# Air Quality Status of Lucknow City–A Case Study

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***Abstract:*** **In this study, an attempt has been made to determine air quality of Lucknow city during the years (2013- 2015). Data of air pollutants ($NO_2$, $SO_2$ and $PM_{10}$) has been analyzed from five monitoring sites of the city which include residential, industrial and commercial areas.**

**The annual average concentrations of $PM_{10}$ for 2013 -2015 range approximately from 60 µg/m$^3$ to 200 µg/m$^3$ exceeding the National Ambient Air Quality Standards for industrial, commercial and residential areas. The annual averaged values range around 8 µg/m$^3$ for $SO_2$ concentrations, and are in the order of 30 µg/m$^3$ for $NO_2$ concentrations. However, $NO_2$ and $SO_2$ are within the permissible limits. Monthly averages for $PM_{10}$ have highest concentrations in the year 2013 for the years (2013-2015), and indicate distinct seasonality during winter months. The months of December and January demonstrate higher concentrations of $PM_{10}$ exhibiting influence of winter inversion. These values distinctly exceed 200 µg/m$^3$ in winter, which is more than 3 times the national ambient air quality standard for residential areas.**

**The paper also investigates the count of exceedances of national ambient air quality standards and briefly compares the results with previous air quality studies in Delhi to understand the comparative status of air quality in Lucknow. The exceedance count is high with values above 100 for all the years and all sites except Aliganj, which is a residential site. The 24-hr averages for $PM_{10}$ violate 24-hr industrial and residential standards of 150 µg/m$^3$ and 100 µg/m$^3$ respectively for all the five sites considered in this study irrespective of site characteristics.**

***Keywords: Air quality, $PM_{10}$, $SO_2$ and $NO_2$.***

## I. INTRODUCTION

There are many reasons that cause air pollution, which make it a ubiquitous problem in present days. However, typically it is caused by increasing transportation, industrialization and urbanization. Therefore, human anthropogenic activities are the main causes of air pollution ultimately adversely affecting human health, vegetation and environment. Gaseous air pollutants such as $NO_2$ and $SO_2$ can undergo chemical transformations in the atmosphere and form nitrates and sulphates which become aerosol constituents. A significant amount of nitrogen oxide emissions, consisting of nitric oxide (NO) and nitrogen dioxide ($NO_2$) primarily attributed to combustion of biomass and fossil fuels contribute to air pollution processes such as photochemical smog and formation of acid rain precursors. Nitrous oxide ($N_2O$) mainly emitted from agricultural activities causes destruction of ozone in the stratosphere and is an important greenhouse gas causing global warming [1]. Over the past 150 years, global emissions of nitrogen oxides into the atmosphere have been increasing steadily. Hewitt revealed that $SO_2$ constitutes the primary component of sulphur oxides ($SO_x$) released during fossil fuel combustion [2], which reacts quickly with water vapor to form sulphuric acid. This sulphuric acid condenses onto aerosol particles and quickly dissociates to form sulfate aerosols. The relationship between $SO_2$ and particulate matter indicates that any health outcome attributed to $SO_2$ may in fact be due to particulate matter or substances adsorbed on particulate matter. Particulate matter may carry materials with toxic or carcinogenic effects. Fine particulates penetrate deep into lungs causing pulmonary diseases [3]. Moreover, they contribute to acidification, winter smog and other serious environmental issues.

There are significant gaps in clearly documented thresholds of exposure-response relationships for long-term as well as short-term effects on health. However there is strong evidence on the effect of exposure to air pollutants on acute and chronic effects on human health, affecting a number of different systems and organs within the human body ranging from minor upper respiratory irritation to chronic respiratory and heart diseases lung cancer, acute respiratory infections in children and chronic bronchitis in adults, aggravating pre-existing heart and lung disease, or asthmatic attacks [4]. Although particulate matter displays strong association with mortality, it is still unclear what characteristics, such as particle size and chemical constituents, are responsible for this association [5].

In India, large amounts of gaseous and particulate pollutants regularly emitted by industries, thermal power plants and vehicles (both heavy duty diesel vehicles such as trucks and gasoline fuelled cars) cause great health risks. Upadhyay revealed that health impact of air pollutants is extremely significant in polluted urban regions of India [6,7]. Delhi, the national capital is already ranked high (11$^{th}$ globally) among the most polluted cities in the world in terms of particulate matter concentrations. Amongst the world's twenty most polluted cities with high aerosol concentrations, four of these are located in Uttar Pradesh namely Allahabad, Firozabad, Lucknow and Kanpur. Lucknow, the capital of Uttar Pradesh is currently ranked 18$^{th}$ globally [8].

All criteria pollutants especially excess of respirable particulate matter concentrations ($PM_{10}$) play a major role in deteriorating health effects [9]. The major sources of pollution of $PM_{10}$ are on-road transport, the rising numbers of which counteract the benefits of vehicular emissions control programmes. Other sources of pollutants include coal-based thermal power plants, small-scale industries, road dust and non-road sources such as construction activities. Transport both local and long-distance can have a significant impact as well [10]. As the incidence of respiratory diseases in most of the major cities in India like Lucknow has increased considerably over the years, evaluation of ambient air quality is imperative. Assessment of ambient air quality is a method to verify the effectiveness of the control measures implemented, and for early detection of potentially harmful changes in atmospheric composition [11]. Keeping in view the harmful health impacts of air quality among the citizens of Lucknow, the present study is carried out with the following objectives: to evaluate current status of air quality in Lucknow, to understand site-to-site variability of air pollutants, to evaluate seasonal and annual variability of air pollutants and develop an understanding of processes contributing to high particulate matter concentrations. Although past studies have been carried out regarding air pollution in Lucknow [12,13], there is a need to periodically estimate the dynamic effectiveness of emission management strategies. This study explores that issue by evaluating the current status of air quality over Lucknow for a recent time period (2013-2015).

## II. METHODOLOGY

### *A. Study area*

Lucknow is the capital and largest city of Uttar Pradesh. It is the third largest city in north, east and central India after Delhi and Kolkata and the second largest city in north and central India after New Delhi. Lucknow is popularly known as the city of Nawabs, a multicultural and a heritage city. The city is situated between 26$^0$ 52'N latitude and 80$^0$ 56'E longitude at an elevation of approximately 123 meters above sea level and covers an area of 2,528 square kilometers. It is situated in the middle of the Indus-Gangetic Plain and located in a seismic zone. The primary geographical feature is Gomti River that divides it into the trans-Gomti and Cis-Gomti regions. Lucknow has a humid subtropical climate with cool dry winters from mid-November to February and dry hot summers from late March to June. The rainy season is from July to mid-September.

Today, Lucknow city has become a hub of elevated investment in technology, institutes, real estate and integrated in many commercial and industrial activities that has lead to increased urbanization. According to Road Transport Office (RTO) Lucknow, registered vehicles are also increasing with increasing population. Since the air quality standards in India have been classified in groups industrial, residential, commercial, we have selected five locations for our study that encompass these categories as depicted in Figure 1.

The commercial observational sites are Capoor's Hotel and SMK Chowk, residential locations are Mahanagar and Aliganj and industrial site is Talkatora. These commercial areas are situated in the city where large amounts of air pollution occur due to two wheelers and three wheelers. Talkatora area has groups of small and medium industries such as manufacturing, paint etc. which collectively emit significant air pollutant emissions.

### *B. Data Availability*

Three criteria air pollutants viz. $NO_2$, $SO_2$ and $PM_{10}$ were considered for three years from 2013 to 2015. The data was collected from Uttar Pradesh Pollution Control Board, Lucknow and official website of Central Pollution Control Board, Delhi (http://www.cpcb.nic.in). The data satisfy CPCB's requirements that annual arithmetic mean considered at a particular site must have a minimum of 104 measurements in a year, twice a week 24 hourly at uniform interval. The operations and maintenance of monitoring sites in Delhi are undertaken by Uttar Pradesh Pollution Control Board. The National Ambient Air Quality Standards (NAAQS) for 24-hr averages and annual averages for the relevant air pollutants and procedures of observational data measurements are detailed in Table1.


Fig. 1. Data sites in Lucknow

Table 1. National Ambient Air Quality Standards (NAAQS)

| Pollutant | Time Weighted Average | Concentration in Ambient Air | | |
|---|---|---|---|---|
| | | Industrial, Residential, Rural and Other Areas | Ecologically Sensitive Area (notified by Central Government) | Methods of Measurement |
| Sulphur Dioxide ($SO_2$), µg/m³ | Annual* <br> 24 hours** | 50 <br> 80 | 20 <br> 80 | -Improved west and Gaeke <br> -Ultraviolet Fluorescence |
| Nitrogen Dioxide ($NO_2$), µg/m³ | Annual* <br> 24 hours** | 40 <br> 80 | 30 <br> 80 | -Modified Jacob & Hochheiser (Na-Arsenite) <br> -Chemiluminescence |
| Particulate Matter (size less than 10 µm) or $PM_{10}$ µg/m³ | Annual* <br> 24 hours** | 60 <br> 100 | 60 <br> 100 | -Gravimetric <br> -TOEM <br> -Beta attenuation |
| Particulate Matter (size less than 2.5 µm) or $PM_{2.5}$ µg/m³ | Annual* <br> 24 hours** | 40 <br> 60 | 40 <br> 60 | -Gravimetric <br> -TOEM <br> -Beta attenuation |
| Ozone ($O_3$) µg/m³ | 8 hours* <br> 1 hour** | 100 <br> 180 | 100 <br> 180 | -UV Photometric <br> -Chemiluminescence <br> -Chemical Method |
| Lead (Pb) µg/m³ | Annual* <br> 24 hours** | 0.50 <br> 1.0 | 0.50 <br> 1.0 | -AAS/ICP method after sampling on EPM 2000 or equivalent filter paper <br> -ED-XRF using Teflon filter |
| Carbon Monoxide (CO) mg/m³ | 8 hours* <br> 1 hour** | 02 <br> 04 | 02 <br> 04 | -Non Dispersive Infra Red (NDIR) spectroscopy |
| Ammonia ($NH_3$) µg/m³ | Annual* <br> 24 hours** | 100 <br> 400 | 100 <br> 400 | -Chemiluminescence <br> -Indo phenol blue method |
| Benzene ($C_6H_6$) µg/m³ | Annual* | 05 | 05 | -Gas chromatography based continuous analyzer <br> -Adsorption and desorption followed by GC analysis |
| Benzo(a)Pyrene (BaP) - particulate phase only, ng/m³ | Annual* | 01 | 01 | -Solvent extraction followed by HPLC/GC analysis |
| Arsenic (As), ng/m³ | Annual* | 06 | 06 | -AAS/ICP method after sampling on EPM 2000 or equivalent filter paper |
| Nickel (Ni), ng/m³ | Annual* | 20 | 20 | -AAS/ICP method after sampling on EPM 2000 or equivalent filter paper |

* Annual arithmetic mean of minimum 104 measurements in a year at a particular site taken twice a week 24 hourly at uniform intervals.
** 24 hourly or 8 hourly or 1 hourly monitored values, as applicable, shall be complied with 98% of the time, they may exceed the limits but not on two consecutive days of monitoring.

Source : http://cpcb.nic.in/National_Ambient_Air_Quality_Standards.php

The quality assurance and quality control procedures are presented in more details at the website given below: (http://cpcb.nic.in/oldwebsite/Air/cgcm/cgcm.html).

### *C. Data Analysis*

The metrics used to determine data characteristics at different observational sites were annual averages, monthly averages, 24-hr averages, exceedance counts, standard deviations and wind rose.

Spatio-temporal analysis of air pollutants reveal short term, seasonal and long term variations. Annual averages indicate the representative long-term effect of the air pollutants. Air quality guidelines based on annual averages of criteria pollutants with averaging time of one year is based on evidence for the lowest pollutant level associated with observable chronic and mostly irreversible adverse effects [14] based on the properties of air pollutants in different meteorological and emission profiles. Similarly, air quality guidelines on short-term 24-hr averages of air pollutants with averaging times of 24-hr is based on evidence for the lowest pollutant level associated with observable acute adverse effects during temporary exposure.

A process to understand the status of air quality in a region is to consider whether the threshold values long-term (annual averages) and short-term (24-hr averages) of air pollutants as mandated by CPCB are met and if not to what extent the standards are violated. This will provide an idea about the degree to which the given regions have met their air quality objectives.

Monthly averages are good indicators of overall trends throughout the year and help better comprehend seasonal patterns in air quality.

Count of exeedances denotes days with exceedances of 24-hr averaged threshold values given for 'high' pollution concentrations and the pollutants violating the standards are noted. This depicts the number of days with detrimental levels of those particular air quality values.

Computation of standard deviation denotes variability of air pollution data and allows comparison of variability estimates between different air pollutants.

A wind rose is a graphical representation to display speed and direction of wind and distribution of wind at a location for a certain time period. Strong winds aid in dilution and dispersion of air pollutants whereas wind direction carries air pollutants downwind from source.

## III. RESULTS AND DISCUSSION

### *A. Annual Averages*

The annual average concentrations of $PM_{10}$ from 2013 to 2015 range approximately from 160 µg/m$^3$ to 200 µg/m$^3$ exceeding the NAAQS for the industrial, commercial and residential areas as depicted in Figure 2. Annual Averages of $PM_{10}$ concentrations do not show much annual variability in any of the five sites but remain above National Ambient Air Quality Standards for all the three years. Talkatora the industrial site has the highest annual average concentrations of $PM_{10}$ for all the years. The residential and commercial sites have similar levels of $PM_{10}$ concentrations. There is a slight decline of annual averaged values from 2013-2015. However, for all the three years the annual averages exceed the national ambient air quality standards for annual averages (industrial standard 120 µg/m$^3$ and residential standards 60 µg/m$^3$). Air pollutants from traffic, road dust, bio-fuel burning are primary reasons for air pollution in Lucknow [12] and medium- small scale industries as evident in Talkatora [15]. The results obtained are similar to earlier studies [15] emphasizing the need for more effective planning measures for reduction of $PM_{10}$ concentrations. However, $NO_2$ and $SO_2$ are within the permissible limits. This might be due to the fact that $NO_x$, and $SO_x$ which form part of the discharge from car exhausts are indirectly harmful. They contribute to the production of secondary aerosols. These precursors are the chemicals that react to form particles after exiting through the exhaust stream of on-road mobile sources in a gas-to-particle conversion process [16]. The annual averages for $SO_2$ for (2013-2015) range around 8 µg/m$^3$ and for $NO_2$ around 30 µg/m$^3$ showing usage of low-sulfur gasoline fuel and enhancement in vehicle technology. Industrial emissions of $NO_x$ and $SO_x$ are also lower in Lucknow city.

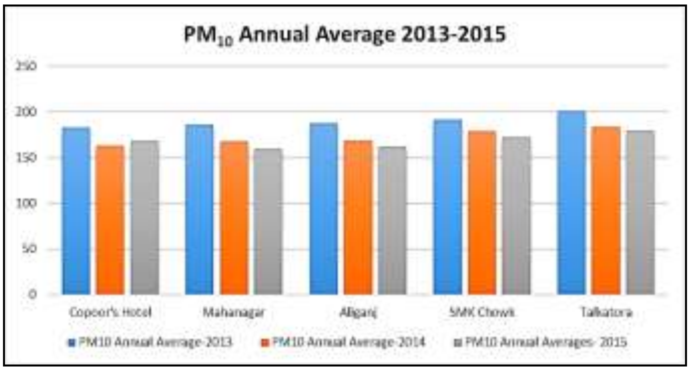


Fig. 2. Annual Averaged $PM_{10}$ concentrations for all sites.

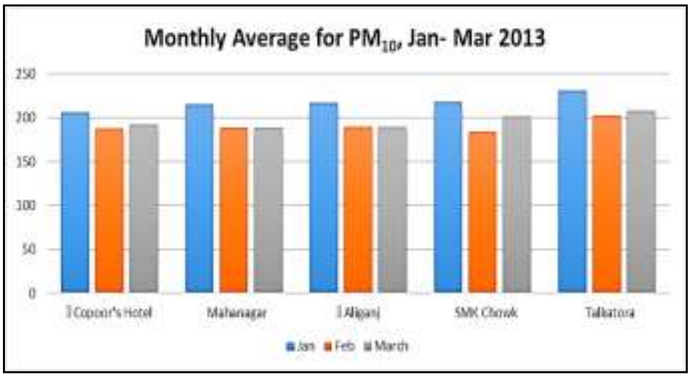


Fig. 3a. Monthly Averaged $PM_{10}$ concentrations (January -March 2013) for all sites

### *B. Monthly Averages*

Figures 3 (a,b,c,d) denote monthly averages for $PM_{10}$ for a typical representative year 2013 which has the highest concentrations amongst the three years. There is distinct seasonality with winter months December and January showing the highest concentrations exhibiting influence of winter inversion. The values markedly exceed 200 µg/m$^3$ in winter more than 3 times the residential national ambient air quality standards. This would suggest that mobile sources of $NO_x$ emissions (whether on-road or off-road), would contribute more heavily towards particulate matter formation during the winters. The industrial region of Talkatora has highest concentrations during all seasons. As expected the monsoon months (mid-June September) have lower concentrations though still exceeding limits. Conversely, emissions of ammonia ($NH_3$) from agricultural and other sources would contribute to particulate matter formation during the summer months when mobile source emissions are not as active in $PM_{2.5}$ formation [17]. This study on Lucknow corroborates our results on Delhi that aerosol concentrations are higher in the winter months, due to an increase in the bio-mass burning for heating purposes which explains higher peaks of $PM_{10}$ at residential sites such as Delhi Engineering College in winter [11,18].

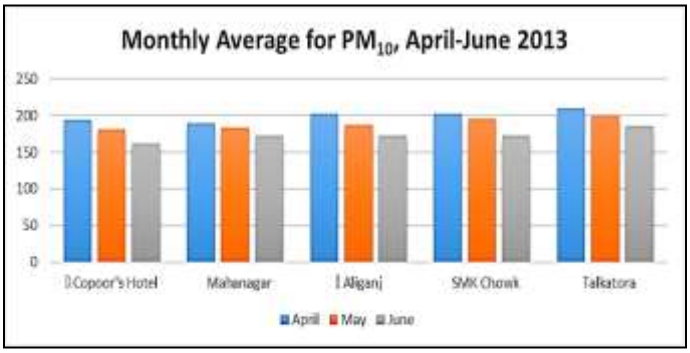


Fig. 3b. Monthly Averaged $PM_{10}$ concentrations (April-June 2013) for all sites.

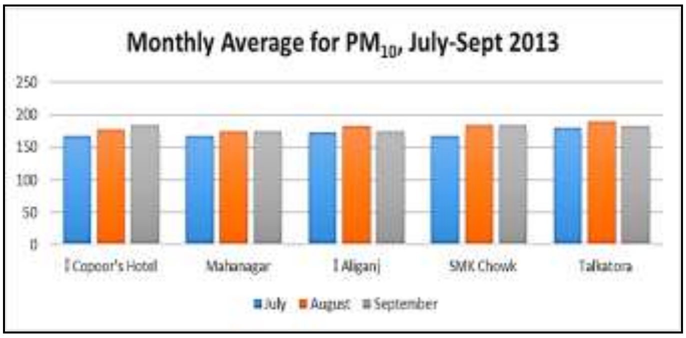


Fig. 3c. Monthly Averaged $PM_{10}$ concentrations (July-Sept. 2013) for all sites.

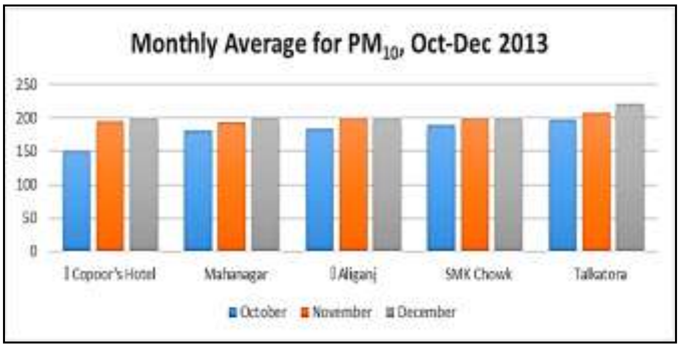


Fig. 3d. Monthly Averaged $PM_{10}$ concentrations (Oct. -Dec. 2013) for all sites.

### C. *Count of Exceedances*

As seen in Figure 4, the exceedance count is high above 100 for all the years with little annual variability. Aliganj has lower exceedance counts in 2015 but still above 100. This is expected with high $PM_{10}$ concentrations prevalent throughout the year as seen in earlier analyses. Since there is no decreasing trend in exceedances this indicates future years will also have high $PM_{10}$ concentrations unless adequate control measures in case of diesel vehicular traffic. We had revealed in our earlier study [11] on Delhi that the exceedance of $PM_{2.5}$ and $PM_{10}$ indicates that the stringent measures imposed on vehicular emissions were inadequate in controlling $PM_{2.5}$ and $PM_{10}$. Additional controls on vehicle exhaust, construction activity and road side dust are important additional sources for fine particulate matter.

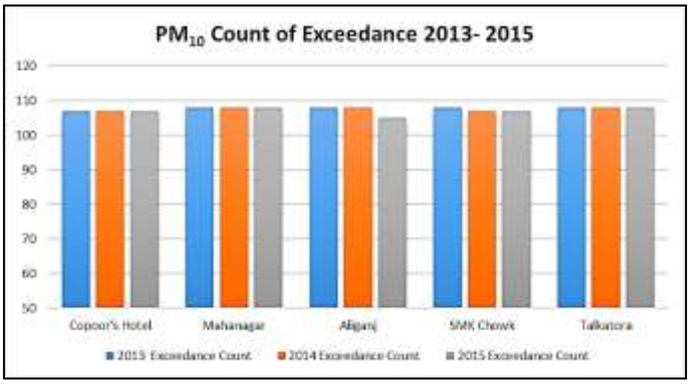


Fig. 4. Exceedance count of annual averages (2013-2015) for all sites.

### D. *Twenty-four hour Averages*

Like annual averages the 24-hr averages for $PM_{10}$ violate 24-hr industrial and residential standards of 150 µg/m$^3$ and 100 µg/m$^3$ for all the five sites considered in this study irrespective of site characteristics (figures not shown). The results corroborate with the findings of Mishra et al. [19] and Pandey et al [20], that 24 hour averages of $PM_{10}$ were higher than the respective NAAQS 24 hourly standards, which may lead to the substantial burden of disease and premature deaths in the population. Higher $PM_{10}$ concentrations were observed in December, January and February months. Higher $PM_{10}$ concentration levels identified between late autumn and early spring that contributed to hazardous levels of air quality that exceeded standards [21]. Concentrations of $SO_2$ and $NO_x$ were within NAAQS standards but higher in winter months. Similar trends were also observed [22,23]. The concentrations were highest during the winter season, perhaps due to a collective impact of anthropogenic activities, boundary layer processes, retarded photochemical loss owing to less solar intensity and surface wind patterns as well.

### E. *Standard Deviation analysis*

Fig. 5 for Standard Deviation Plot represents variability of 24-hr averaged air pollutants. Highest variabilities in 24-hr $PM_{10}$ concentrations were observed in Cooper's hotel and Aliganj. High variability makes it difficult to implement effective pollution control measures. However, there is less variability in 2015 compared to 2013 and 2014 showing that meteorology may have a role in the variability. Meteorological factors such as wind speed, precipitation and mixing height all play important roles in determining the pollutant levels for a given rate of pollutant emission [24,25]. Overall annual averaged $PM_{10}$ concentrations in Lucknow for the sites considered in this study exhibited reductions of 9.11 % and 11.19% in the years 2014 and 2015 respectively in comparison to the year 2013. Mainly in the month of June, reduction in $PM_{10}$ concentrations was observed, due to effect of precipitation. The lowest concentrations of pollutants were observed during the monsoon season, due to efficient wet scavenging by precipitation [23]. $NO_2$ and $SO_2$ have lower inter-annual variabilities in 24-hr averaged values compared to $PM_{10}$ concentrations.

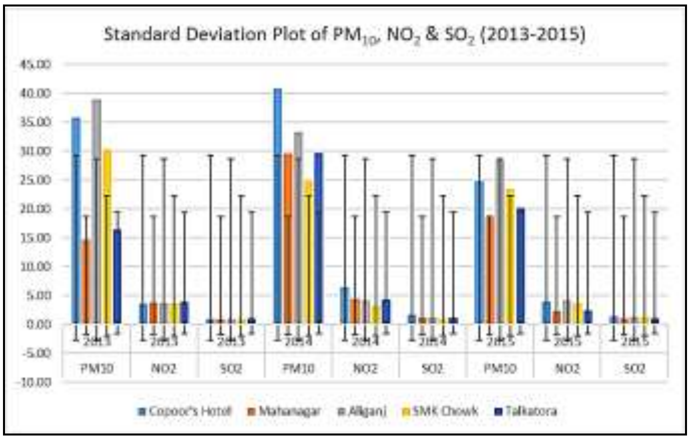


Fig. 5. Standard Deviation analysis (2013-2015) for all sites.

### *F. Wind rose*

As a representative of winter months when air pollution concentrations are the highest, the month of January in 2013 has been selected to illustrate wind direction and wind speed patterns as shown by wind rose (Fig. 6) for 10 days. There is a seasonal variation in wind direction and speed causing distribution and dispersion of pollutants change. The wind direction is predominantly from north and then northwest during winter (December to February). The pre-monsoon months (March to May) flow from North-East to South-West and West directions (figures not shown). The shift of the monsoon winds to the west-northwest brings polluted air masses to the measurement site after September [23]. The frequent change of wind direction and speed create turbulent conditions and contribute to local disturbances in the environment. Local disturbances cause dust storm and hazy conditions which increase particulate matter concentration in the ambient air [26].

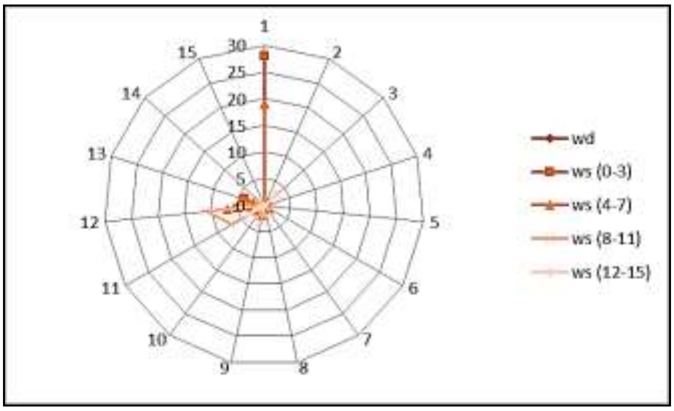


Fig. 6. Wind rose for 01 – 10 January 2013 of Lucknow city.

The predominant wind corridors are North East, North, South and West during monsoon. Frequent rains cause wet deposition resultantly, air borne particulates and other pollutants dispersed in the atmosphere settled down on the earth. The changes in wind velocity and reversal of its direction carry the pollutants away from sources as well as increase the possibilities of dilution of concentration of pollutants also [27]. Therefore, the period from May to September is the less polluted period of the year. The post monsoon period (October and November) is also a clean period with calm condition and a little wind from North direction. The winter months (November to February) are relatively calm compared to the other months of the year.

## IV. CONCLUSION

The underlying essential features summarizing the study are:

- Recent air quality data analysis (2013-2015) for Lucknow reveals that $SO_2$ and NOx meet National Ambient Air Quality Standards for both 24-hr average concentrations and annual average concentrations.
- $PM_{10}$ 24-hr and annual standards are exceeded in all the sampling sites irrespective of whether the sites are residential, commercial or industrial but comparatively higher at industrial site.
- There are not much annual variations in case of $NO_2$ and $SO_2$ in 2013 -2015 while there is distinct seasonal variation with higher concentrations in winter months and lowest concentrations during monsoon for all pollutants.
- $PM_{10}$ has significant seasonal and inter-annual variability.
- Mobiles sources and road dust seem to be the biggest sources of particulate matter. Enhancement of fuel quality or substitution of diesel fuel with compressed natural gas (CNG), incorporation of 4 –stroke engines in two-wheelers, better traffic management to prevent traffic congestions are some of the air pollution control measures that need to be incorporated in Lucknow to bring down aerosol levels.

As the results of this study of Lucknow (2013-2015) show similar findings as our air quality assessment on Delhi (2004-2009), extended analysis of air quality in Lucknow is recommended to have a complete representation of the current knowledge on particulate matter and their adverse effects in the Lucknow region. This kind of analysis would be helpful to policy makers to develop suitable measures to prevent further deterioration of air quality of Lucknow and to prevent the development of hazardous situation as in Delhi that is deleterious for human health.

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