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Current Status of Air Quality of Lucknow City and Their Health Effects

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Abstract

The study was carried out during the current year (March, 2022 - February 2023) to see the status of air quality of Lucknow city by monitoring and assessment of some selected air pollutants namely Respirable Particulate Matter (PM_{10}), Sulphur dioxide (SO_2), Nitrogen dioxide (NO_2) levels, and also AQI of urban Lucknow at 5 representative air pollution monitoring sites located at different locations categorized as two residential (Mahanager and Aliganj), two commercial (Hazratganj and Ansal T.C.) and one industrial (Talkatora) areas. The results revealed the 24 hours concentration of PM_{10} in the range of 111.24 to 240.89 µg/m^3 with an average of 178.09 µg/m^3. The average values of PM_{10} irrespective of locations were found to be above the permissible limit (PM_{10} = 100 µg/m^3) prescribed by NAAQ and WHO guidelines. Similarly, 24 hours average concentration of SO_2 and NO_2 were found in the range of 6.96 to 11.50 and 25.28 to 44.41 µg/m^3 with an average concentration of 8.58 and 33.58 µg/m^3 respectively and all the values were below the permissible limits (80 µg/m^3). The 24 hours AQI was recorded in the range of 103 to195 with an average of 149 which was graded unhealthy to severe by NAAQ and WHO throughout the year. The seasonal variations in PM_{10}, SO_2 and NO_2 were noticed and found to be maximum 218.20, 10.32 and 41.43 µg/m^3 respectively, in winter and minimum 123.47, 7.19 and 28.31 µg/m^3 respectively, in monsoon season. Similar seasonal variations in AQI were also recorded. It was reported maximum 177 µg/m^3 in winter (November -February) and mminimum 111 µg/m^3 in monsoon (July – October) season. When above findings were correlated with human health, it was seen to be incident of asthmatic attack, cardiac arrest, strokes, and bronchitis, as well as premature death from heart ailments and lung disease increased during winter season in comparison to other seasons. Studies showed that the excess RSPM exposure can impair development of brain in children.

Keywords: PM_{10}, SO_2, NO_2, Ambient Air Quality (AQI), human health, Lucknow city,

INTRODUCTION

Lucknow is a historical, most populated and largest state capital city of Uttar Pradesh situated near the river Gomati and spread both side of river bank of Gomati. In 18th and 19th century, it was rolled by Muslim rulers so commonly known as "City of Nawabs". Like other metropolitan cities, air quality of urbon Lucknow is also dangerous. Many reports revealed that urban air quality of Lucknow city is detoriating day by day especially in winter season, mainly due to rapid growth of urbanization, industrialization, transportation and construction activities. (Kumar *et* al., 2023; Kumar & Dwivedi, 2021; Akanksha et al., 2020; Bharti *et al.,* 2017).

Air is a natural resources available free of cost. Clean air is the basic needs of every living organism. An healthy adult person required 8 L air per minute for breathing. When air is get polluted, it threaten every living organism (Ghorani-Azam *et al.* 2016). Air of megacities are being polluted by multiple natural and anthropogenic sources like urbanization, industrialization, rapid growth of human population and increasing number of automobiles on the roads (Satterthwaite et al. 2010). Although pollutants released by these aactivities are naturally self regulated and absorbed up to a certain extent, and helps in restoring the air quality but when its limits are exceeded, these pollutants are accumulated in the environment and deteriorate air quality. WHO report (2006) data revealed that there are more than 80% of urban population are exposed to air quality levels above the NAAQ standards and WHO guideline limits (WHO, 2006). However, in recent studies it has been observed that there are about 90% of world population living in the unhealthy air quality limits (WHO, 2016). It to be seems, past few decades due to human activities such as industrialisation, fossil fuels burning, rapid increase in automobiles number and intensively use of agrochemicals have accelerated the levels of harmful gases like SO_2, NO_2, CO, O_3 and particulate matter (PM) in environment to worrying levels (Wu *et al*. 2020; Gurjar *et al.* 2016).

Pandey *et al.* (2011 and 2013) reported effect of SO_2 on human health and suggested that the short-term exposure of SO_2 can harms the respiratory system, specially, in old aged persons and childrens. However, its longer exposure can cause heart and pulmonary diseases. Similarly, Atkinson *et al.* (2018) have been reported that the excess exposure of NO_2 and CO causes cardiovascular mortality, ischaemic heart diseases and cerebrovascular diseases. High concentration of CO in air also impaired O_2 supply to critical organs like brain and heart which induces dizziness, unconsciousness and even death.

Several workers reported some common components of air pollutants such as $PM_{2.5}$, PM_{10}, O_2 , NOx, etc are emitted from vehicles used fossil fuels and it accumulated in the environmental air, harming the living organisms in different ways. Recent studies suggested that RSPM in urban areas of Lucknow city above the prescribed standards NAAQ (P_{10} = 100) and WHO guideline. Excess concentration PM cause many severe detrimental healh effects on human. The effects of PM on human health depend on the chemical composition of PM, shape, size, frequency and duration of exposure. Indian standard of ambient air is limited with two specified size of PMs such as $PM_{2.5}$ and PM_{10}. The elevated levels of these PMs in air causes, morbidity and mortality in humans.

Thus it needs of massive camping and awareness programs for common men especially in the urban areas of all metropolitan cities including Lucknow, regarding the air pollution and its consequences on human health. Unlimited growth of human population corresponding to increases number of vehicles for transportation which severely affecting the sustainable development and gradually becoming unbearable.

In reference to above facts, the present study has been planned to observe the current status of air quality of Lucknow city and their adverse effects on human health. For this purpose secondary data were collected from 5 representative monitoring sites of different localities of Lucknow city in current year (2022-2023).

Study location and data collection

Lucknow is lagest and most populated city of Uttar Pradesh, located in northern India between 26°85′ N latitude and longitude 80°95′ E. It is popularly known as the "City of Nawabs". Like other metropolitan cities, the air quality of Lucknow is also found to be poor and unhealthy. According to World Air Quality Report (IQAir, 2019), Lucknow has placed on 11th rank among the top 15th most polluted cities of the world and in an another reports, January, 2019 it was placed on 9th rank in top 10 most polluted cities of the world.

For the assessment of ambient air quality (AQI) in Lucknow city, secondary data has been obtained from the Uttar Pradesh Pollution Control Board (UPPCB), the Central Pollution Control Board (CPCB), and the Centre for Science and Environment (CSE). The assessment of the monthly average concentration of ambient air pollution in Lucknow has been conducted with the recorded data (from Annual Report UPPCB, 2022–2023) against 5 monitoring stations are 2 residential (Mahanager and Aliganj), 2 commercial (Hazratganj and Ansal T. C.) and 1 industrial (Talkatora) area for each month and comparing the average value with the given NAAQ Standards. Seasonal variations in AQI and its three representative components such as PM_{10}, SO_2 and NO_2 were also recorded.

Source of air pollution in Lucknow

Multiple factors are responsible for causing air pollution in Lucknow city, among them transportation is the main factor, where use of large number of poorly-maintained diesel and petrol vehicles and poor traffic controlling management makes it major contributor in air pollution. Additionally it, there are several large, medium and small-scale industries situated in 04 designated Industrial sites in and around Lucknow city named, Talkatora Udyog Asthan, Amausi, Chinhat and Sarojini Nagar industrial areas, and about 255 operational brick kiln situated around city also contribute in air pollution.

Presently, Lucknow included in Smart City Yojana results a huge ongoing construction activities viz., roads and fly over construction, metro rail construction, and multistory apartment construction have also been contributing to the air pollution. Besides these, several others domestic, industrial and commercial activities, urbanization, deforestation, population growth and energy consumption are major driving force of air pollution in Lucknow. Thus the major causes of air pollution in Lucknow city can be attributed to emissions from transportation, diesel generators, industrial, domestic and construction activities, burning of biomass, municipal solid or waste and garbage, crop residue and resuspension of road dust.

Data Analysis and Results

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

The 24 hours mean concentration of PM_{10} was observed in Mahanagar, Aliganj, Hazratganj, Ansal T.C. and Talkatora were 163, 166, 201, 190.66 and 173.34 µg/m^3, respectively. It was recorded maximum 190.66 µg/m^3 in Ansal T.C. (commercial area) and minimum 163 µg/m^3 in Mahanagar (residential area) (Table-1, Fig. 1)

Table-1. Monthly average concentrations of PM_{10} (µg/m^3) in different localities of Lucknow city (2022-2023)

Locations	Type	Months												Average
			Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	
Mahanagar	R	189.33	186.30	171.90	187.30	132.00	124.90	131.90	100.97	187.54	-	201.27	189.83	163.00
Aliganj	R	214.30	202.70	160.80	178.30	98.47	79.20	88.90	135.13	203.56	-	256.25	214.30	166.00
Hazaratganj	C	202.12	233.95	232.56	225.44	145.82	140.39	155.14	184.00	232.90	-	261.19	202.12	201.00
Ansal T. C.	C	218.45	216.80	214.30	205.50	155.60	182.40	179.40	100.97	179.84	-	225.61	218.45	190.66
Talkatora	I	217.33	215.70	186.90	195.20	97.94	71.20	78.30	166.38	209.15	-	251.28	217.33	173.34
Average		165.80	211.09	193.0	198.34	125.87	119.61	123.12	137.49	202.59	-	239.12	200.83	174.28

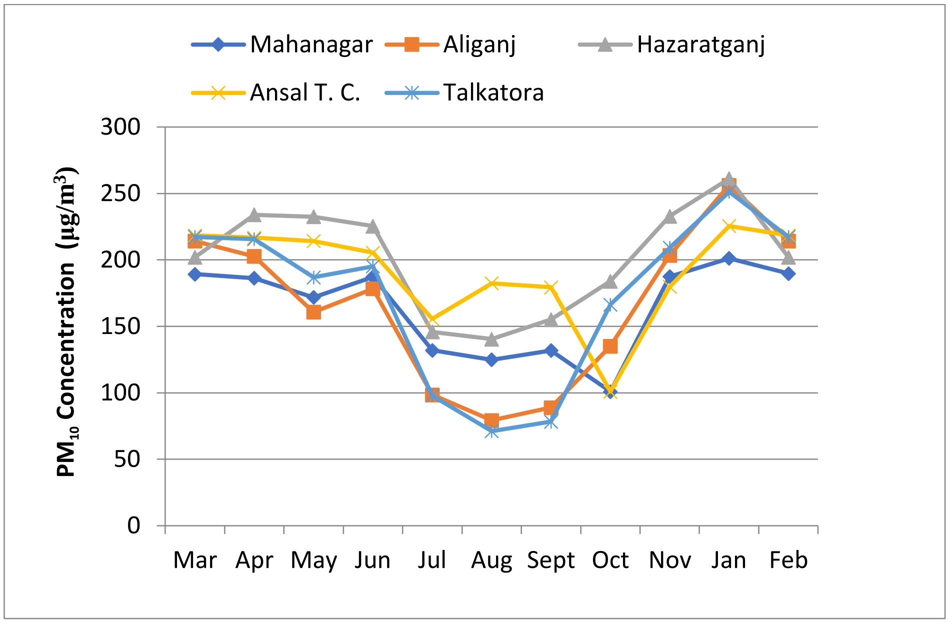

Figure-1. Monthly variations of PM_{10} concentrations in different localities of Lucknow city

In residential areas (Mahanagar and Aliganj), the 24 hours average concentrations of PM_{10} were in the range of 102.05 to 228.76 µg/m^3 with an average of 165.15 µg/m^3. In commercial areas (Hazratganj and Ansal T.C.) the average concentrations of PM_{10} were in the range of 142.49 to 243.4 µg/m^3 with an average of 195.96 µg/m^3 respectively. In industrial area (Talkatora) the average concentrations of PM_{10} were in the range of 71.20 to 251.28 µg/m^3 with an average of 174 µg/m^3 (Table-2).

The seasonal variations in PM_{10} concentrations were also recorded in residential, commercial and industrial areas. In residential area 24 hours average concentrations of PM10 was observed 186.14, 111.50 and 208.69 µg/m^3 in summer (March - June), monsoon (July - October) and winter (November - December), respectively. Similarly in commercial areas PM10 was recorded 218.42, 155.46 and 220.01 µg/m^3; and in industrial area 203.78, 103.45 and 225.92 µg/m^3 in summer, monsoon and winter, respectively.

The maximum concentration of PM_{10} was recorded 225.92 µg/m^3 in winter in industrial area and was minimum 111.50 µg/m^3 in monsoon in residential area.(Table-3, Fig. 2).

Table-2. Monthly variations of PM_{10} (µg/m^3) concentrations in residential, commercial and industrial areas of Lucknow city

Locations Type	Months												Average
	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	
Residential areas (R)	201.81	194.15	165.80	182.80	115.23	102.05	110.40	118.35	195.27	-	228.76	202.06	165.15
Commercial areas (C)	210.28	224.50	223.43	215.47	150.71	161.39	167.27	142.49	206.37	-	243.40	210.28	195.96
Industrial areas (I)	217.33	215.70	186.90	195.20	97.94	71.20	78.30	166.38	209.15	-	251.28	217.33	173.34

Table-3. Seasonal variations of PM_{10} (µg/m^3) concentrations in residential, commercial and industrial areas of Lucknow city

Locality Type	Summer season (March - June)	Monsoon season (July - October)	Winter season (November- February)
Residential areas (R)	186.14	111.50	208.69
Commercial areas (C)	218.42	155.46	220.01
Industrial areas (R)	203.78	103.45	225.92

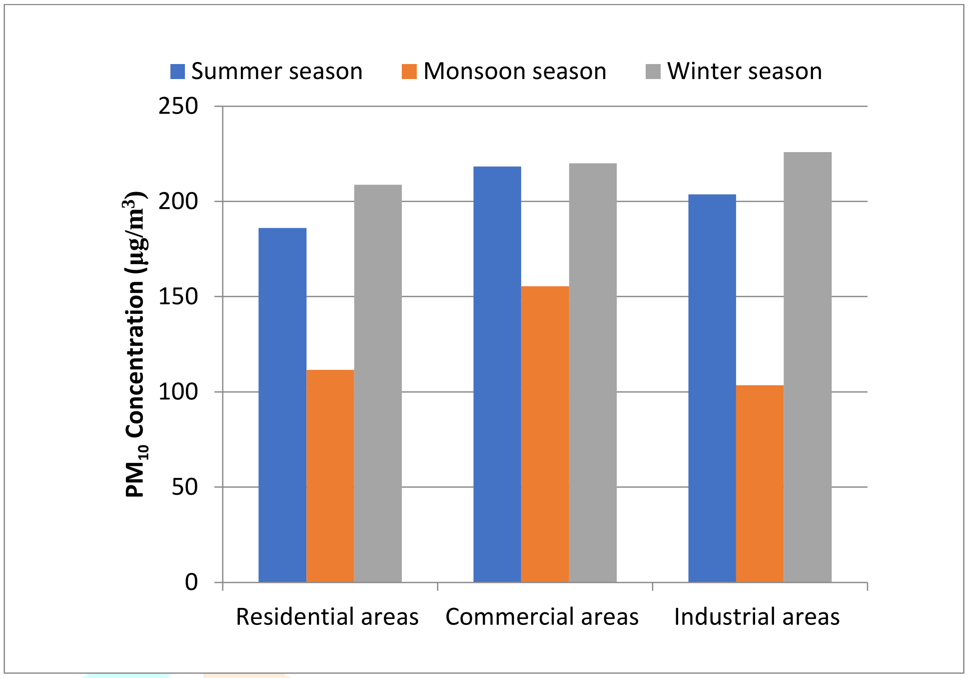

Figure-2. Seasonal variations of PM_{10} concentrations in residential, commercial and industrial areas of Lucknow city

All the values of PM_{10} were recorded above the prescribed NAAQ Standard of 100 µg/m3, except industrial area (Talkatora) in month of August. It was recorded 71.20 µg/m^3 (Table-1).

Sulphur dioxide (SO_2)

The 24 hours mean concentration of SO_2 was observed in Mahanagar, Aliganj, Hazratganj, Ansal T.C. and Talkatora were 8.21, 8.16, 8.97, 8.55 and 8.73 µg/m^3, respectively. It was recorded maximum 8.97 µg/m^3 in Hazratganj (commercial area) and minimum 8.16 µg/m^3 in Aliganj (residential area) (Table-4, Fig. 3).

Table-4.Monthly average concentrations of SO_2 (µg/m^3) in different localities of Lucknow city (2022-2023)

Locations	**Type**	**Months**												**Average**
		Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	
Mahanagar	R	8.98	8.40	8.40	7.20	7.40	6.70	6.70	7.39	8.19	-	10.62	10.42	8.21
Aliganj	R	8.32	9.00	9.70	7.40	6.39	6.10	6.70	8.49	7.80	-	10.53	9.35	8.16
Hazaratganj	C	8.17	9.54	7.44	8.40	7.58	8.08	6.36	9.33	9.29	-	12.70	11.82	8.97
Ansal T. C.	C	8.05	8.80	8.70	7.90	7.50	7.30	7.24	7.39	8.33	-	11.56	11.35	8.55
Talkatora	I	9.89	10.40	8.20	6.40	6.80	6.80	6.70	8.95	8.29	-	10.57	13.06	8.73
Average		8.68	11.02	8.49	7.46	7.13	6.99	6.60	8.31	8.38	-	11.19	11.20	8.68

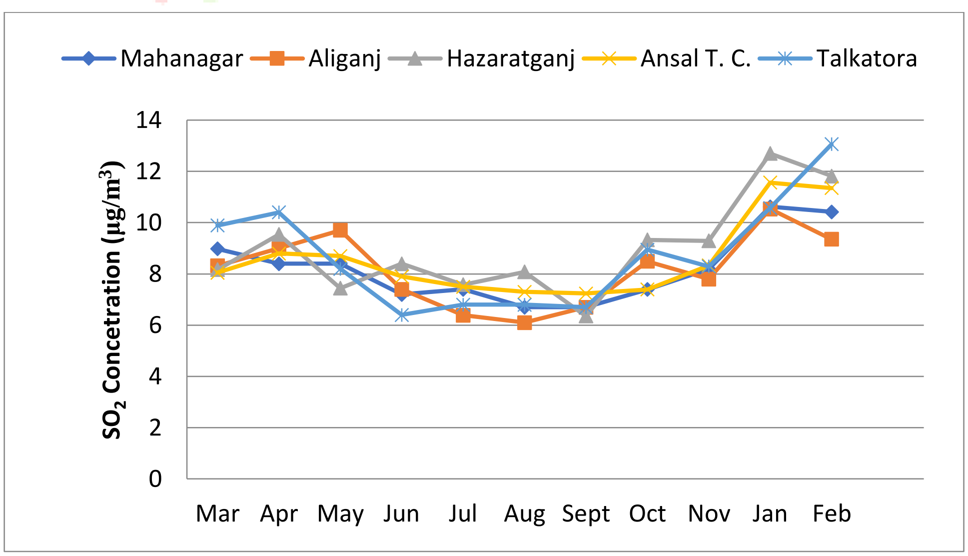

Figure-3. Monthly variations of SO_2 concentrations in different localities of Lucknow city

In residential areas (Mahanagar and Aliganj), the 24 hours average concentrations of SO_2 were in the range of 6.4 to 10.57 µg/m^3 with an average of 8.18 µg/m3. In commercial areas (Hazratganj and Ansal T.C.) the average concentrations of SO_2 were in the range of 6.8 to 12.13 µg/m^3 with an average of 8.02 µg/m^3 respectively. In industrial area (Talkatora) the average concentrations of SO_2 were in the range of 6.4 to 13.06 µg/m^3 with an average of 8.81 µg/m^3 (Table-5).

The seasonal variations in SO_2 concentrations were also recorded in residential, commercial and industrial areas. In residential area 24 hours average concentrations of SO_2 was observed 8.42, 6.67 and 9.48 µg/m^3 in summer (March - June), monsoon (July - October) and winter (November - December) respectively. Similarly in commercial areas SO_2 was recorded 8.22, 7.59 and 10.84 µg/m^3; and in industrial area 8.96, 7.31 and 10.64 µg/m^3 in summer, monsoon and winter, respectively

Table-5. Monthly variations of SO_2 (µg/m^3) concentrations in residential, commercial and industrial areas of Lucknow city

Locations Type	Months SO2												Average
	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	
Residential areas (R)	8.65	8.70	9.05	7.30	6.89	6.40	6.70	7.94	7.99	-	10.57	9.88	8.18
Commercial areas (C)	8.11	9.17	8.07	8.10	7.54	7.69	6.80	8.36	8.81	-	12.13	11.58	8.02
Industrial areas (I)	9.89	11.02	8.49	6.40	6.80	6.80	6.70	8.95	8.29	-	10.57	13.06	8.81

Table-6. Seasonal variations of SO_2 (µg/m^3) concentrations in residential, commercial and industrial areas of Lucknow city

Locality Type	Summer season (March - June)	Monsoon season (July - October)	Winter season (November- February)
Residential areas (R)	8.42	6.67	9.48
Commercial areas (C)	8.22	7.59	10.84
Industrial areas (R)	8.95	7.31	10.64

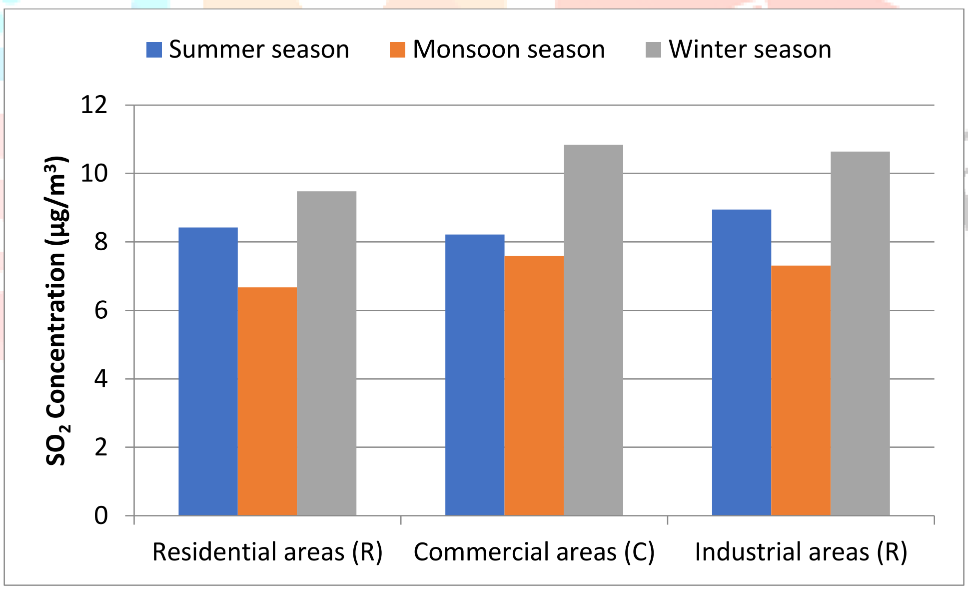

Figure-4. Seasonal variations of SO_2 concentrations in residential, commercial and industrial areas of Lucknow city

The maximum concentration of SO_2 was recorded 10.84 µg/m^3 in winter in commercial area and was minimum 6.67 µg/m^3 in monsoon in residential area (Table-6, Fig.-4).

All the values of SO_2 were recorded below the prescribed NAAQ Standard (80 µg/m^3) and WHO guidelines (20 µg/m^3).

Oxides of Nitrogen (NO_x)

The 24 hours mean concentration of NO_2 was observed in Mahanagar, Aliganj, Hazratganj, Ansal T.C. and Talkatora were 33.63, 33.62, 33.89, 32.13 and 35.32 µg/m^3, respectively. It was recorded maximum 35.32 µg/m^3 in Talkatora (industrial area) and minimum 32.13 µg/m^3 Ansal T.C. (commercial area) Table-7, Fig. 5)

Table-7.Monthly average concentrations of NO_2 (μg/m^3) in different localities of Lucknow city (2022-2023)

Locations	Type	Months												Average
		Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	
Mahanagar	R	36.90	35.70	31.10	31.00	24.10	25.60	29.50	29.54	41.12	-	45.97	39.49	33.63
Aliganj	R	36.96	30.00	26.70	31.70	23.36	22.20	23.30	32.69	38.55	-	41.67	40.76	33.62
Hazaratganj	C	37.35	31.90	30.20	29.00	23.38	23.17	27.80	37.76	42.84	-	48.01	41.46	33.89
Ansal T. C.	C	43.57	28.90	32.40	31.40	21.48	24.70	24.91	29.54	35.71	-	43.18	37.64	32.13
Talkatora	I	34.36	33.90	33.70	32.90	30.15	28.00	30.60	39.52	40.88	-	43.81	40.76	35.32
Average		44.75	32.08	30.82	31.20	24.49	24.73	27.22	33.81	39.82	-	44.52	40.02	31.47

The seasonal variations in NO_2 concentrations were also recorded in residential, commercial and industrial areas. In residential area 24 hours average concentrations of NO_2 was observed 32.50, 26.28 and 41.25 μg/m^3 in summer (March - June), monsoon (July - October) and winter (November - December), respectively. Similarly in commercial areas NO_2 was recorded 43.09, 26.59 and 41.47 μg/m^3; and in industrial area 33.26, 32.06 and 41.57 μg/m^3 in summer, monsoon and winter, respectively

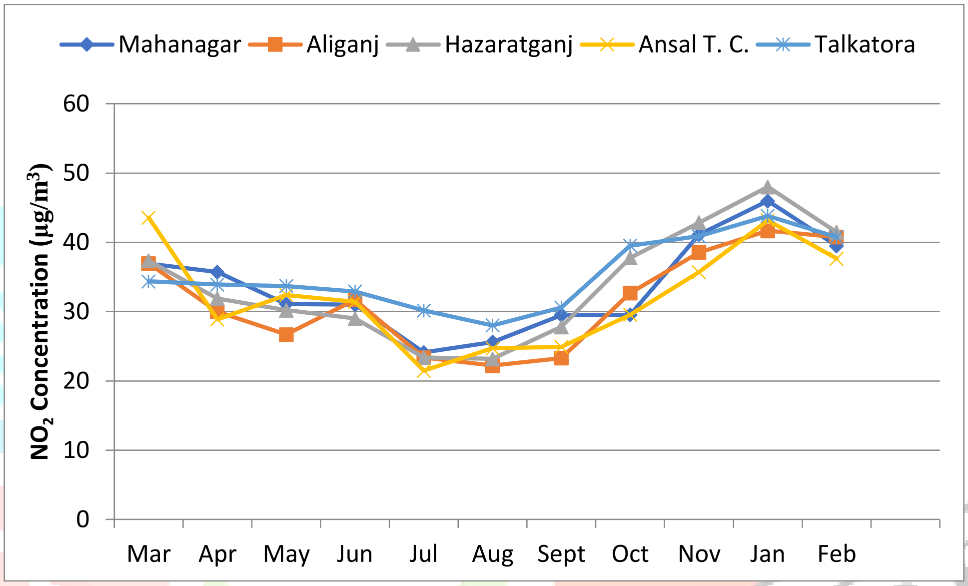

Figure-5. Monthly variations of NO_2 concentrations in different localities of Lucknow city

The maximum concentration of NO_2 was recorded 41.57 μg/m^3 in winter in industrial area and was minimum 26.28 μg/m^3 in monsoon in residential area (Table-9, Fig.9).

All the values of NO_2 were recorded below the prescribed NAAQ Standard of 80 μg/m^3.

Table-8. Monthly variations of NO_2 (μg/m^3) concentrations in residential, commercial and industrial areas of Lucknow city

Locations Type	Months												Average
	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	
Residential areas (R)	36.93	32.85	28.90	31.35	23.73	23.90	26.40	31.11	39.83	-	43.82	40.12	32.63
Commercial areas C)	40.46	30.40	31.30	30.20	22.43	23.93	26.35	33.65	39.27	-	45.59	39.55	33.01
Industrial areas (I)	34.36	32.08	33.37	32.90	30.15	28.00	30.60	39.52	40.88	-	43.81	40.02	35.09

Table-9. Seasonal variations of NO_2 (μg/m^3) concentrations in residential, commercial and industrial areas of Lucknow city

Locality Type	Summer season (March - June)	Monsoon season (July - October)	Winter season (November- February)
Residential areas (R)	32.50	26.28	41.25
Commercial areas (C)	33.09	26.59	41.47
Industrial areas (R)	33.26	32.06	41.57

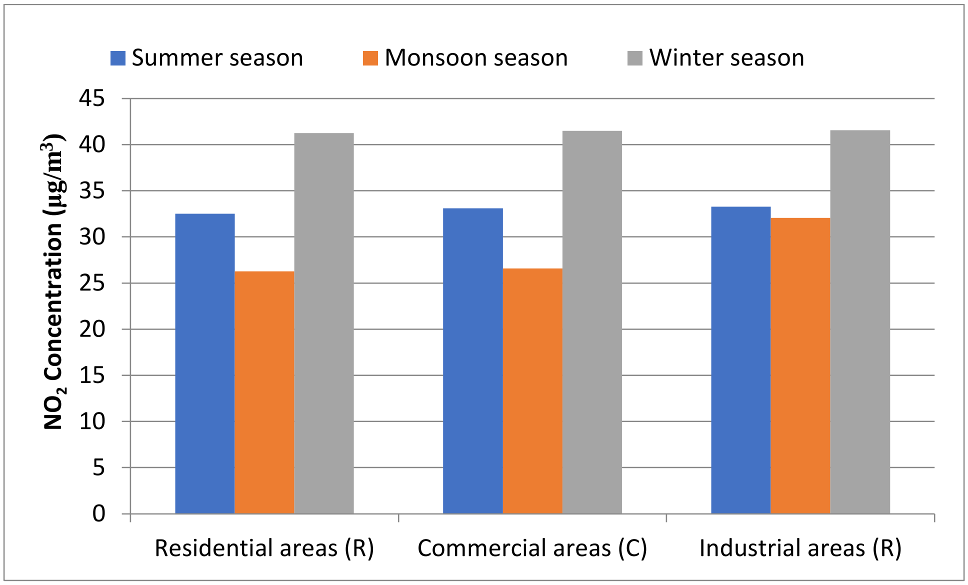

Figure-6. Seasonal variations of NO_2 concentrations in residential, commercial and industrial areas of Lucknow city

Ambient Air Quality (AQI)

The 24 hours mean level of AQI was observed in Mahanagar, Aliganj, Hazratganj, Ansal T.C. and Talkatora were 141, 141.18, 170.36, 159 and 143, respectively. It was recorded maximum 170.36 in Hazratganj (commercial area) and minimum 141 in Mahanagar (residential area) (Table-10, Fig.7).

In residential areas (Mahanagar and Aliganj), the 24 hours average levels of AQI were in the range of 98 to 187 with an average of 141. In commercial areas (Hazratganj and Ansal TC) the average levels of AQI were in the range of 128.5 to 197.5 with an average of 164, respectively. In industrial area (Talkatora) the average levels of AQI were in the range of 78 to 201 with an average of 143 (Table-11)

Table10. Monthly average of ambient air quality (AQI) in Lucknow city (2022 - 2023).

Locations	**Type**	**Months**												**Average**
		Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	
Mahanagar	R	160	158	141	158	121	117	109	101	158		168	165	141
Aliganj	R	176	168	133	152	98	79	87	123	169		206	162	141.18
Hazaratganj	C	168	189	188	184	130	127	137	156	188		211	196	170.36
Ansal T. C.	C	179	178	176	170	137	155	153	101	153		184	163	159
Talkatora	I	178	177	158	163	98	71	78	123	173		201	156	143
Average		172.20	174	159.20	165.40	116.80	109.80	112.80	120.80	168.20		194	168.40	151.05

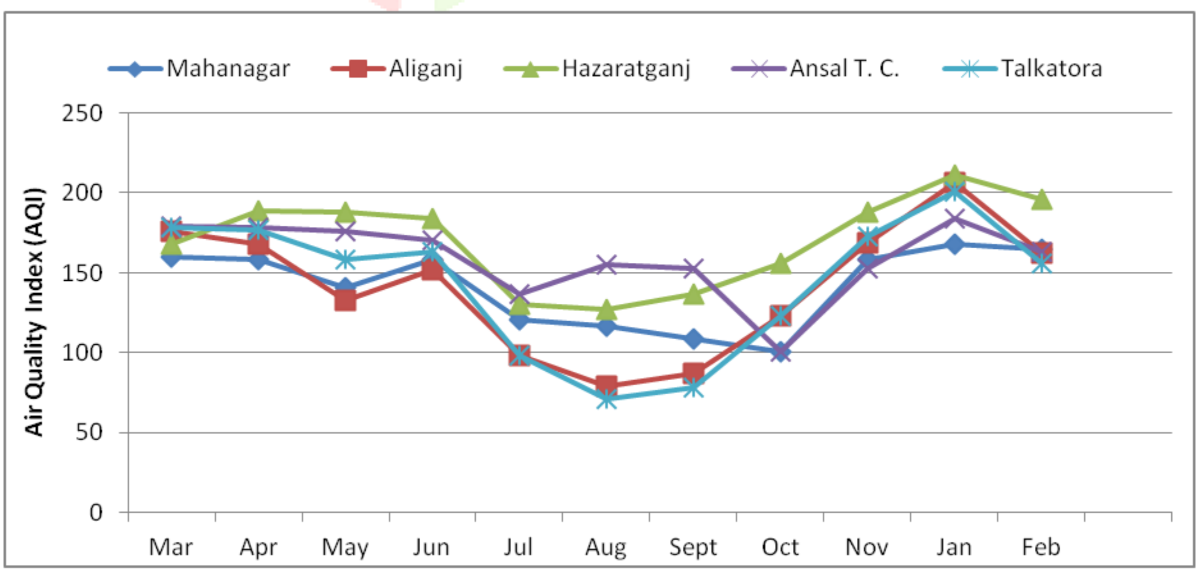

Figure -7. Monthly variations of AQI in different localities of Lucknow city

Table-11. Monthly variations in AQI in residential, commercial and industrial areas of Lucknow city

Locations Type	Months												Average
	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	
Residential areas (R)	168	163	137	155	109.5	98	98	111.5	163.5		178	164	141
Commercial areas (C)	173.5	183.5	182	177	133.5	141	145	128.5	170.5		197.5	179.5	164
Industrial areas (I)	178	177	158	163	198	71	78	123	173		201	156	143

The seasonal variations in AQI levels were also recorded in residential, commercial and industrial areas. In residential area 24 hours average level of AQI was observed 155.8, 105.3 and 171.5 in summer (March - June), monsoon (July - October) and winter (November - December), respectively. Similarly in commercial areas AQI was recorded 179,136.9 and 182.5, and in industrial area 169, 92.5 and 176.7 in summer, monsoon and winter, respectively (Table-12, Fig.8)

The maximum levels of AQI was recorded 182.5 in winter in commercial area and was minimum 92.5 in monsoon in industrial area (Table-12)

All the values of AQI were recorded above the prescribed NAAQ Standards (0-50).

Table-12. Seasonal variations in AQI in residential, commercial and industrial areas of Lucknow city

Locality Type	Summer season (March - June)	Monsoon season (July - October)	Winter season (November- February)
Residential areas (R)	155.8	104.3	171.5
Commercial areas (C)	179	136.9	182.5
Industrial areas (R)	169	92.5	176.7

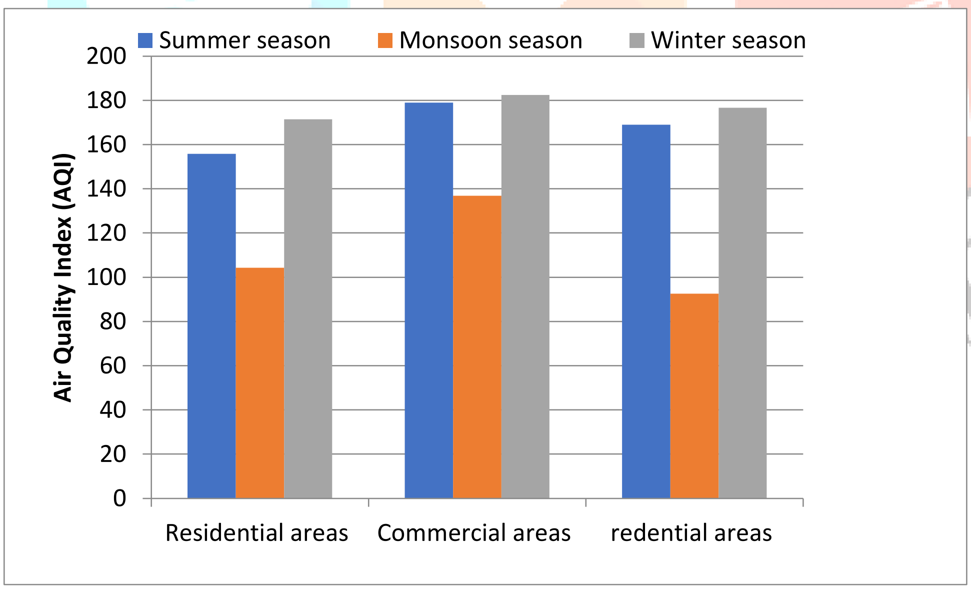

Figure-8. Seasonal variations in AQI in residential, commercial and industrial areas of Lucknow city

Health Effects

In present scenario, air pollution has been considered to be the world's largest environmental health threat. Annually, air pollution causes about 7 million deaths in the world. Detoriated or unhealthy air quality causes and exacerbates a number of diseases, ranging from asthma to cancer, cardiovascular and pulmonary illnesses. According to International Agency for Research on Cancer the air containing outdoor particulate matter associated with carcinogenic chemical and metal residues etc. are one of major cause of cacer in human beings.

Recently W.H.O. estimated, the exposure to air pollution is an important risk factor for major non-communicable diseases. It is the largest contributor to the burden of disease from the environment.

The chief pollutants which affecting human healths are particulate matter, sulphur oxides (SO_2), nitrogen oxides (NO_2) and ozone (O_3). Among these particulate matters is main concern, which penetrates deep into the lungs and mostly causes pulmonary and cardiac associated morbidity and mortality (Sahu *et al*., 2014; Sadeghi *et al.*, 2015). The hazards effect of PMs on health depends on its size, chemical composition and duration of the exposure.

Particulate matter (PM) is made up of small airborne particles like dust, soot and drops of liquids. The majority of PM in urban areas is formed directly from burning of fossil fuels by automobiles, power plant, non-road equipment, industrial emissions and construction activities and indirectly from gases and vapours.

Coarse particulate matter (PM_{10}) causes nasal and upper respiratory tract diseases whereas fine particles ($PM_{2.5}$) penetrate deeper into the lungs and causes asthma, heart attacks, bronchitis and strokes as well as premature death from cancer, lung disease and heart ailments. Some one reported higher exposure $PM_{2.5}$ can impair brain development in children (Bentayeb *et al*., 2013; Gao *et al*., 2014). Long term exposure of PM causes pulmonary bronchitis and chronic obstructive pulmonary diseases (COPD) and increases the risk of cardiopulmonary and lung cancer (Zhou et al., 2014; Pelucchi et al., 2009)

Nitrogen oxide (NOx) is combination of NO and NO_2 primarily emitted by motor engines and mostly traffic related pollutants. Its high concentration present around the roads and highways which can lead to a higher risk of heart disease, asthma and bronchitis. Excess concentration of NO2 causes coughing and pulmonary wheezing, irritation in eyes, mouth and throat, headache, dyspnea and cheast pain (Hesterberg et al., 2009).

Similarly, sulphur dioxide (SO_2) is also emitted into the air by the burning of fossil fuels that contain sulphur like coal, metal extraction and smelting, ship engines, and heavy equipment operated by diese, diesel generators etc. Its higher concentration in environment causes eye irritation, worsens asthma, increases susceptibility to respiratory infections and impacts the cardiovascular system (Chen *et al*., 2007). Besides these SO_2 and NO_2 combines with water during rainfall and form sulphuric acid and nitric acid, respectively. Rain water contains these acids referred as acid rain, which is mainly responsible for deforestation.

DISCUSSION

In developing countries, India has fastest growing economy and comes in 2^{nd} place among the developing countries after China. Therefore all Indian megacities and towns rapidly involved in infrastructure development, construction activities, urbanization, and industrialization. Besides these, introduction and establishment of several small, medium and large industries in or around the metropolitan cities are also responsible for air pollution. Harmful and uncontrolled emissions of these industries are severely affecting the air quality. Almost all cities of India having higher concentration of Respirable Suspended Particulate Matter (PM_{10}) than the prescribed limits of NAAQS and WHO guidelines. Several workers have been earlier reported higher concentrations of PM_{10} in air of Indian megacities such as in Delhi (Trivedi et al., 2014), Kolkata (Das et al., 2015), Raipur (Girri et al., 2013), Kanpur (Singh and Gupta, 2015) and Lucknow (Lawrence & Fatima, 2014; Saini et al., 2022)

In present investigation higher concentration of PM_{10} in Lucknow city were recorded in throughout year (2022-2023), which is above than the prescribed standards NAAQS and WHO guidelines. It may be attributed due to undergo rapid industrialization, urbanization and various constructive activities like construction of flyovers, roads, highways, multistory apartments and shopping malls are develop within or around the Lucknow city. Various scientific reports suggested that the almost all developed countries, such as the U.S., France, Britain, Germany etc. have already passed this phase (Yang et al., 2018). The increased concentrations of PM in megacities can be attributed to increasing vehicular exhaust, construction, transportation, increasing fossil fuel use by power-heavy industries and biomass combustion (Saini *et al*., 2022; Lin *et al*., 2018; Pant *et al*., 2016 and Guttikunda et al., 2014). Urban areas of Lucknow city also shows significant seasonal variations in PM concentrations, it was reported maximum in winter and minimum in monsoon. The higher concentration of

PM_{10} reported in present study in winter coincide with massive emissions from fossil fuel, burning of agricultural residues, climatic conditions and biomass burning for heating in winter (Yang et al., 2017; He *et al*., 2017 and Deka & Hoque, 2014). The adverse climatic conditions in winter like high humidity, slow winds and lower boundary layer height may also promote the accumulation of PM pollutants in air (Massey *et al*., 2012). In monsoon season PM_{10} concentrations were reported minimum, which can be attributed due to the rainfall most of the PM washoff from the air and settle down in ground (Ganguly *et al*., 2015; Saini *et al*., 2022). The other possible reason may be significant decline PM concentrations in monsoon season due to suspension of construction activity in this period. The average annual concentrations of PM_{10} reported highest in commercial areas and lowest in residential area. In previous studies it was recorded maximum in industrial areas followed by commercial and residential areas. The increased PM_{10} in commercial areas attributed due to extra vehicular activities and poor traffic controlling system (Mumtaz *et al*., 2017). However, decreased PM_{10} concentration in industrial areas shown more focus of pollution controlling authorities on these areas. The similar observations and suggestions has been given by Saini *et al*. (2022).

Rapid industrial development and urbanization are responsible for elevation of PMs emission. Exposure of PMs (PM_{10} and $PM_{2.5}$) pollution has been associated with increased risks of cardiovascular, lungs and cerebrovascular diseases (Laden et al, 2006; Pope *et al*., 2009 and Pope *et al*., 2011). According to the World Health Organization (WHO), air pollution is 92% global burden of diseases of the world's population, currently about 3 millions annual deaths were reported over the world where the level air quality exceeds from the WHO guideline (W.H.O., 2016). Cohen *et al*. (2005) were reported the higher concentration of PM causes 8 lakhs premature death and 6.4 millions people last their life per year over the world.

The decreased SO_2 and NO_2 concentrations from the prescribed standards values (60 $\mu g/m^3$) of NAAQ and WHO guidelines were observed in present study is similar to the observations of Mumtaz *et al*. (2017) and Saini et al. (2022). They were earlier reported similar observations in Lucknow city. The monthly average concentration of SO_2 and NO_2 were found maximum in February and March, respectively, whereas minimum in September and July, respectively. In case of seasonal variations concentration of SO_2 and NO_2 were reported maximum in winter season in industrial area and minimum in monsoon season in residential area. The present findings were found to be similar to Saini et al. (2022). They were reported maximum concentration of SO_2 and NO_2 in industrial areas during winter and minimum in residential areas during monsoon. The average increasement of SO_2 and NO_2 in winter may be associated due to excessive burning of fossil fuels like coal and oil in industries, traffic congestion, burning of agricultural residues, burning of biomass for heating houses to prevent cooling and uncontrolled use firecrackers in celebration of New Year and festivals like Dashhara and Diwali. Besides, these meteorological conditions during winter also help in accumulation of pollutants in the environment. The minimum concentration of SO_2 and NO_2 were reported in monsoon period may be attributed due to rainfall which washout pollutants from air. Similar observations and findings were earlier reported by Mumtaz *et al.* (2017) and Saini *et al.* (2022).

The increased concentrations of SO_2 and NO_2 in winter season may be due to increasing burning of biomass and adverse environmental conditions. Some workers reported correlation between increased gaseous pollutants together increasement of hospitalization because most sensitive persons like children, elderly people and pregnant women are highly affected.

Thus the increased AQI were recorded in Lucknow city throughout the assessment year 2022-2023) from NAAQS and WHO guidelines. It was reported most severe during winter season and mild unhealthy during monsoon. Severe unhealthy AQI in winter season attributed may be due climatic conditions, buring of biomass, increased construction activities etc. However decreased AQI in monsoon season from winter and summer may be due to least construction activities and vehicular exhaust. The other significant reason decline in AQI during monsoon is rainfall which washout pollutants from air. Similar findings and observations were also reported by Lawrence and Fatima (2014) and Saini *et al*. (2022).

Conclusion

This study carried out to assess the current status of air quality of Lucknow city. For this purpose secondary data were collected from Uttar Pradesh Pollution Control Board website and analyzed monthly and seasonally variations in PM_{10}, SO_2 and NO_2 of 5 representative locations. Study results revealed there is a higher concentration of PM_{10} occurs throughout year from the prescribed NAAQ Standards and WHO guidelines but it was less than the previous years. Its peak concentration was reported in month of January, 2023 in winter season and minimum in month of August, 2022. Concentration of SO_2 and NO_2 were observed below the prescribed levels in every month in study year. In monsoon season concentration of both SO_2 and NO_2 was found to be lower than the summer and winter.

Although the great efforts carried out by state and central pollution control boards to slowing down pollution which results concentration of SO_2 and NO_2 become reduce from prescribed NAAQ Standard but problem related to PM_{10} is remain still constant and it was found above the prescribed limits throughout year in Lucknow city, which is great matter of concern. Thus it needs massive camping and awareness programme for common people in megacities by pollution control board authorities in association with social welfare groups and educational institutions.

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