Assessment of Ambient Air Quality of Lucknow City

Post-Monsoon 2021

सीएसआईआर-भारतीय विषविज्ञान अनुसंधान संस्थान
CSIR-INDIAN INSTITUTE OF TOXICOLOGY RESEARCH
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CONTENTS

Salient Features of the Study

- **Geographical Position** : 26^{o} 52' N Latitude, 80^{o} 56' E Longitude, 128 m above Sea Level
- **Area** : 310 sq. km.
- **Population** : 2815033 as per 2011 Census
- **Projected Population** : 65 lakhs as per Master Plan 2031
- **General Climate of Lucknow City** : Subtropical climate, cool dry winter (Dec-Feb) & summer (Mar-Jun). Temperature about 45°C in summer to 3°C in winter. Average annual rainfall about 100 cm.
- **Total Vehicle number of Lucknow city as on 31/03/2021** : 2514461
- **Growth of Vehicles over 2019-2020** : 4.5%
- **Total No. of Fuel Filling Stations (Petrol/Diesel/CNG)** : 149
- **Consumption of Petrol** : 191149 kL
- **Consumption of Diesel** : 176660 kL
- **Consumption of CNG** : 26860650 kg
- **Major Sources of Pollution** : Automobiles, D.G. Sets, biomass burning, construction activities, dry sweeping of roads
- **Parameters Monitored** : PM_{10}, $PM_{2.5}$, SO_2, NO_2 and Noise Levels
- **Study Conducted by** : Environmental Monitoring Division CSIR-IITR, Lucknow

ASSESSMENT OF AMBIENT AIR QUALITY OF LUCKNOW CITY DURING POST-MONSOON, 2021

1.0 SUMMARY

The Post-Monsoon ambient air quality assessment of Lucknow city was carried out by the Environmental Monitoring Division of CSIR Indian Institute of Toxicology Research, Lucknow during the months of September-October, 2021. Air quality status was evaluated by monitoring and assessing critical and health affecting air pollutants like ***1. Respirable Suspended Particulate Matter*** *(PM_{10}, cut off size ≤10 µm, and* ***Fine Particulate Matter*** *($PM_{2.5}$, cut off size ≤ 2.5 µm);* ***2. Indicator Gases*** *(Sulphur dioxide (SO_2) and Nitrogen dioxide (NO_2); and* ***3. Noise levels*** *at 9 representative locations which are grouped into 3 categories viz.;* ***i. Residential area, ii. Commercial area*** *and* ***iii. Industrial area.***

The 24 hr concentrations of PM_{10} ranged from 67.5 µg/m^3 to 313.5 µg/m^3 with an average of 160.1± 35.8 µg/m^3 while in case of $PM_{2.5}$, the 24 hr concentrations ranged from 25.7 µg/m^3 to 199.4 µg/m^3 with an average of 79.1± 13.5 µg/m^3. Irrespective of the locations, the average values of PM_{10} and $PM_{2.5}$ were found to be above the permissible limits of 100 µg/m^3 for PM_{10} and 60 µg/m^3 for $PM_{2.5}$ prescribed by Central Pollution Control Board, New Delhi.

The 24 hr concentrations of SO_2 ranged from 10.0 to 18.6 µg/m^3 with an average of 14.1± 1.6 µg/m^3 while the 24 hr concentrations of NO_2 ranged from 19.8 to 67.9µg/m^3 with an average of 36.4± 5.5 µg/m^3. The average values of SO_2 and NO_2 were well below the permissible limits of 80 µg/m^3 for both SO_2 and NO_2 as prescribed by CPCB, New Delhi (NAAQS-2009).

The day time and night time noise levels ranged from 44.6 to 82.2 dB(A) and 48.6 to 79.6 dB(A) in residential areas and from 52.1 to 88.3 dB(A) and 49.1 to 86.7 dB(A) in commercial areas, respectively. These measured values were above their respective day time standard of 55 dB(A) and night time standard of 45 dB(A) for residential areas and 65 dB(A) and 55 dB(A) for commercial areas respectively. At Amausi Industrial area, the day time and night time noise levels were between 60.6 to 92.7 dB(A) and 60.3 to 96.7 dB(A) respectively. The average values are above the standard of 75 dB(A) for day time and 70 dB(A) for night time recommended for Industrial areas.

The present study reveals that the levels of pollutants like inhalable particulate matter, gases, and noise are gradually increasing due to the fact that air quality monitoring of Post-Monsoon 2021 was held after complete unlock following Govt. directives while the Post-Monsoon 2020 study was held completely during lockdown period. The overall trend reveals that all pollutants are increasing in Lucknow city.

1.1 INTRODUCTION

According to The Air (Prevention and Control of Pollution) Act, 1981, "Air pollution is the presence of any solid, liquid, or gaseous substances including noise in the atmosphere in such concentration as may be or tend to be injurious to human beings or other living creatures or plants or property or environment". Contaminants are defined as inputs of alien and potentially toxic substances into the environment e.g. chemical/microbial contaminant; not all contaminants are pollutants, as their concentrations may be too low to cause visible impacts while pollutants are defined as anthropogenically-introduced substances that pollute water or the atmosphere or those that have harmful effects on the environment.

Gases in earth's atmosphere: On the earth, the atmosphere helps make life possible. The atmosphere is a mixture of gases surrounding a planet or other celestial body. Nitrogen and oxygen are by far the most common gases; dry air is composed of about 78% nitrogen (N_2) and about 21% oxygen (O_2), argon, carbon dioxide (CO_2), and many other gases in much lower amounts and the sum total of these make up <1% of the atmosphere's mixture of gases. It also includes water vapor. The amount of water vapor present varies a lot, but on an average it is around 1%. Besides providing us with something to breathe, it shields us from most of the harmful ultraviolet (UV) radiation coming from the Sun, warms the surface of our planet by about 33° C (59° F) via the greenhouse effect, and largely prevents extreme differences between day-time and night-time temperatures.

There are also many small solid particles and liquid droplets - "suspended" in the atmosphere which are known as "Aerosols". The sources of these aerosols include industrial emission, dust, mist, smoke, volcanic ash, spores & pollen, salt from sea spray and many more. Sometimes, gas molecules can be converted to larger sized molecule of particles through agglomeration during formation of secondary pollutants viz. sulphur dioxide molecule to ammonium sulphate molecule.

Particles are broadly grouped into 3 large classes (i) Suspended Particulate Matter >100 µm, (ii) Respirable Particulate Matter <10 µm and (iii) Nano-particles <0.01 µm. Particles <2.5 µm, a fraction of PM_{10} are categorized as more dangerous and are a subject of health concern due to their tininess and relatively greater surface area. They penetrate up to the alveolar sac and become the cause of cardiovascular and respiratory ailments including bronchitis, asthma and many more illnesses. Cigarette smoke, poly aromatic hydrocarbons, coal-dust particles and indoor air pollution in rural areas are the major causes of lung cancer.

Layers of earth's atmosphere: The atmosphere grows thinner (less dense and lower in pressure) as one moves upward from Earth's surface. It gradually gives way to the vacuum of outer space. There is no precise "top" of the atmosphere. Air becomes so thin at altitudes between 100 and 120 km up that for many purposes that range of heights can be considered the boundary between the atmosphere and space. However, there are very thin but measurable traces of atmospheric gases hundreds of kilometers above Earth's surface.

There are 5 different regions or layers in earth's atmosphere. Each has characteristic temperatures, pressures, and phenomena. The troposphere is the lowest layer, where most clouds are found and almost all weather phenomena occur. Some jet aircrafts fly in the next higher layer, the stratosphere, which contains the jet streams and the ozone layer. Temperatures reach their lowest (-90°C) in the mesosphere, because in this layer there are almost no air molecules to absorb heat energy. The sky also changes from blue to black in the mesosphere, because there are very few molecules for light to refract off from there. The thermosphere, the farthest layer is the widest layer of the atmosphere and absorbs much of the harmful radiation that reaches earth from the Sun. The exosphere represents the transition from Earth's atmosphere to space.

Impact of COVID-19 Period: Air pollution and emissions of the planet-heating gas CO_2 had also fallen rapidly as the COVID-19 virus spread; also there had been a sharp drop in liquid fuel use and emissions in urban areas over 15 months (April-2020 to June 2021). Experts believe that full/ partial lockdowns at different time periods most

likely lead to an overall fall in pollutants discharge/ emissions this year. Levels of air pollutants and global warming gases over some cities and regions have shown a significant drop as COVID-19 virus impacts factory work and travel.

The problem of environmental pollution: The subject of detrimental impacts of environmental pollution/ change has received much attention in the news media for some time. Scientists, policy makers, and the public have become increasingly concerned about the threat that such changes in the environment can bring about. Growing numbers of scientists from a variety of disciplines have been systematically studying specific aspects of this change and are attempting to identify effective strategies for preventing or mitigating potentially catastrophic effects.

According to the WHO 2018, 13 out of 20 cities in India have been identified as the most polluting cities across the world. This has caused air pollution to become one of the foremost public health concerns in most developing countries. Considering the excess pollution levels, ever-increasing vehicle numbers and health concerns of the population, the National Clean Air Programme has identified 122 non-attainment cities in 23 states of the country including Lucknow, to reduce the particulate matter concentration in the next 5 years.

Lucknow has witnessed significant growth during the last decade and has recorded increasing levels of air pollution as compared to other cities located in the Indo Gangetic plains. Air pollution in Lucknow is mainly due to unprecedented growth of population and high vehicular density. Rapid industrialization and urbanization are the major sources of particulate matter (PM_{10} and $PM_{2.5}$) and gases (NO_x and SO_x).
Every city has its own carrying capacity, beyond which the city certainly has to face all round challenges (air/ noise/ water pollution, solid waste/ health problem, traffic jam and so on) with progress of time.

CSIR- IITR Initiative for Air Quality Assessment in Lucknow: CSIR- Indian Institute of Toxicology Research, Lucknow is one of the leading environmental research institute in the country and always remains in the fore-front by contributing in

many ways viz. environmental study cum research, monitoring of industrial emissions, urban/ indoor/ confined air pollution, exhibitions, seminars, workshops, lectures and formulating policies, strategies and guidelines, for the benefits of industry and to protect public health through policymaking and increasing mass awareness.

CSIR- IITR had started air quality survey of Lucknow city in 1997 and being continued assessment of Lucknow city at nine locations for particulate matters (PM_{10} and $PM_{2.5}$), gases (SO_2 & NO_x), noise levels and heavy metals (lead and nickel) twice in a year representing the pre-monsoon (April-May) and post-monsoon periods (September-October) for 25 years.

Vehicular and fuel consumption inventory for Lucknow city were carried out and primary information collected from RTO as on March 31, 2021 which showed increase of 4.45% from last year 2019-20 in Table 1. The total number of CNG and Electric city Bus services of UPSRTC by 2021 in Lucknow are 92 and 40 respectively (Table-2 & 3). Different oil and gas companies provided total number of fuel outlets (petrol, diesel and CNG) in Lucknow are 149 (Table 4). Fuel comparisons between 2020 and 2021 years are presented in Table 5 and it is found the consumption of Petrol, CNG and LPG decreased about 3.8%, 65.5% and 11.1% respectively while diesel consumption increased to 13.5% by 2021. Distribution and number of CNG vehicles in Lucknow is summarized in Table 6.

Objectives of the post-monsoon (September-October) - 2021 air quality survey are mentioned below:

- *To assess the levels of ambient air quality parameters with respect to particulates (PM_{10} & $PM_{2.5}$), gases (SO_2 & NO_2) and day and night time noise levels,*
- *To find out the trends of air pollutants over a period of time for Lucknow city,*
- *To generate the current baseline data for future use and to adopt abatement measures which can reduce the air pollution levels in the city and*
- *To create public awareness on the current status of air quality in Lucknow city.*

Table 1: Comparison of Vehicle Numbers in Lucknow

S. No.	Type of Vehicles	No. of Registered Vehicles as on 31st March		Increase in %
		2020-21	2019-20	
1.	Multi Articulated	6648	6144	8.20
2.	Light, Medium & Heavy Weight Vehicles (Four Wheelers)	51603	47745	8.08
3.	Light Commercial Vehicles (Three Wheeler)	3798	3652	3.99
4.	Buses	4383	4291	2.49
5.	Omni Buses	489	489	0.0
6.	Taxi	37993	30362	20.08
7.	Light Motor Vehicles (Passenger)	10557	10157	3.93
8.	Two Wheelers	1860778	1804077	3.14
9.	Motor Cycle on hire	384	384	0.0
10.	Car	330596	313597	5.14
11.	Jeep	105707	85689	23.36
12.	Tractors	28022	27136	3.26
13.	Trailers	1989	1961	1.40
14.	Others	71514	71506	0.01
	TOTAL	**2514461**	**2407190**	**4.45**

Source: RTO, Lucknow

Table 2: Details of Lucknow CNG City Bus Service, 2021

S. No.	Route No.	To and Fro	No. of Buses	Frequency (minutes)
1.	105	Raja ji Puram – Mawaiyya – Charbagh – GPO – Sikanderbagh – Nishatganj – Polytechnic – Awadh Bus Station (Kamta) – BBD	11	17
2.	301	Scooter India – Krishna Nagar – Awadh Hospital – Alambagh – Mawaiyya – Charbagh – GPO – Sikanderbagh – Nishatganj – Badshah Nagar – Ram Ram Bank – Engg. College	9	18
3.	401	Kashiram Yojna – Para Chowki - Awadh Hospital – Alambagh – Mawaiyya – Charbagh – GPO – Sikanderbagh – Nishatganj – Badshah Nagar – Gol Market – PS Gudmba – Integral University	6	30
4.	502	Charbagh- Hussanganj - GPO – Sikanderbagh - Gol Market – Bhoothnath – HAL - Polytechnic – Awadh Bus Station (Kamta)	15	09
5.	601	Dubagga – Balaganj – Chowk – Medical College – Kaiserbagh- Hussanganj – Charbagh – Mawaiyya – Alambagh – Awadh Hospital	12	10
6.	701	Dubagga – Faridipur – Buddheshwar- Para – Manak Nagar – Awadh Hospital – Pakri Pul – Telibagh – Utrathia – SGPGI	19	06
7.	801	Balaganj - Dubagga – Bhitauli – Tedhi Puliya – Khurram Nagar – Sector 25 – Munshi Puliya – Polytechnic – Kamta – Virajkhand Bus Station	19	08
8.	901	Charbagh – Mawaiyya – Tedhi Puliya Alambagh – Jail Road – Pasi Qila – Jyoti Gas – CRPF Chouraha – Azad Engg. College	1	120
		Total	**92**	

Source: City Bus Service, Dubagga Depot

Table 3: Details of Lucknow Electric City Bus Service, 2021

S. No.	Route No.	To and Fro	No. of Buses	Frequency (minutes)
1.	301-E	Dubagga – Buddheshwar – Awadh Hospital - Alambagh – Mawaiyya – Charbagh – GPO – Sikanderbagh – Gol Market – Engg. College – Madiyawo – Bhitauli – I.I.M. College	10	30
2.	701-E	Dubagga – Faridipur – Buddheshwar- Para – Manak Nagar – Awadh Hospital – Pakri Pul – Telibagh – Utrathia – SGPGI	12	30
3.	801-E	Balaganj - Dubagga – Bhitauli – Tedhi Puliya – Khurram Nagar – Sector 25 – Munshi Puliya – Polytechnic – Kamta – Virajkhand Bus Station	08	35
4.	1001-E	Dubagga – Buddheswer – Awadh Hospital – Charbagh – Sikanderbagh – Balu Adda – Fun Cinema – Lohiya Park – CMS – Dayal Paradise – Manoj Pandey Chauraha – Husariya – Virajkhand Bus Station	10	25
		Total	**40**	

Source: City Bus Service, Gomti Nagar Depot

Table 4: Fuel Outlets in Lucknow City

S.No.	Agency	Number of outlets as on 31st March 2021
1.	Indian Oil Corporation (IOC)	51
2.	Bharat Petroleum Corporation Ltd. (BPCL)	32
3.	Hindustan Petroleum Corporation Ltd. (HPCL)	33
4.	Compressed Natural Gas Stations (CNG)*	33
Total		**149**

Source: Indian Oil Corporation (IOC), Lucknow, Bharat Petroleum Corporation (BPCL), Hindustan Petroleum Corporation (HPCL), * CNG Source: Green Gas Limited, Lucknow.

Table 5: Fuel Consumption in Lucknow City

S. No.	Agency	Petrol in kL			High Speed Diesel in kL			CNG in Kg		
		Apr. 20 to Mar. 21	Apr.19 to Mar. 20	% Change	Apr. 20 to Mar. 21	Apr.19 to Mar. 20	% Change	Apr. 20 to Mar. 21	Apr.19 to Mar. 20	% Change
1.	IOC	85316	102547	-16.8	66726	79137	-15.7	11563212	15700482	-26.4
2.	BPCL	48883	56657	-13.7	33984	37800	-10.1	918151	158682	478.6
3.	HPCL	56950	39403	44.5	75950	38746	96.0	1840921	1860688	-1.1
4.	Green Gas	-	-	-	-	-	-	12538366	42359025	-70.4
Total		**191149**	**198607**	**-3.8**	**176660**	**155683**	**13.5**	**26860650**	**77798729**	**-65.5**
LPG in Ton										
5.	IOC	**Apr. 20 to Mar. 21**	**Apr.19 to Mar. 20**	**% Change**	-	-	-	-	-	-
		1737	1954	-11.1						

Source: Indian Oil Corporation (IOC), Lucknow, Bharat Petroleum Corporation (BPCL), Hindustan Petroleum Corporation (HPCL), CNG Source: Green Gas Limited, Lucknow.

Table 6: Distribution of CNG Vehicles

S. No.	Vehicles	Number		% Change
		2020-21	2019-20	
1.	Auto Rickshaws	4343	4343	-
2.	Tempo Taxi	2575	2575	-
3.	Buses (UPSRTC)	260	260	-
4.	Buses (Private)	40	40	-
5.	School Buses	1557	1557	-
6.	School Van	2231	2231	-
7.	Private Vehicles	472	472	-
8.	Private Cars	24539	21168	15.92
	Total	**36017**	**32646**	**10.32**

Source: RTO, Lucknow, Green Gas Limited, Lucknow

1.2 MONITORING LOCATIONS, METEOROLOGY OF LUCKNOW CITY & METHODOLOGY OF THE STUDY

1.2.1 Monitoring Locations

Nine air quality monitoring locations representing different activities/ areas i.e., four in residential, four in commercial cum traffic and one industrial area were selected for the Post-Monsoon 2021 study as summarized in Table 7 and Figure 1 and adopted methodologies are given in Table 8.

Table 7: Monitoring Locations

S. No.	Locations	Activities
1	Aliganj	Residential
2	Vikas Nagar	Residential
3	Indira Nagar	Residential
4	Gomti Nagar	Residential
5	Charbagh	Commercial cum traffic
6	Alambagh	Commercial cum traffic
7	Aminabad	Commercial cum traffic
8	Chowk	Commercial cum traffic
9	Amausi	Industrial

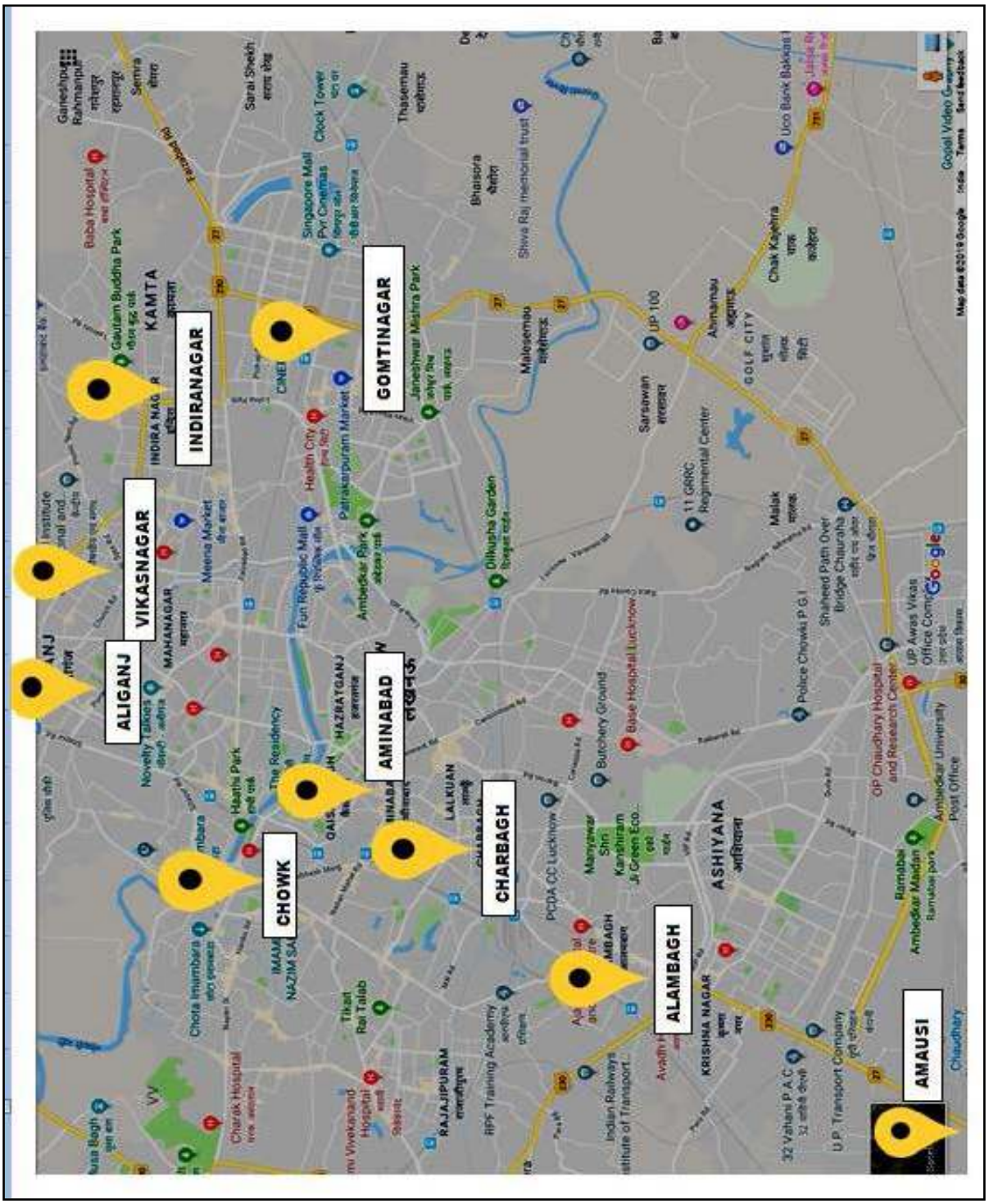


Figure 1: Ambient Air Pollution Monitoring Locations in Lucknow City

1.2.2 Weather Conditions during Post Monsoon Study

Weather condition especially wind speed, wind direction, temperature, humidity, rainfall and solar radiation play a key role in dispersal and dilution of air pollutants released in the atmosphere.

The direction from which wind is blowing/ coming to the receptors is very important. A wind rose diagram is a tool which graphically displays wind speed and wind direction and frequency of wind speed for a particular location over a period of time. The diagrams normally comprises of 16 radiating spokes, around the circle indicates the amount of time that the wind blows from a particular direction. Colors along the spokes indicate the categories of wind speed.

Higher wind speed, higher temperature and good solar radiation create unstable condition which favour for the dispersal and dilution of pollution while calm/low wind speed, low temperature, lower intensity of solar radiation and high humidity favours the build up of pollution in the lower atmosphere especially breathing zone .

The dominant wind direction was from South-South-West to North-North-East during the study period. The Calm condition (low wind speed condition) ranged from 6.2 to 10.4%. These calm condition impact air pollution to build up in lower atmosphere. The wind conditions are depicted in below Figure and status of temperature and relative humidity (RH) are presented in below table for the study period in Lucknow city.

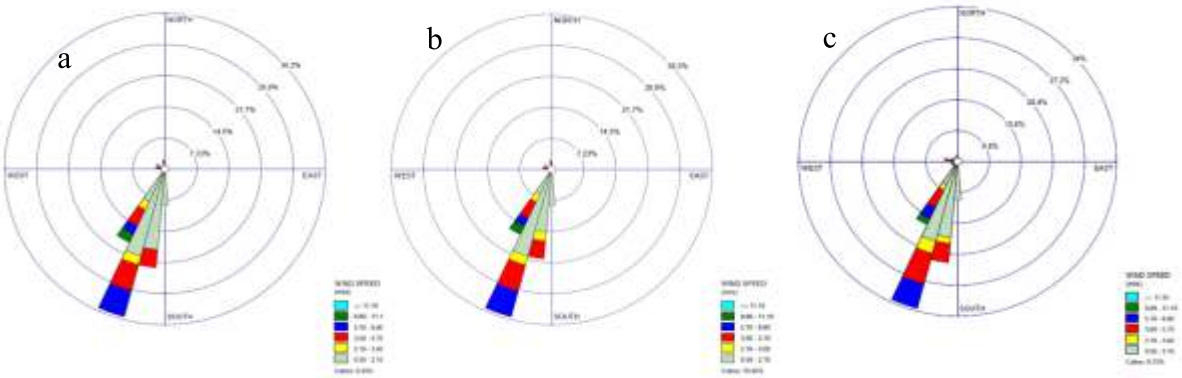


Figure : Wind Rose Diagrams / Conditions of Wind Speed and Wind Direction in Lucknow during (a) September-2021 (b) October-2021 and (C) Combine September and October -2021.

Table : Temperature and Relative Humidity during Post-Monsoon 2021

Month	September 2021		October 2021	
	Temperature ˚C	Relative Humidity %	Temperature ˚C	Relative Humidity %
Minimum	22.1	80.7	20.8	58.2
Maximum	28.6	95.5	28.2	95.5
Average	26.4	89.2	25.1	76.9

1.2.3 Methodology of the Study

Summary of methodology followed in the present study is illustrated in Table 8.

Table 8: Parameters and Methodology for Air Quality Monitoring

Sl. No.	Parameters	Time Weighted Average	Methods of Measurement
1	Particulate Matter (PM_{10})	24 hours	Gravimetric
2	Fine Particles ($PM_{2.5}$)	24 hours	Gravimetric
3	Sulphur dioxide (SO_2)	24 hours	Improved West Gaeke
4	Nitrogen Dioxide (NO_2)	24 hours	Modified Jacob & Hochhesier (Na-Arsenite)
5	Noise Level	1 hour	The measurement of noise level was carried out during the day (6 AM to 10 PM) and night time (10 PM to 6 AM) by Noise Level Meter

1.3 RESULTS

The detailed results of air quality monitoring during the Post-Monsoon period are presented in Table 9 and Figure 2 and 3.

1.3.1 Respirable Suspended Particulate Matter (RSPM or PM_{10})

In residential areas (Aliganj, Vikas Nagar, Indira Nagar and Gomti Nagar), the 24 hours average concentrations of PM_{10} were in the range of 67.5 to 249.3 µg/m^3 with an average of 127.8± 11.1 µg/m^3. In commercial areas (Charbagh, Alambagh, Aminabad and Chowk) the average concentrations of PM_{10} were in the range of 104.9 to 313.5 µg/m^3 with an average of 184.1± 27.8 µg/m^3 respectively. In industrial area (Amausi), the average concentration of PM_{10} was 193.5 µg/m^3.

The maximum 24 hours mean concentration of PM_{10} was observed in Vikas Nagar (140.9 µg/m^3) in residential area and Chowk (217.8 µg/m^3) in commercial areas. All the values of PM_{10} were above the prescribed National Ambient Air Quality Standard (NAAQS) of 100 µg/m^3 for industrial, residential, rural and other areas respectively.

1.3.2 Fine Particulate Matter ($PM_{2.5}$)

In residential areas (Aliganj, Vikas Nagar, Indira Nagar and Gomti Nagar), the 24 hours average concentrations of $PM_{2.5}$ were in the range of 34.0 to 132.3 µg/m^3 with an average of 74.4± 8.1 µg/m^3. In commercial areas (Charbagh, Alambagh, Aminabad and Chowk) the average concentrations of $PM_{2,5}$ were in the range of 25.7 to 199.4 µg/m^3 with an average of 78.9±16.0 µg/m^3 respectively. In industrial area (Amausi), the average concentration of $PM_{2.5}$ was 99.0 µg/m^3.

The maximum 24 hours mean concentration of $PM_{2.5}$ was observed in Gomti Nagar (82.8 µg/m^3) residential area and Chowk (97.8 µg/m^3) in commercial area. All the values of $PM_{2.5}$ were above the prescribed NAAQS of 60 µg/m^3 for industrial, residential, rural and other areas.

Table 9: Concentration (µg/m^3) of PM_{10}, $PM_{2.5}$, SO_2 and NO_2 during Post-Monsoon 2021

Location	PM_{10} (RSPM)			$PM_{2.5}$			SO_2			NO_2		
Residential												
	Min	**Max**	**Avg**	**Min**	**Max**	**Avg**	**Min**	**Max**	**Avg**	**Min**	**Max**	**Avg**
Aliganj	104.7	189.0	131.6	53.3	71.1	76.2	10.5	15.6	13.7	32.6	39.9	35.4
Vikas Nagar	67.5	249.3	140.9	34.1	132.3	75.3	10.0	13.2	11.6	22.1	67.9	38.0
Indira Nagar	102.4	151.4	123.6	34.0	85.4	63.3	11.2	16.2	13.4	19.8	45.3	28.4
Gomti Nagar	71.1	158.8	115.0	35.3	130.3	82.8	11.5	13.4	12.5	25.0	45.1	35.1
Min	67.5			34.0			10.0			19.8		
Max	249.3			132.3			16.2			67.9		
Avg	127.8			74.4			12.8			34.2		
SD	11.1			8.1			0.9			4.1		
Commercial												
Charbagh	122.3	202.2	159.4	64.1	93.2	86.2	13.5	18.2	16.1	26.8	49.9	41.9
Alambagh	147.1	178.6	163.3	58.7	81.6	68.0	14.1	15.5	15.0	33.8	58.6	43.7
Aminabad	104.9	268.9	195.7	34.9	88.6	63.4	13.8	18.6	15.1	28.0	54.6	41.9
Chowk	138.6	313.5	217.8	25.7	199.4	97.8	11.3	18.3	13.8	19.3	38.5	29.1
Min	104.9			25.7			11.3			19.3		
Max	313.5			199.4			18.6			58.6		
Avg	184.1			78.9			15.0			39.2		
SD	27.8			16.0			0.9			6.8		
Industrial												
Amausi	178.6	204.8	193.5	86.3	112.1	99.0	13.7	19.7	16.1	20.2	45.6	34.2
NAAQS	**100**			**60**			**80**			**80**		
WHO Standard	**45**			**15**			**20**			**40***		

N=6, *= Annual Average, NAAQS=National Ambient Air Quality Standard

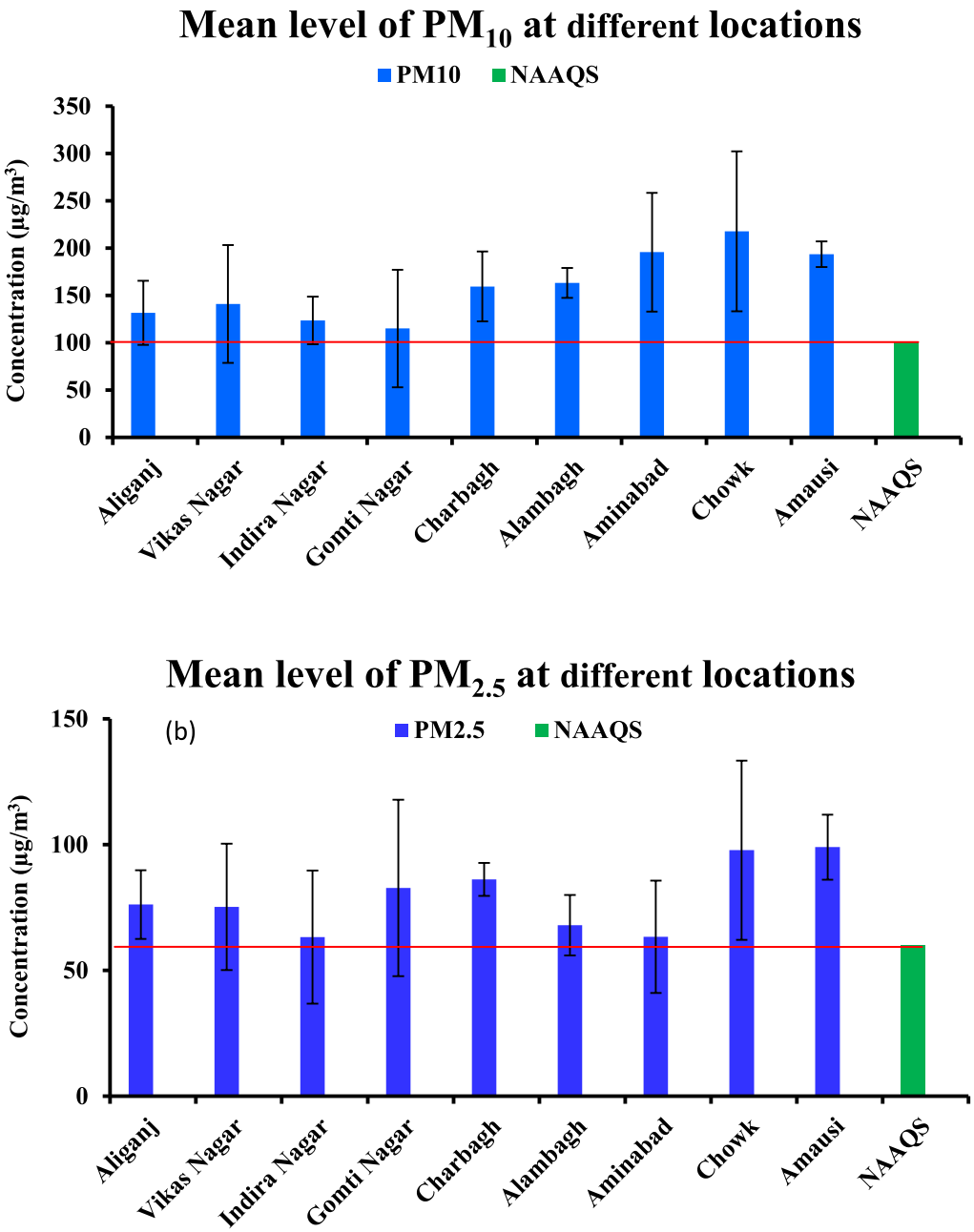


Figure 2: Concentration (µg/m^3) of (a) PM_{10} and (b) $PM_{2.5}$ in different areas of Lucknow city during Post-Monsoon Season (2021) compared with prescribed National Ambient Air Quality Standard (NAAQS)

1.3.3 Sulphur dioxide (SO_2)

In residential area (Aliganj, Vikas Nagar, Indira Nagar and Gomti Nagar) the levels of SO_2 was in the range of 10.0 to 16.2 µg/m^3 with an average of 12.8± 0.9 µg/m^3. In commercial areas (Charbagh, Alambagh, Aminabad and Chowk) the average concentrations of SO_2 were in the range of 11.3 to 18.6 µg/m^3 with an average of 15.0± 0.9 µg/m^3. In industrial area (Amausi), the mean level of SO_2 was 16.1 µg/m^3.

All the values of SO_2 were well below the prescribed NAAQS of 80 µg/m^3 for all the locations.

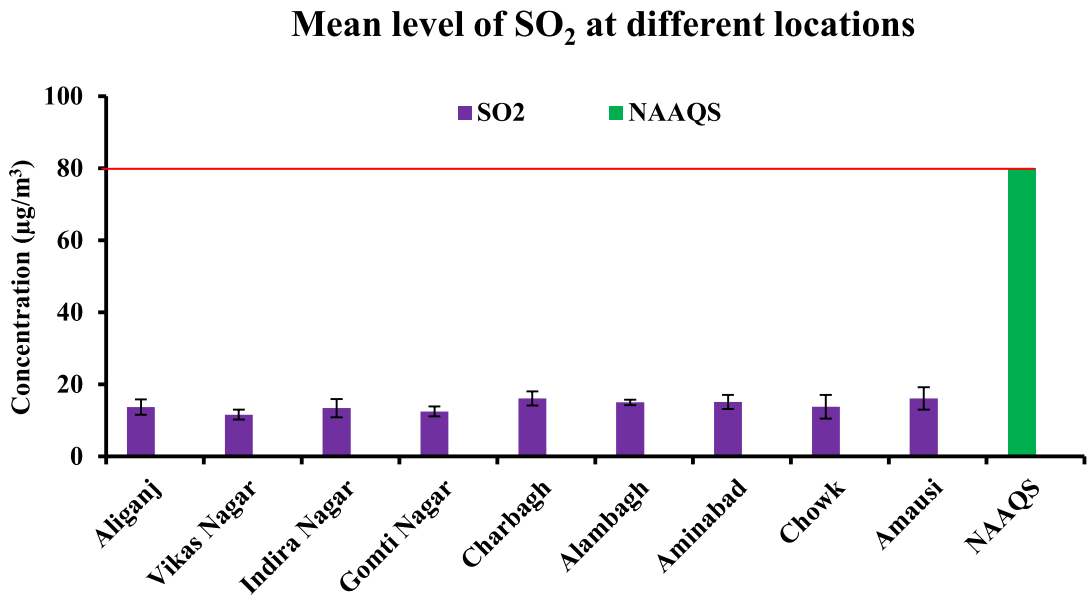


Figure 3: Concentration (µg/m^3) of SO_2 in different areas of Lucknow city during Post-Monsoon season (2021) compared with prescribed National Ambient Air Quality Standard (NAAQS)

1.3.4 Nitrogen dioxide (NO_2)

In residential areas (Aliganj, Vikas Nagar, Indira Nagar and Gomti Nagar) the 24 hours average concentrations of NO_2 was in the range of 19.8 to 67.9 µg/m^3 with an average of 34.2± 4.1 µg/m^3. In commercial areas (Charbagh, Alambagh, Aminabad and Chowk) the average concentrations of NO_2 were in the range of 19.3 to 58.6 µg/m^3 with an average of 39.2± 6.8 µg/m^3. In industrial area (Amausi), the average concentration was 34.2 µg/m^3.

All the values of NO_2 were within the prescribed NAAQS of 80 µg/m^3 for all the monitoring locations.

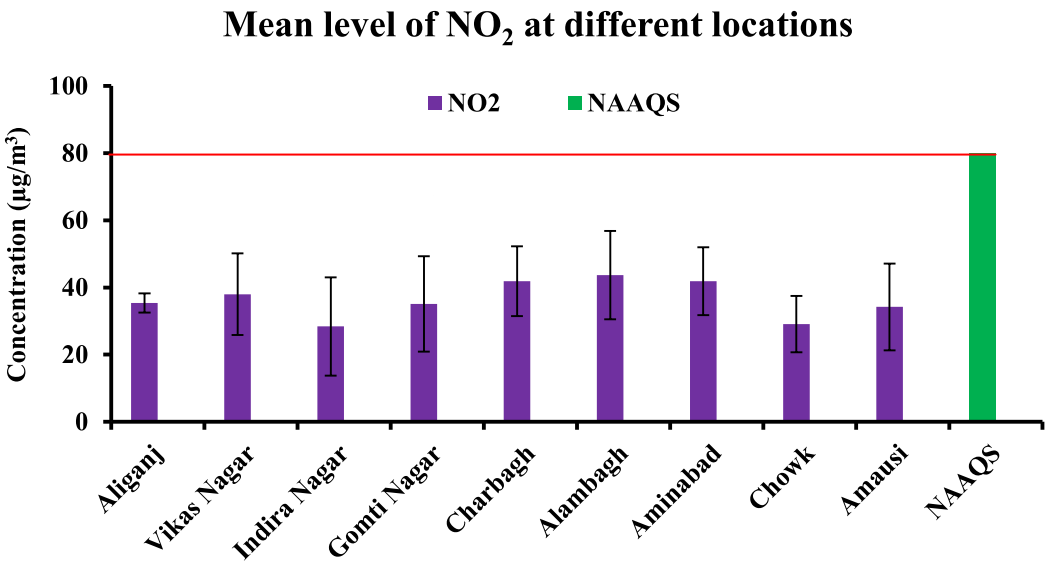


Figure 4: Concentration (µg/m^3) of NO_2 in different areas of Lucknow city during Post-Monsoon season (2021) compared with prescribed National Ambient Air Quality Standard (NAAQS)

1.3.5 Noise Level

The noise monitoring data recorded during the Post-Monson period (October, 2021) is presented in Table 10 & Figure 5 and 6. In residential areas, the day and night time average noise levels were recorded between 63.9 to 72.9 dB(A) and 57.8 to 62.5 dB(A) respectively. All the values were higher than their prescribed standards of **55 and 45 dB(A)** for day and night time respectively.

In commercial and traffic area, the day and night time average noise levels were recorded between 71.4 to 78.1 dB(A) and 66.3 to 79.5 dB(A) respectively. All the values were higher than their prescribed standards of **65 and 55 dB(A)** for day and night time respectively In industrial area Amausi, the day and night time noise levels were recorded 78.0 and 79.1 dB(A) respectively. Noise levels at industrial area were recorded higher than their prescribed standards of **75.0 and 70.0 dB(A)** respectively.

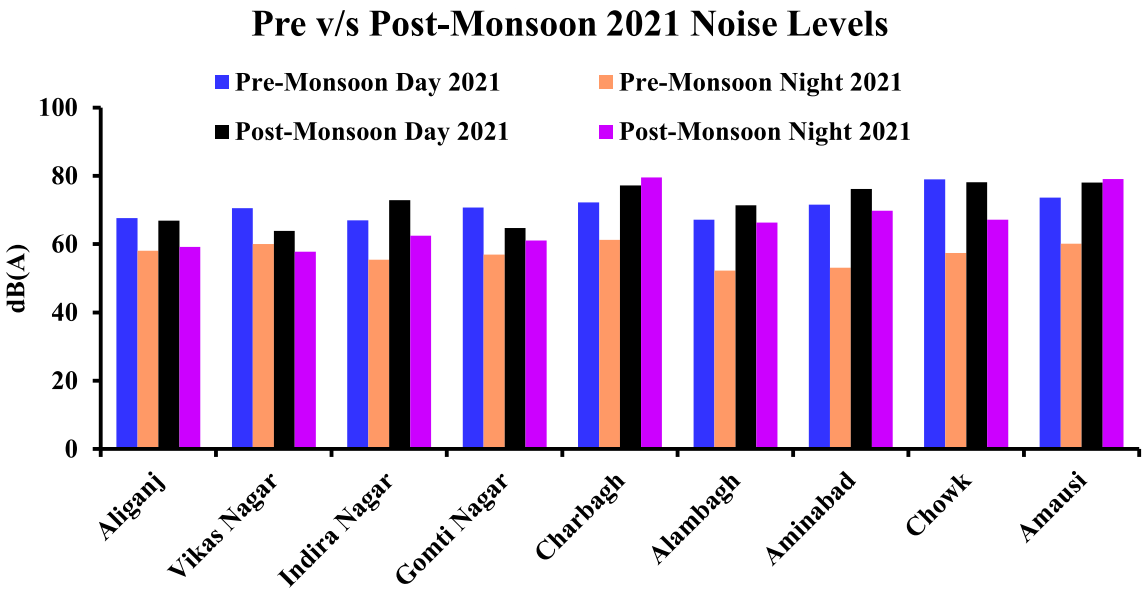


Figure 5: Noise levels (dB(A) in different areas of Lucknow city during Post-Monsoon season (2021) compared with Pre-Monsoon Season 2021

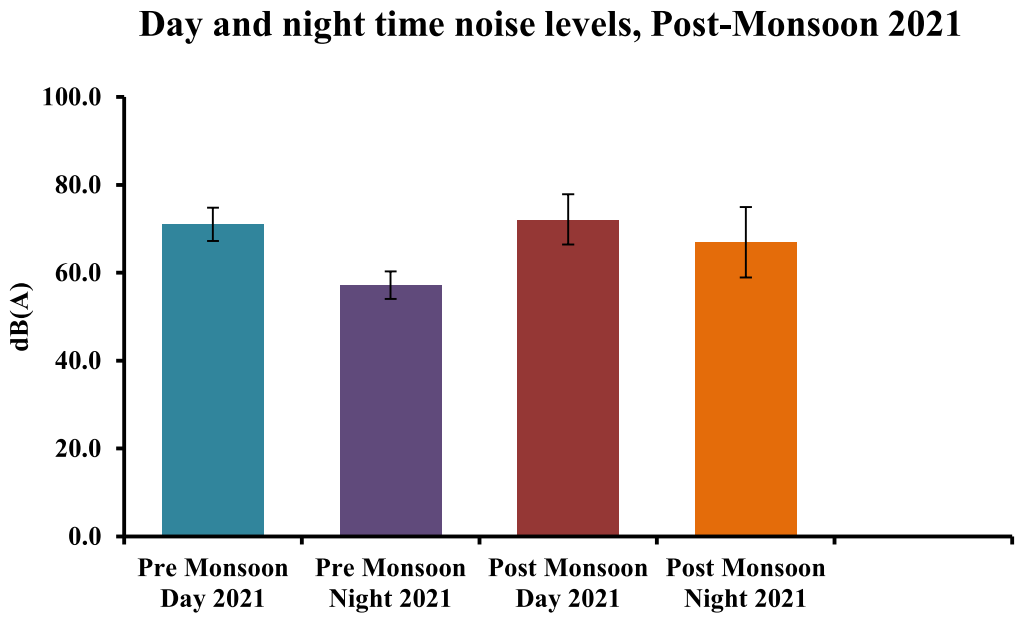


Figure 6: Average Noise levels dB(A) in Lucknow city during Post-Monsoon season (2021)

Table 10: Noise Level dB(A) during Day and Night Time

Location		Pre-Monsoon		Post-Monsoon	
		Day	Night	Day	Night
Aliganj	Min	52.3	48.5	50.4	48.7
	Max	81.4	65.6	82.2	67.5
	Avg (Leq)	67.6	58.1	66.9	59.2
Vikas Nagar	Min	55.8	48.8	51.2	48.9
	Max	82.9	70.6	74.5	69.7
	Avg (Leq)	70.5	60.0	63.9	57.8
Indira Nagar	Min	54.6	50.2	52.3	48.6
	Max	80.5	66.3	82.1	71.9
	Avg (Leq)	67.0	55.4	72.9	62.5
Gomti Nagar	Min	56.3	49.9	53.2	51.3
	Max	79.8	68.4	73.5	79.6
	Avg (Leq)	70.7	56.9	64.7	61.1
Charbagh	Min	59.8	54.6	56.4	69.0
	Max	84.4	74.9	86.8	86.7
	Avg (Leq)	72.2	61.3	77.2	79.5
Alambagh	Min	51.2	49.7	52.5	49.1
	Max	74.8	62.4	88.3	82.3
	Avg (Leq)	67.2	52.3	71.4	66.3
Aminabad	Min	54.9	48.7	52.1	56.2
	Max	79.8	66.6	82.5	80.7
	Avg (Leq)	71.6	53.1	76.2	69.8
Chowk	Min	61.4	48.7	65.1	54.1
	Max	92.8	72.1	85.2	82.4
	Avg (Leq)	79.0	57.4	78.1	67.2
Amausi	Min	57.7	49.5	60.6	60.3
	Max	89.4	76.2	92.7	96.7
	Avg (Leq)	73.6	60.1	78.0	79.1
Minimum		51.2	48.5	50.4	48.6
Maximum		92.8	76.2	92.7	96.7
Mean of 9 Averages		71.0	57.2	72.1	66.9
SD of 9 Averages		3.8	3.1	5.7	8.0

1.4 TRENDS OF AMBIENT AIR QUALITY IN LUCKNOW CITY

The observed PM_{10}, $PM_{2.5}$, SO_2 and NO_2 values from the last three years' have been compared to find out the prevailing trend of air pollution in Lucknow (Fig. 7-10).

1.4.1 Respirable Suspended Particulate Matter (RSPM or PM_{10})

Present analyses results of PM_{10} showed significantly higher levels as compared to the Post Monsoon 2020 (during pandemic time) for all residential, commercial and industrial sampling locations and much lower than Post Monsoon 2019 data (Pre-Covid period). This clearly indicates a rising trend of air pollution with respect to 2020 Post Monsoon data. All the mean values of the present study were found to be higher than the NAAQS-standard (Fig. 7).

1.4.2 Fine Particulate Matter ($PM_{2.5}$)

The results of $PM_{2.5}$ were found to be higher than the previous Post Monsoon 2020 (during pandemic time) at all residential, commercial and industrial sampling locations but much lower side with respect to Post Monsoon 2019 data (Pre- Covid period).

Both, PM_{10} and $PM_{2.5}$ are similar type of particulate matter and are interlinked to each other. They showed similar type of trend and behavior in the atmosphere. All the mean values of $PM_{2.5}$ were found to be higher than the NAAQS-standard (Fig. 8).

1.4.3 Sulphur dioxide (SO_2)

The SO_2 concentrations were was found higher as compared to the previous year, Post Monsoon 2020 data at all the residential, commercial and industrial areas. However, the current values are significantly lower than the Pre- Covid Post Monsoon 2019 data. All the mean values of SO_2 were found to be lower than the NAAQS standard (Fig. 9).

1.4.4 Nitrogen dioxide (NO_x)

The NOx concentrations were found higher as compared to the previous year, Post Monsoon 2020 data for all the residential, commercial and industrial areas. However, the present values are significantly lower than the pre-Covid Post Monsoon 2019 data. All the mean values of NO_2 were found to be lower than the NAAQS standard (Fig. 10).

Overall Trend of Pollution

Overall, the pollution parameters either particulates or gases are in gradually rising trend as compared to Covid situation and other urban activities (2020-21). Most of the industries, restaurants, commercial establishments, road transport, real estates and other urban activities are started operating fully. Mean while, thousands of new vehicles are also roll out. Government bodies have been continuously thriving for improvements like installation of traffic light, sweeping, widening of road, prohibition of trash burning, use of sprinklers to suppress of re-suspended road dust and construction dust, plantation along the road corridors, door to door solid waste collection and proper disposal, better traffic management and others. Time to time seminars and workshops are also organized by different organization to increase mass people awareness about adverse impacts on health and environment and remediations. The mitigative measures taken by the individual/collective or Government bodies shows some improvements to restrict sharp increase of air pollution in Lucknow.

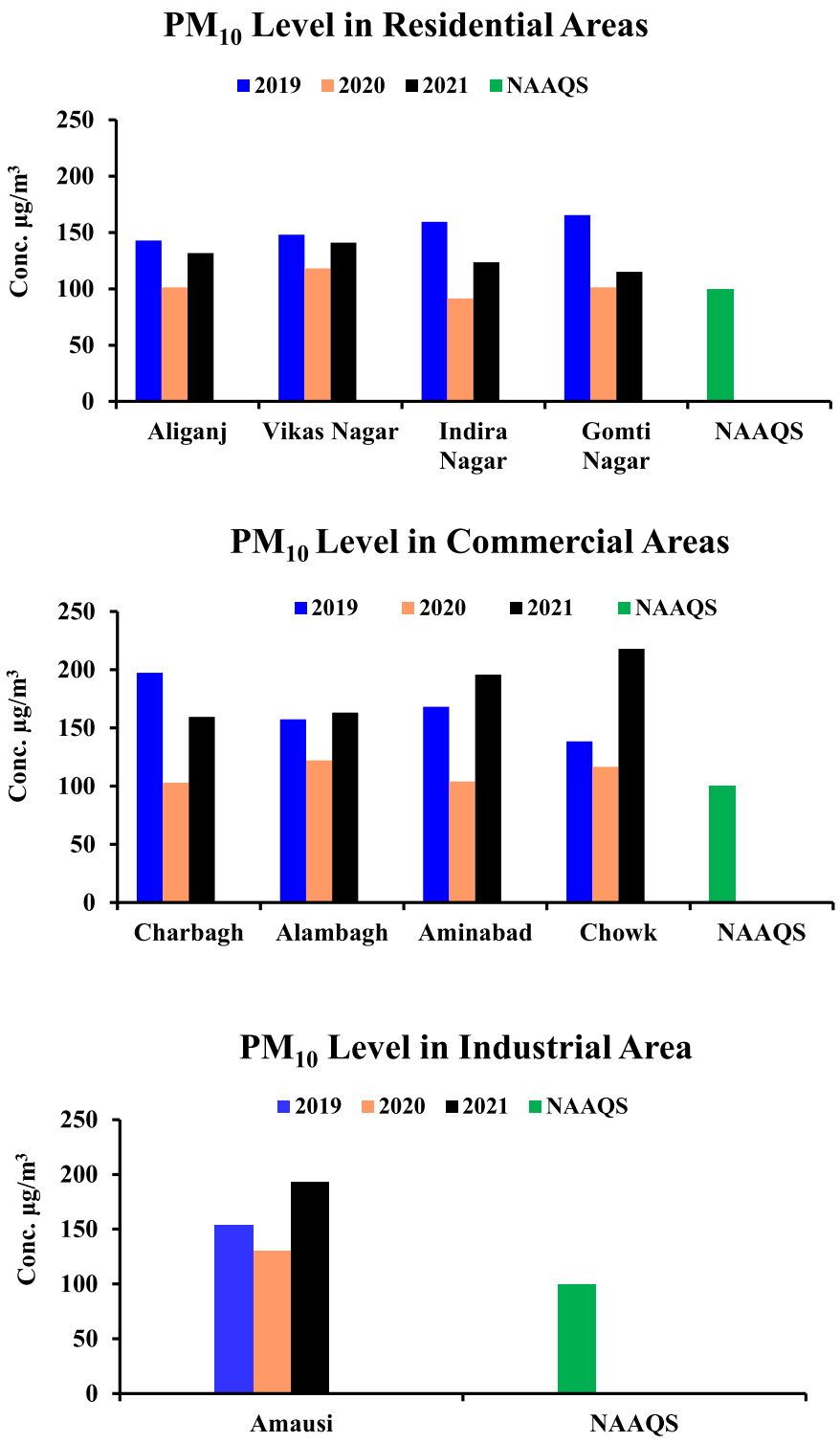


Figure 7: Concentration (µg/m^3) of PM_{10} (RSPM) in Residential, Commercial and Industrial areas of Lucknow city during 2019 to 2021 (Post-Monsoon) and compared with prescribed National Ambient Air Quality Standard

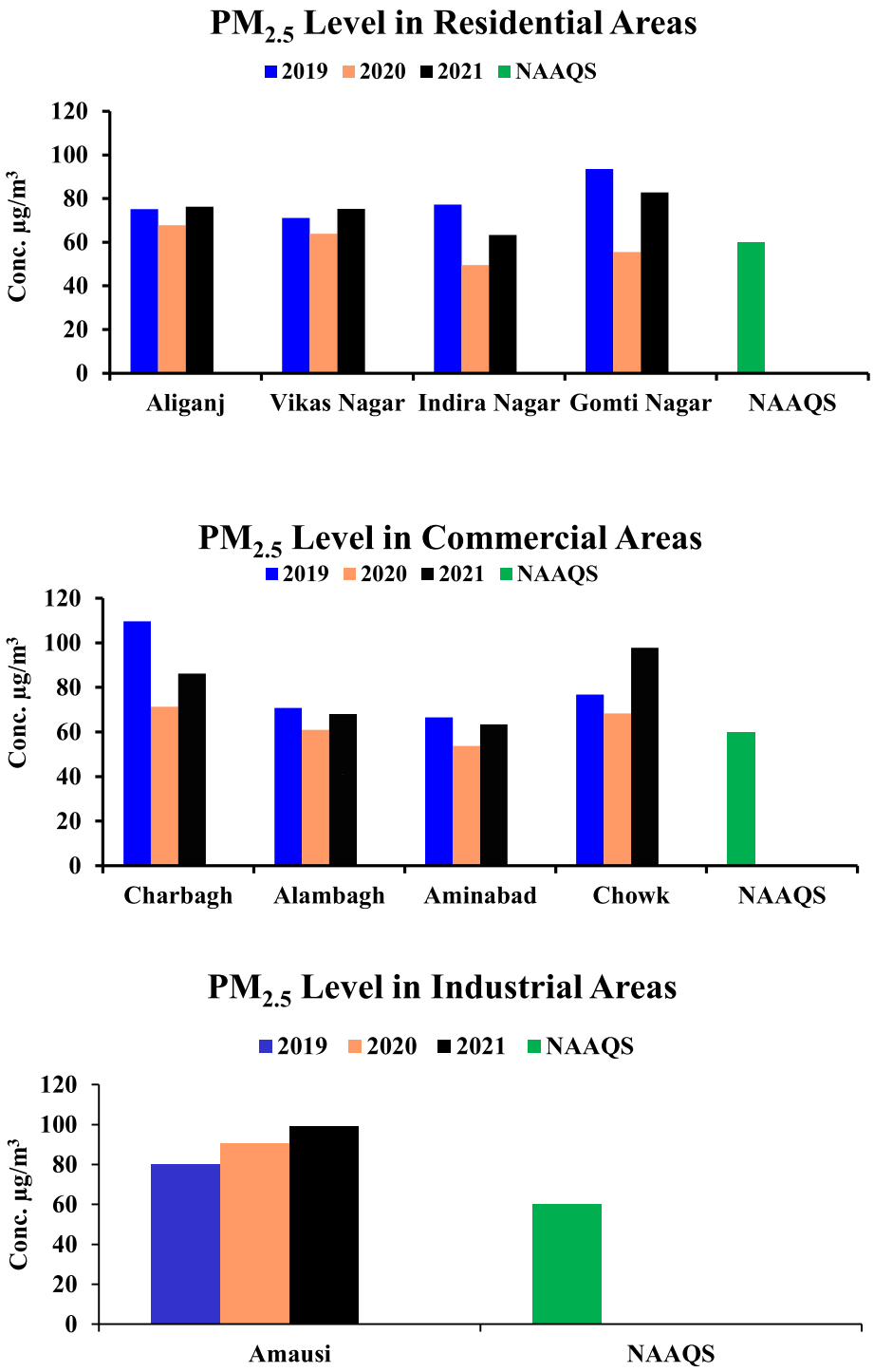


Figure 8: Concentration (µg/m^3) of $PM_{2.5}$ in Residential, Commercial and Industrial areas of Lucknow city during 2019 to 2021 (Post-Monsoon) and compared with prescribed National Ambient Air Quality Standard (NAAQS)

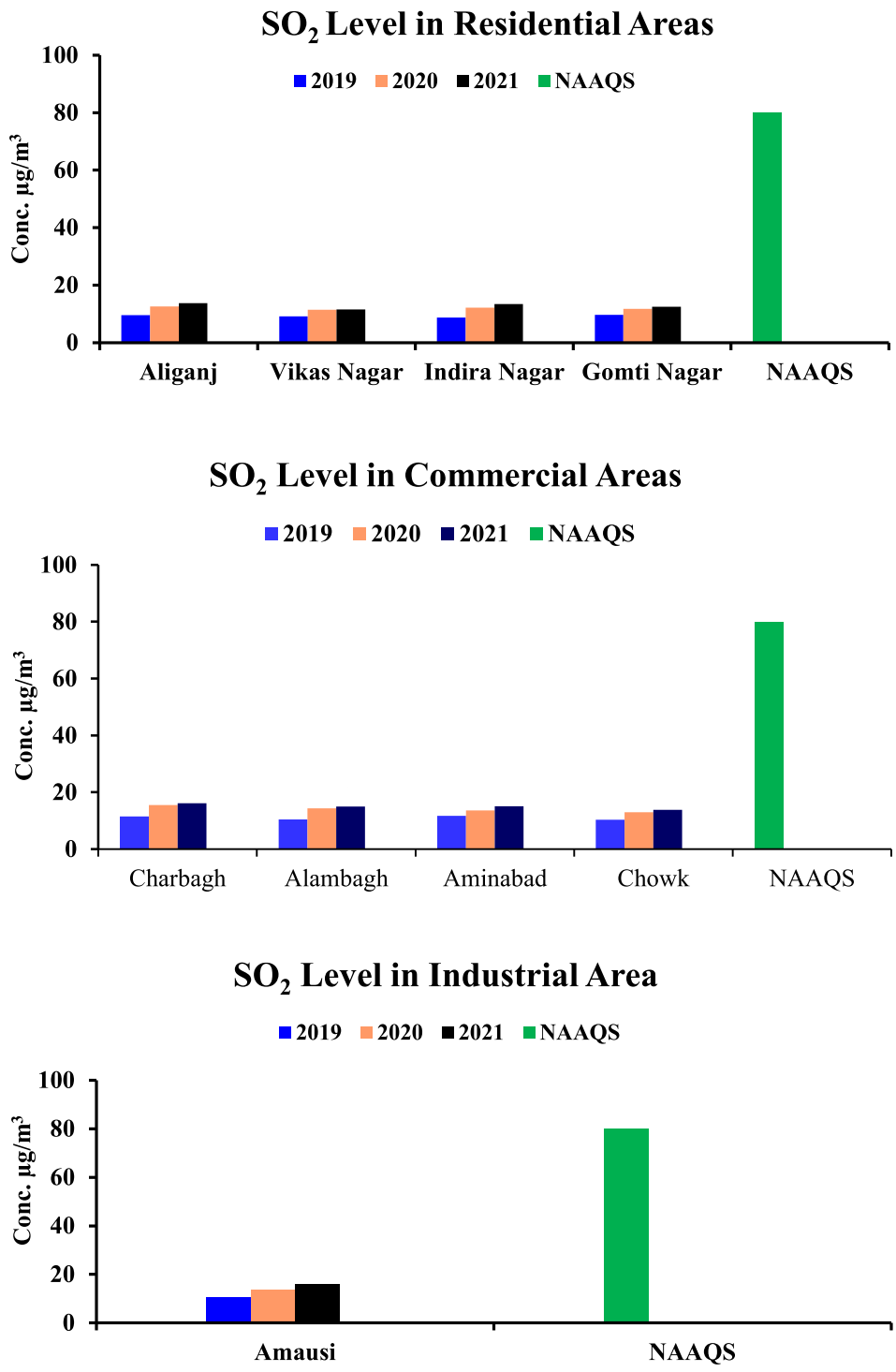


Figure 9: Concentration (µg/m^3) of SO_2 in Residential, Commercial and Industrial areas of Lucknow city during 2019 to 2021 (Post-Monsoon) and compared with prescribed National Ambient Air Quality Standard (NAAQS)

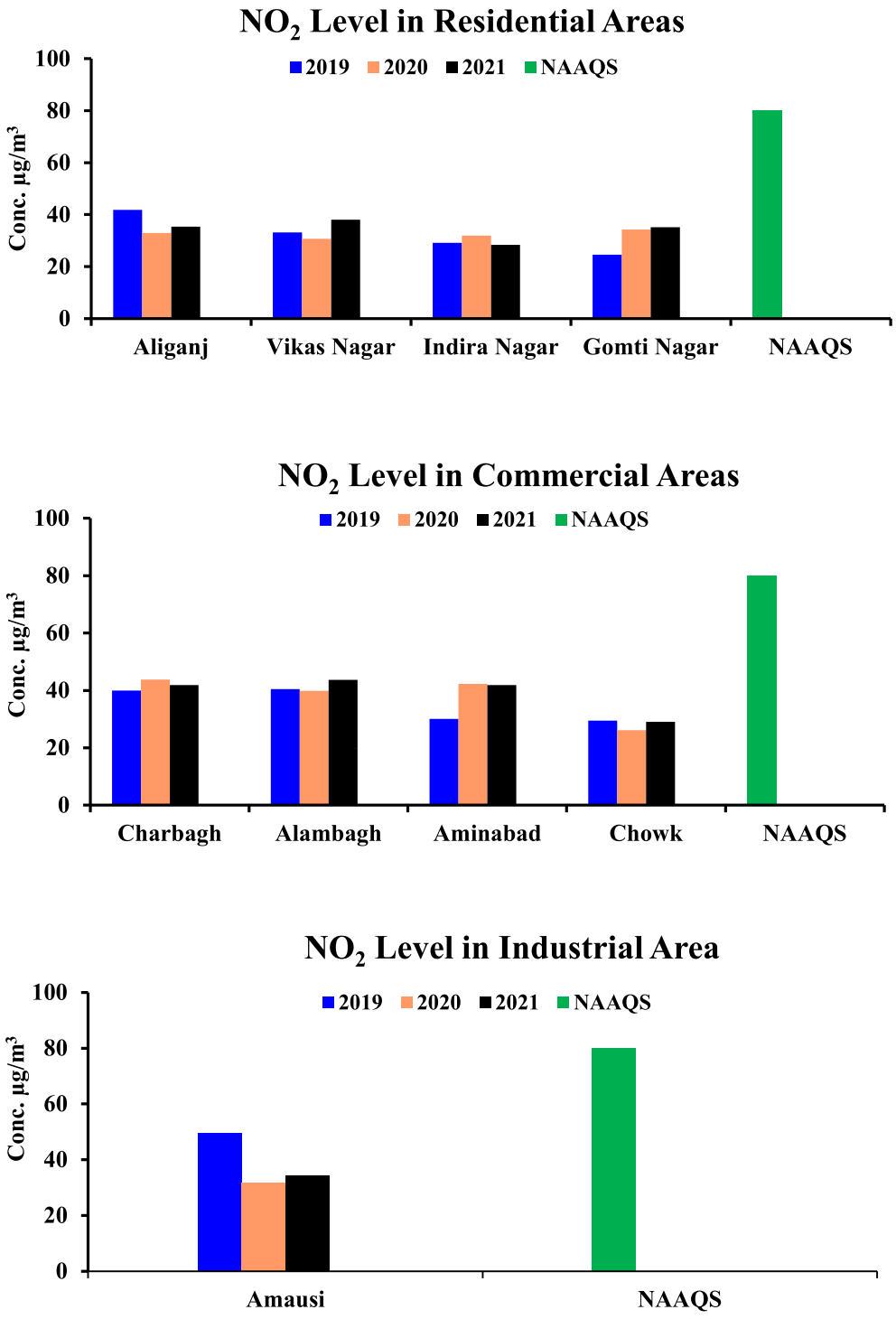


Figure 10: Concentration (µg/m^3) of NO_2 in Residential, Commercial and Industrial areas of Lucknow city during 2019 to 2021 (Post-Monsoon) with NAAQS- Standard

1.4.5 Noise Level

Current year's Post-Monsoon noise data was compared with the corresponding data of the previous 02 years (2019 and 2020) and presented in Figure 11 & 12. The comparative noise levels in residential, commercial and industrial areas are described below:

1.4.5.1 Day time Noise Level

All residential, commercial cum traffic and industrial areas showed increasing trend over that of the previous year. The comparative data are presented in Figure 11.

1.4.5.2 Night time Noise Level

All residential, commercial cum traffic and industrial areas showed increasing trend over that of the previous year. The comparative data are presented in Figure 12.

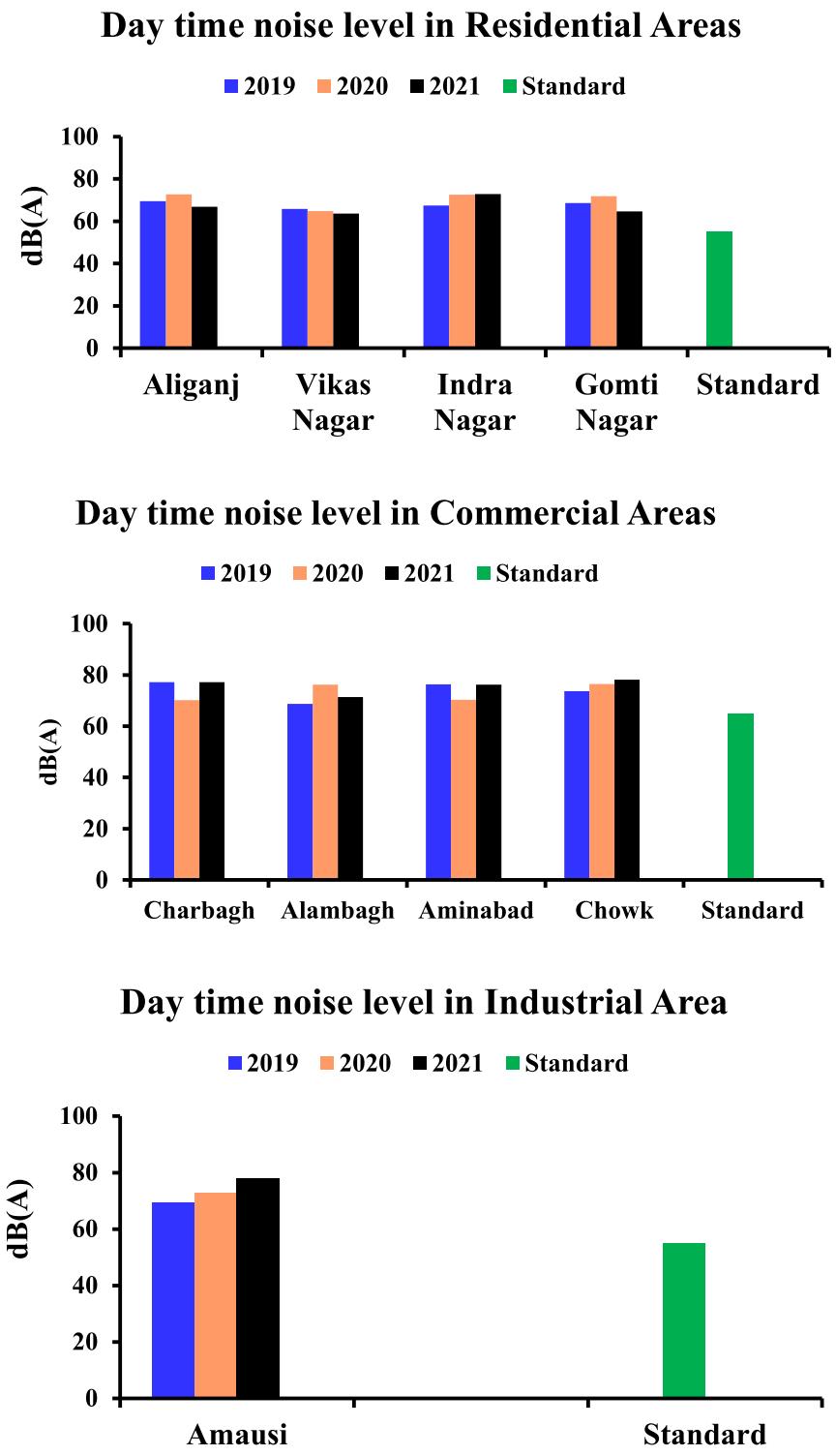
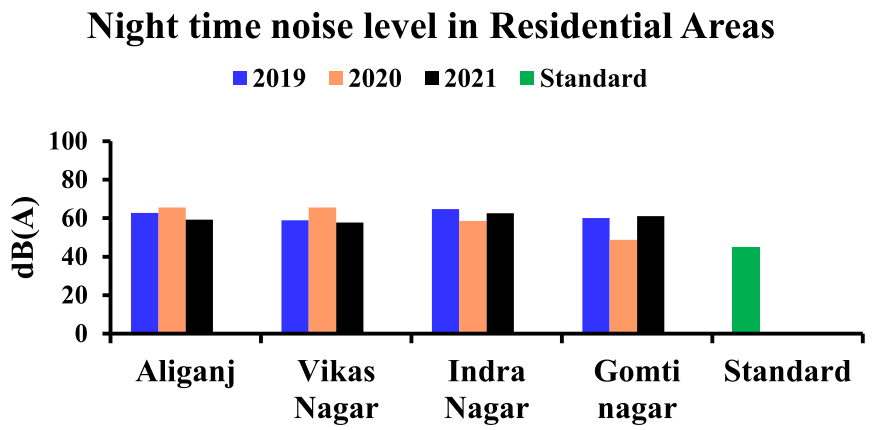
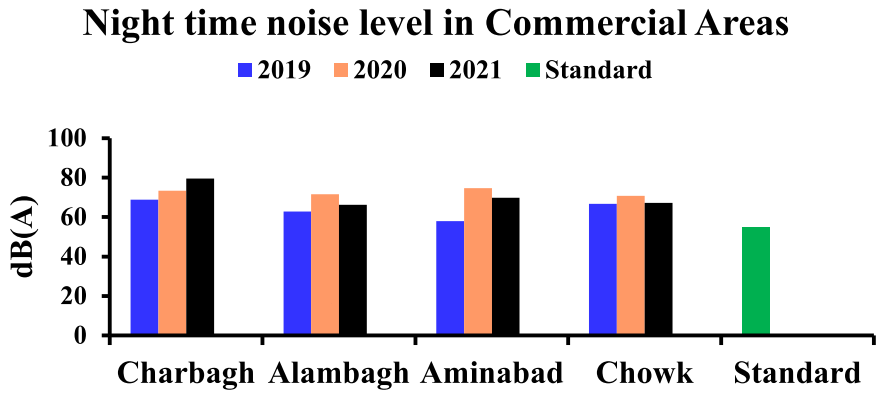


Figure 11: Comparison of day time Noise Level dB(A) in different areas of Lucknow city (Post-Monsoon 2019-2021)





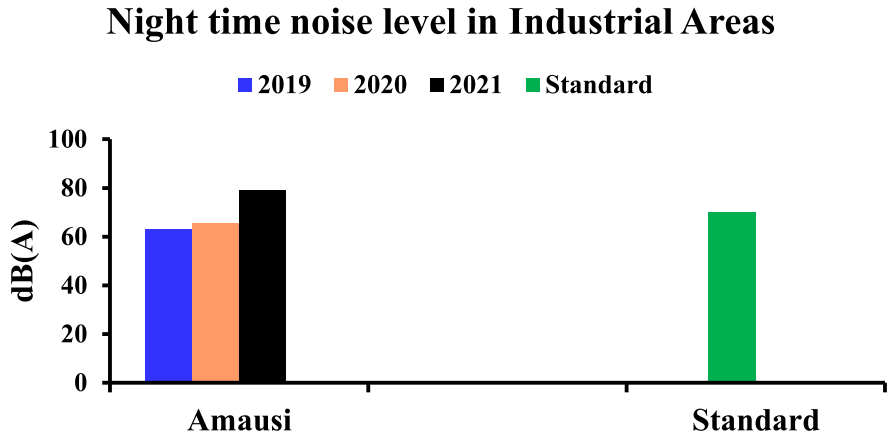


Figure 12: Comparison of night time Noise Level dB (A) in different areas of Lucknow city (Post-Monsoon 2019-2021)

1.5 FINDINGS OF LUCKNOW SURVEY

The inhalable tiny fine particulates levels (PM_{10} and $PM_{2.5}$) always exceeded respective National Ambient Air Quality Standards (NAAQS) of 100 µg/m^3 for PM_{10} and 60 µg/m^3 for $PM_{2.5}$ at all the air monitoring locations. WHO recent standards for *Coarse particulate matter* (PM_{10}) is 45 µg/m^3 (24-hour mean) and 15 µg/m^3 (annual mean) while for *Fine particulate matter* ($PM_{2.5}$), it is 15 µg/m^3 (24-hour mean) and 5 µg/m^3 (annual mean). The concentrations of SO_2 and NO_2 were well below the prescribed NAAQS standard of 80 µg/m^3 at all the locations. However, both gaseous pollutants showed higher spike with comparison to Post-Monsoon 2020.

1.5.1 Particulate Pollution

PM_{10} Particles

The average levels of PM_{10} ranged from 115.0 to 217.8 µg/m^3 with an average of 160.1 µg/m^3. The location wise level and *the surge (%)* over the 2020 Post-Monsoon level of PM_{10} concentration were 131.6 µg/m^3 i.e. *29.8 %* at Aliganj, 140.9 µg/m^3 *i.e. 19.4%* at Vikas nagar, 123.6 µg/m^3 *i.e. 35.2 %* at Indira nagar, 115.0 µg/m^3 *i.e. 13.6%* at Gomti Nagar, 159.4 µg/m^3 i.e. 54.9 % at Charbagh, 163.3 µg/m^3 *i.e. 33.%* at Alambagh, 195.7 µg/m^3 *i.e. 88.0%* at Aminabad, 217.8 µg/m^3 *i.e. 86.6 %* at Chowk and 193.5 µg/m^3 *i.e. 48.8 %* at Amausi.

$PM_{2.5}$ Particles

The average levels of $PM_{2.5}$ ranged from 63.3 to 99.0 µg/m^3 with an average of 79.1 µg/m^3. The location wise level and *the surge (%)* over the 2020 Post-Monsoon level of $PM_{2.5}$ concentration were 76.2 µg/m^3 i.e. 12.4 % at Aliganj, 75.3 µg/m^3 *i.e. 17.8%* at Vikas nagar, 63.3 µg/m^3 *i.e. 27.9%* at Indira nagar, 82.8 µg/m^3 *i.e. 49.2%* at Gomti Nagar, 86.2 µg/m^3 *i.e.20.9%* at Charbagh, 68.0 µg/m^3 *i.e. 11.5%* at Alambagh, 63.4 µg/m^3 *i.e. 18.1%* at Aminabad, 97.8 µg/m^3 *i.e. 43.2%* at Chowk and 99.0 µg/m^3 *i.e. 9.3 %* at Amausi.

In the current Post-Monsoon season, the overall increase of average value of PM_{10} was by 45.6% while $PM_{2.5}$ increased by 23.4% with respect to 2020 Post-Monsoon data. However, the current data decreased by 65.7 % for PM_{10} and by 70.6% for $PM_{2.5}$ with respect to 2019 Post-Monsoon data.

1.5.2 Gaseous Pollutants

The average levels of SO_2 during Post-Monsoon 2021 ranged from 11.6 to 16.1 $\mu g/m^3$ with an average of 14.1 $\mu g/m^3$. The overall increase of average value by 7.7% with respect to 2020 Post-Monsoon SO_2 data but decreased 24.8% with respect to Post-Monsoon 2020 data.

The average levels of NOx during Post-Monsoon 2021 ranged from 28.4 to 43.7 $\mu g/m^3$ with an average of 36.4 $\mu g/m^3$. The overall increase of average value by 5.1% with respect to 2020 Post-Monsoon NOx data but decreased by 55.3% with respect to Post-Monsoon 2020 data.

1.5.3 Noise Levels

The day and night time noise levels at residential and commercial areas have exceeded about 22.0% and 16.5% during day times and 33.7% and 28.5% during night times respectively in comparison with the prescribed standards (55 and 65 dB(A) for day and 45 and 55 dB(A) for night times). However, day and night time noise levels in industrial areas were 4% and 13% above standard values of 75 and 70 dB(A).

Overall results indicate that all the parameters monitored showed increasing trend compared to previous year which may be attributed to relaxation in Lockdown restrictions from 2020 to 2021. District administration/ Lucknow authority has taken many control measures to minimize air pollution which helped to improve air quality of the city.

1.6 POSSIBLE HEALTH EFFECTS OF COMMON PROBLEMS DUE TO AIR POLLUTION

In recent times, air pollution has become a complicated issue as it negatively impacts the health of citizens as well as the economy of the country. As India ascends the path of urbanization and globalization, the rising energy demands and increasing pollution crisis becomes a matter of immediate concern. In almost all cities of India, levels of common pollutants exceeded their National Air Quality Standards (NAAQS).

Particles pollution is always higher than their permissible level. Ozone gas is a colorless secondary pollutant, formed when emissions of nitrogen oxides and other volatile organic compounds react in the presence of sunlight. Although levels of ground-level ozone pollution are substantially low these, levels are unhealthy in urban areas of the country. Both the pollutants are the result of emissions from diverse sources, and travel long distances and across state lines.

Scientific evidence shows that long- and short-term exposure to fine particulate matter ($PM_{2.5}$) can cause premature death and harmful effects on the cardiovascular system, including increased hospital admissions and emergency department visits for heart attacks and strokes. Scientific evidence also links particulate matter to harmful respiratory effects, including asthma attacks.

Elevated ozone levels are linked to increases in hospitalizations, emergency room visits and premature death. Both pollutants cause environmental damage and fine particles impair visibility.

Fine particles can be emitted directly or formed from gaseous emissions including sulfur dioxide or nitrogen oxides. Both sulfur dioxide and nitrogen dioxide pollutants cause multiple adverse respiratory effects. Both pollutants cause environmental damage and are byproducts of fossil fuel combustion.

1.7 RECOMMENDATIONS FOR MITIGATION OF AIR POLLUTION

Our sensible behavior, individual efforts & habits towards protecting environment, can bring a remarkable change to make our city cleaner and greener. There are many individual/ collective/ governmental/ administrative/ legal measures to abate and control air pollution. Some of these are described below:

(A) Planting of deep rooted, storm resistant ornamental plants especially those that are air pollution tolerant is required. Plants not only produce oxygen but also absorb CO_2, other toxic gases and remove dust particles and rains washout the adhered dust particles. Plants act as a natural buffer and purifier of polluted air. These plants will also enhance the scenic beauty along the roads.

(B) Increase green cover and plantation in the middle of the road instead of concrete divider and along corridors of the road network. Further, undertake greening of open areas, stadium/ park, community places, schools and housing societies. All new wider roads should have demarcated land corridors for 2/3 rows of plants.

(C) Better traffic management for smooth plying of vehicles at bottleneck intersections and pollution hotspot traffic junctions/ intersection like Teriphulia, Polytechnic, Munshipulia, Aminabad, Chowk, Hazratganj, Charbagh, Awadh, Transport Nagar etc.

(D) All city zones require CNG/ electric/ hybrid vehicles and petrol private cars. Ultra pure low sulphur fuels to be preferred in the city.

(E) Synchronization of consecutive traffic signals to facilitate smooth traffic flow, thus avoiding repeated stoppage of vehicles at traffic junctions.

(F) Extension of metro network with affordable ticket fare is needed to make it more popular than road vehicles.

(G) For better traffic flow, widening of roads and strict action is required for removal of roadside encroachment and wrong parking. The optimum traffic speed for reduced emission is about 40-45 km/hr which results in lesser pollution.

(H) All industrial estates housing hundreds of small scale industries should use appropriate air pollution control devices like dry/wet scrubbers, bag-filters, electrostatic precipitators and must ensure the desired height of chimneys.

(I) All brick-kilns using old techniques without any air pollution control device are to be modified and revamped.

(J) Paving of roads and pedestrian foot paths to reduce re-suspended dust is essential. Also consider vacuum sweeping, water flushing and sweeping, covering garbage trucks, speed and traffic reduction to better handle re-suspended dust. Apart from road dust, construction sites and construction materials that pile up at road sides are also sources of re-suspended dust. Thus, ensure wet suppression of unpaved areas, material storage handling and transfer operations.

(K) Increase numbers of electric vehicles and charging stations to encourage their use.

ACKNOWLEDGEMENT

We, (CSIR-IITR, Lucknow) express our sincere thanks and gratitude to those who provided required data with respect to vehicular population, transport, fuel consumption (Petrol/Diesel/CNG/LPG/Green Gas). Their names and designation are mentioned below:

Mr. R P Dwivedi, RTO, **Mr. Akhilesh Kumar Dwivedi ARTO** (Administration), **Mr. Sanjai Tiwari ARTO** (Enforcement), **Mr. P.V. Shukla** (DBA) Lucknow,
Mr. Vinod Kumar, Assistant Regional Manager, City Transport Services Ltd. Gomtinagar, Lucknow,
Mr. Manoj Sharma, Assistant Regional Manager, **Mr. Amir Najir Station Incharge,** City Transport Services Ltd, Dubagga Depot, Lucknow,
Mr. Mukesh Bharadwaj, Sr. Manager, Retail Sales, IOC, Lucknow,
Mr. Pravir Muttu, Chief Manager, Business Planning (Retails), U.P., BPCL **Mr. Shantanu Singh, Sales Office**r, BPCL, Lucknow,
Mr. Sanjai Srivastava, Dy. Gen. Manager, HPCL, Lucknow, **Mr. Ashutosh, Manager** (RE & Analytic), HPCL, Lucknow,
Mr. Sharat Kumar, Director Commercial, Green Gas Ltd, Lucknow and **Mr. Surya Prakash Gupta, Chief Manager** (Marketing), Green Gas Ltd, Lucknow.

We also express our sincere thanks and gratitude to those who provided necessary facilities and support to our field team at different monitoring localities.

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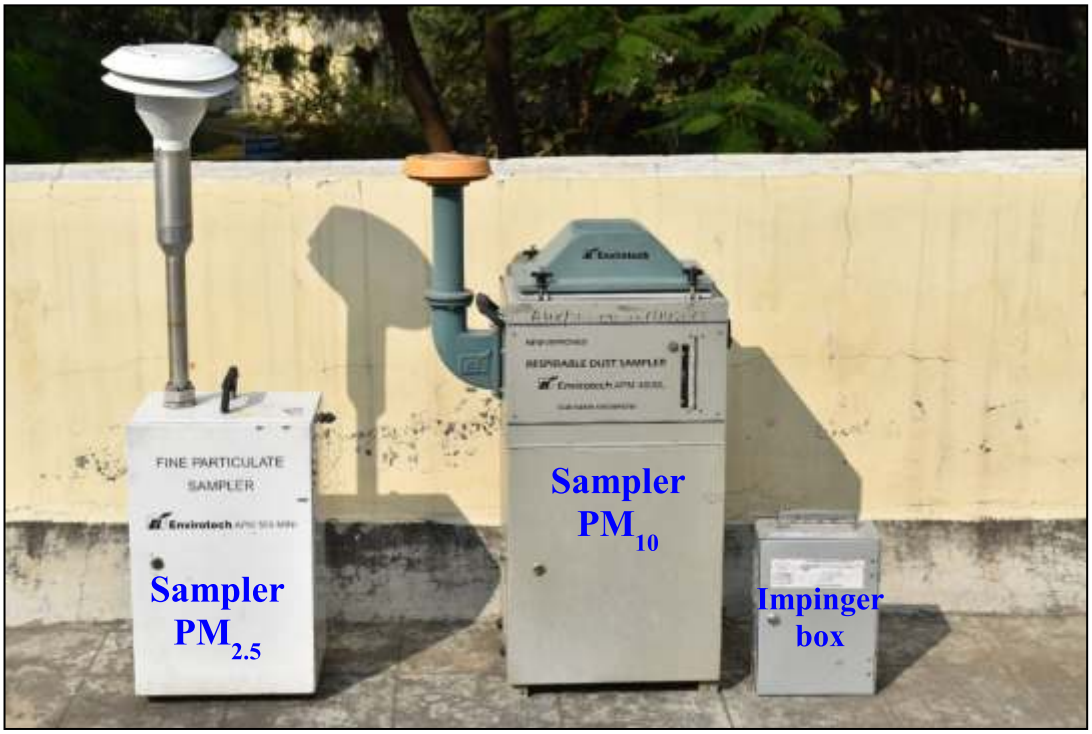
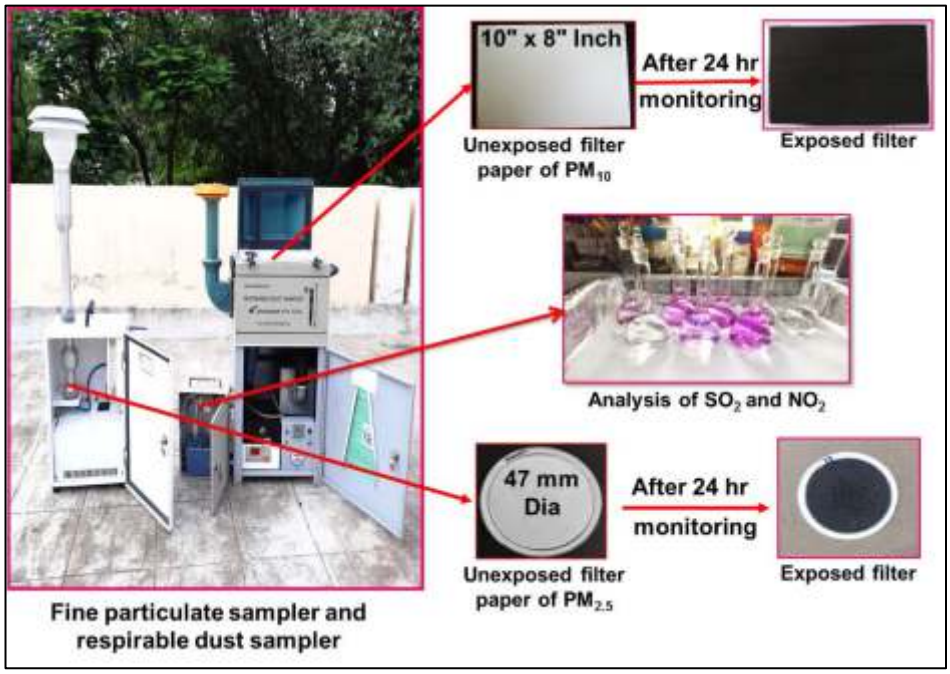


Fine particulate sampler and respirable dust sampler along with gaseous sampling attachment

Internal components of fine particulate sampler, respirable dust sampler and impinger box for $PM_{2.5}$, PM_{10},SO_2 and NO_x sampling



Analysis of particulate and gaseous samples collected from fine particulate sampler and respirable dust sampler

Atomic Absorption Spectroscopy (AAS), modern instrument for heavy metal analysis