI's inventory (5), the PM2.5 emissions are dominated by 36 % of industrial and 39 % of residential combustion sectors. Just 4% of transport contributes PM2.5 emissions at the National level ,however, these emissions are concentrated

in the urban areas only . Moreover, being ground-based sources, their contribution to prevailing air quality levels could be much high.(6)

Table 1 :AQI of different Cities of India

Year	Ahmedbad	Bengaluru	Chandigarh	Chennai	Delhi	Kolkata	Lucknow	Mumbai	Pune	Varanasi	Vishakhapatanam
2015	116.74	70.48		113.61	229.55		182.01	110.22	163.6	197.71	
2016	163.31	91.43		115.03	256.37	94.94	227.85	93.84	142	226.27	97.65
2017	197.27	68.82		94.7	227.48	103.9	225.25	107.46	93.28	218.58	114.3
2018	158.13	80.29		99.17	228.41	133.96	217.33	112.37	96.42	211.83	119.54
2019	152.55	81.88	138.14	87.72	214.62	136.5	188.86	102.66	100.2	214.79	112.38
2020	117.93	64.54	75.05	68.52	185.14	111.12	171.94	94.68	85.44	154.25	95.52
2021	122.59	69.58	103.71	66.21	208.58	123.65	159.54	112.18	95.68	143.93	106.28
2022	117.68	78.12	133.84	71.6	209.19	112.98	139.78	120.52	116.6	94.84	110.31
2023	110.13	72.59	138.81	78.08	203.63	106.06	127.2	119.82	123.9	64.48	129.38
2024	114.45	73.94	151.76	71.85	208.93	100.86	125.78	91.28	96.58	55.51	110.27
2025	100.73	71.98	108.63	74.67	180.67	54.93	118.25	83.2	94.17	60.94	113.47

Across all 11 cities analysed, every single location reported AQI values above safe limits for most or all the decade. Even the least polluted metros frequently exceeded recommended thresholds. Northern Cities Show Persistent High Pollution , Cities such as Lucknow, Varanasi, and Ahmedabad show consistently high AQI levels ,Lucknow and Varanasi frequently stayed above 200 until 2020. Slight downward trends appear, but 2025 values still exceed safe air quality.

Overall, the data confirms that every major Indian city analysed experiences unhealthy air quality for a significant portion of the year, and even improving cities remain outside the safe AQI range. Despite recent policy interventions and technological improvements, India's top cities continue to face serious air-quality challenges, highlighting the need for more aggressive pollution-control strategies, sustained enforcement measures, and long-term urban planning reforms. (7)

Both PM10 and PM2.5 mainly comes from different sector of emission, and have different level chemical compositions. Emissions from these sources of combustion of gasoline, diesel fuel, oil or wood produce most of the PM2.5 pollution found in outdoor air, as well as a small proportion of PM10. Also PM10 consist dust from landfills and agriculture, construction sites, wildfires and brush,waste burning. Industrial sources, wind-blown dust from open lands, pollen and fragments of bacteria [8]. Nitrogen dioxide (NO_2) and sulfur dioxide (SO_2) are the two most critical gaseous pollutants that affect regional and global air quality, human health, ecological conditions, and climate change.NO_2 can fade fabrics and reduce visibility. Respiratory irritation, mucus production, bronchitis, and bronchospasm are the health problems that result from SO_2 emissions.Global warming and eutrophication are two significant impacts of NO_2 and SO_2 pollution. (9)

STUDY AREA

Lucknow is located at 26.8467°N, 80.9462°E, and is the capital city and administrative headquarters of the Indian state of Uttar Pradesh (Figure 3). The city is located in the Awadh region, known as India's granary. It is ranked twelfth-most populous urban agglomeration in India.Total area coverd by Lucknow district is 2,528 sq km.Barabanki is surrounded by Eastern side, Unnao on western side , Raebarielly on the southern side and Sitapur and Hardoi districts on the northern side . Lucknow locates on the north-western riverside of the Gomti , which flows through the city. Some smaller lake are beta, kukrail,

loni,beta .From the south of the city 5 sai river flows and raebraielly district located on east side. There are four tehsils in Lucknow districts; Bakshi ka Talab, Lucknow, Mahilabad, Mohanlalganj. The Lucknow Municipal Corporation area is part of the Lucknow tehsil. [10]

Lucknow district rank 5th in the state with a population of 3.7 million. The population of Lucknow city (Nagar Nigam) as per 2011 census is 2.8 million. The decal population growth rate in Lucknow city during 2001-11 is 28.81%.The average increase in population of the city from 1971 to 2011 is 3.22% per year . This has caused the expansion of city from 600 sq. km to 980 sq. km within a span of 10 years since 1999. According to census 2011, Lucknow has population density of about 8049 persons/Km2. The city has 609 slums with 148117 households. It has an extreme tropical climate with extreme cold and dry winters from Dec to Feb and dry, From april to June hot and dry summer hot summers. Late June to September rainy season, when it gets south and west winds brings monsoon with an average rainfall of 1000 milli metre. In winter max. temperature is around 25 degree Celsius and minimum temperature is around 3 to degree Celsius. Always summer are the hottest month of the year 40 to 45 degree Celsius. [10]

Number of vehicles has been grown by 160 percent in comparisons to population growth of 25 percent from 2001 to 2011. The present review based on monitoring conducted in Lucknow identified particulate matter as main pollutant in the city. High traffic densities and abnormal meteorological factors adversely influenced Ambient Air Quality of Lucknow especially during winter. Ambient Air Quality is being monitored regularly by the Board. At source emission monitoring i.e. stack monitoring of industries is also being done regularly and action is being taken accordingly on the basis of analysis report. If any industry is found violating the standards firstly show-cause notice is issued to the industry followed by closure under Air (Prevention and Control of Pollution) Act, 1981.[11]

Implication on Health and Economy

Air pollution, intensified by climate change, represents a major global environmental health threat that is contributing to a wide range of adverse health outcomes even at the lowest measurable concentrations. While air pollution is associated with both short-term (acute) and long-term (chronic) health effects ,repeated short-term exposure events can contribute to broader declines in population health. Acute respiratory and cardiovascular events may shorten life expectancy, exacerbate chronic disease, and worsen underlying vulnerabilities, particularly in communities with limited access to healthcare or where poor air quality occurs frequently [12]Asthma, chronic obstructive pulmonary disease (COPD), lung cancer,and other respiratory illnesses are among the morbidity and mortality from exposure to airborne pollutants, Airborne pollutants are particularly harmful in urban areas because of the ease of emissions during the traffic congestion and the industrial activities. Nitrogen dioxide (NO_2), sulfur dioxide (SO_2), carbon monoxide (CO), and ground level ozone (O_3) are among the most harmful pollutants that increase respiratory inflammation and decrease lung function decline.Long-term exposure to air pollution induces many health problems such as respiratory problems, cardiovascular disease, neurologic disorders, stroke, and cancer. [13]

Due to rapid climate change, industrial expansion, urbanization, stubble burning, and population growth have further diversified and intensified pollution sources. [14] .Air pollution costs Indian firms to loss upto $95 billion dollar(USD) every year, and 3% loss of India's total GDP. To improve economic prospects and save lives, especially businesses and policymakers must become more dynamic advocates for clean air by showing how much the economy and society stands to gain. [15]

Air pollutants impacts the business in three ways They are (i) Loss of worker productivity due to illness and also death of worker , e.g., in term of opportunity cost , (ii) loss of consumer turnout results in revenue loss ,(iii) It result in mortality due to air pollution. These costs differ in both the intensity and their directness of impact on businesses. It results in work absenteeism and lower on-the-job productivity by impairing workers' cognitive and physical performance. In China a study of workers of call Centre due to air pollution related disease lost productivity is over 2 billion USD . Low consumer falls hinder the overall revenue capacity of businesses. Also lower air quality results in a reducing customer visit, which result in low footfalls.A study carried out in Spain regarding the credit card transactions reveals i.e 10% of every increase in particulate matter ,most people in Spain spent only 20-30 million euro less per day.[16]

India's NAAQS have taken six components into consideration: land use patterns, pollutants, average time of exposure (annual, daily, eight hourly and hourly), levels of pollution, monitoring methods, and conditions (for example, the 24-hour or 8 hours averaged values should meet the NAAQS guideline levels 98% of the time in a year. However, the NAAQS don't have a health component. India has lacked evidence-based research linking impacts of air pollution on morbidity and mortality.[17]

Material and Method

Time series analysis is a cherished technique in economics for measuring and forecasting long-term trends. The least squares method (LSM) is a vital tool for modelling economic data. This statistical method helps in fitting a trend line to a dataset, permitting economists to make informed judgments based on historical data.A helpful statistical method for figuring out a regression or best-fit line for a particular outline is least-squares approach. [18]

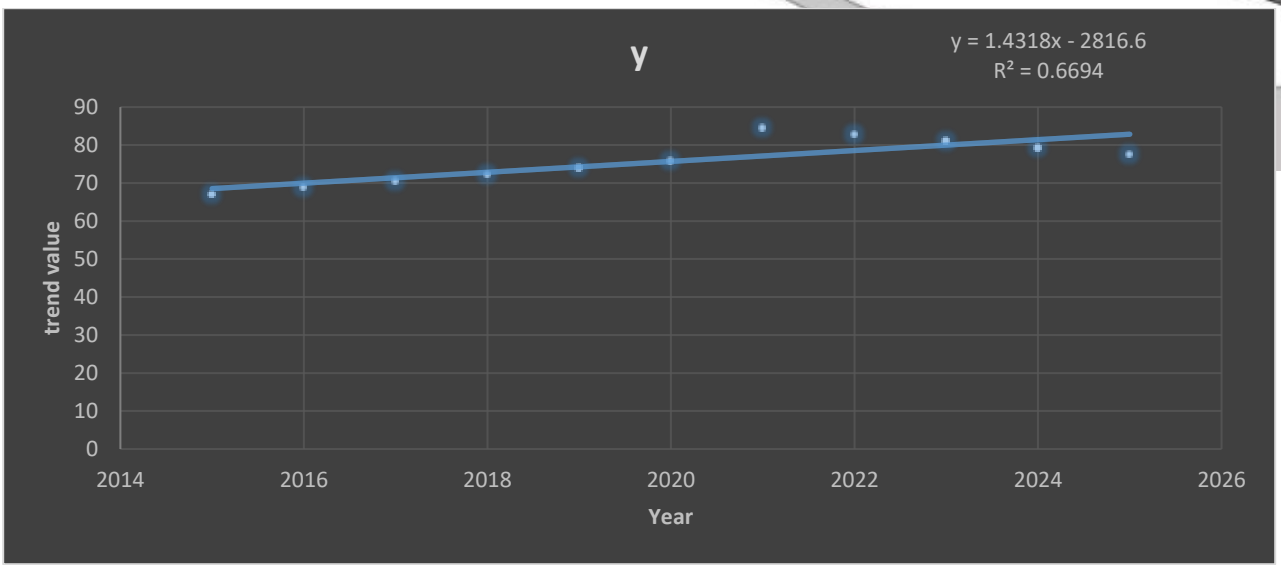
The monthly mean values of air pollutants were collected from the Central Pollution Control Board(CBCP), New Delhi (2024-2025), Uttar Pradesh Pollution Control Board (UPPCB)and National Ambient Air Quality Monitoring Programme (NAMP) 2015-2023.The data for the analysis is from 2015-2025 of $PM_{2,5}$,PM_{10},NO_2 and SO_2have been considered for five zone Hazratganj, Mahanagar ,Ansal TC and Gomtinagar ,Aliganj,Talkatora based on Industrial Residential and Commercial. As complete data is available expect for PM 2.5 only data is available from 2024-2025. In frequency of monitoring the number of days is not equal across years of data collection under National Ambient Air Quality Monitoring Programme (NAMP). For $PM_{2,5}$,PM_{10},NO_2 and SO_2 annual average mean value is calculated for this study by taking the monthly average of the years. Least square is used for calculating the annual trend value and also R-squared evaluates the scatter of the data points around the fitted regression line. [19]

Table 2. Annual Average Trend in Yearly Air pollutants $PM_{2,5}$,PM_{10},NO_2 &SO_2

Years	[123]Average Yearly Value	Time dev.origin 2020	Square	Product of x &y	Trend Value
	y	x	x^2	xy	a+bx=y
2015	67.91666667	-5	25	-339.5833333	75.70+1.75(-5)=66.95
2016	79.8	-4	16	-319.2	75.70+1.75(-4)=68.7
2017	94.66666667	-3	9	-284	75.70+1.75(-3)=70.45
2018	83.33333333	-2	4	-166.6666667	75.70+1.75(-2)=72.2
2019	82.16666667	-1	1	-82.16666667	75.70+1.75(-1)=73.95
2020	78.27777778	0	0	0	75.70+1.75(0)=75.7
2021	77.75427407	1	1	77.75427407	75.70+1.75(5)=84.45
2022	70.984133	2	2	141.968266	75.70+1.75(4)=82.7
2023	65.25739815	3	3	195.7721944	75.70+1.75(3)=80.95
2024	65.78847222	4	16	263.1538889	75.70+1.75(-2)=79.2
2025	66.81271991	5	25	334.0635995	75.70+1.75(1)=77.45
	832.7581085		102	-178.9044437	832.7

In above table a short cut method of least square is applied. In which regression equation Y=a+bx is used and the columns of Years, Y, X, X^2, XY were used to estimate the equation. From the above table it has been observed that all pollutants are an increasing trend through the year, though little decline can be observed from year 2015 to 2020 after that from 2021-2023 between it started increasing but in 2024 to 2025 a decreasing trend value is seen, still it is not very satisfactory trend according to NAAQ standards limit in Lucknow.

[32]. **Source :Data from CBCP &UPPCB and Research Compilation**



The above graph indicates the yearly trend of the variable (y) from 2015 to 2025 of eleven years' data to analysethe trend of air pollutants by applying the linear trend line.

$$Y=1.4318x-2816.6$$

Slope 1.4318 shows that the value of y increasing by approximately 1.4318 units per year, which means positive slope and upward trend over the years. $R^2=0.6694$ is the coefficient of determination.it means that 66.94% of the variation is explained by linear trend and rest 33.06% is due to lack data of $PM_{2.5}$.

Table 3: National Ambient Air Quality Standards (NAAQS)

Pollutant	Time Weighted Average	Concentration in Ambient Air	
		Average Rural, Industrial and Residential and other Areas	Ecologically sensitive area (By Central Gov. notification)
Sulphur Dioxide (SO2),µg/m³	Annual *	50	20
Nitrogen Dioxide (NO2),µg/m3	Annual *	40	30
Particulate Matter(<10µg)or PM10µg/m3	Annual *	60	60
Particulate Matter (< 2.5 microns) or PM2.5 µg/m3	Annual *	40	40

[43]

Conclusion

More than decade Air Pollution level is very high double or triple the standard limits of NAAQS in Lucknow. It is harmful not only for humans and the economy but also reason for environmental degradation resulting in climate change.

Despite the efforts by the state government and Central government still air pollution is increasing yearly wise though it is slow but above the standard limits of NAAQS. Air Pollutant data is taken from both the CPCB and UPPCB in which monitoring days are also not same. Insufficient monthly data of PM2.5 from 2015 to 2023.PM2.5 is very harmful air pollutant as studied by many scientist and reviewed in their literature that it impacts the health in worst way like asthma, premature deaths in those people who are suffering from lung disease, silent heart attack and also low socio economic country and people will more effected due to poor health condition. Also it impacts the economy of the Lucknow city due to the loss of working days.

[44] Source: Central Pollution Control Board(CPCB)* Annual Arithmetic Mean (AAM) of min.104 only measurements in a particular site taken twice a week 24 hourly at uniform intervals in a year (Central Pollution Control Board)

Recommendations

More awareness programmes should be conducted by the government for all and especially for low socio economic people regarding the air pollution and its negative effects. Strict action along with implementation should be for industrial areas if they are not following the rules and regulation of the government. More plantation and environment friendly product are used for both the commercial and residential purpose**.**

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