Assessment and chemical characterization of atmospheric particulate matter in Lucknow city, Uttar Pradesh, India

SUMMARY

SUBMITTED TO
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Summary

Air pollution has become as a serious concern worldwide, especially in developing nations. In India, poor air quality has steadily increased in last several decades due to the increasing pace of anthropogenic activities, such as rapid urbanization, industrialization, modernization and vehicular increased. Among the main sources of air pollution, automobile is one of the most responsible sources throughout the globe, especially in megacities. A variety of hazardous air pollutants comes from diverse sources, with particulate matter being one of the most suspected air pollutants. Atmospheric $PM_{2.5}$ and PM_{10} are considered as key air pollutants, which contain many toxic chemicals including toxic elements/metals, inorganic/organic particles, usually extremely toxic to human beings and can pose several potential diseases such as allergies, respiratory, asthma, cardiovascular, neurological and reproductive diseases and sometimes death. According to WHO, the level of APs increased alarmingly worldwide. Around 91% of people breathe in polluted air worldwide, resulting in IHD/CAD (34%), LRIs (21%), stroke (20%), COPD (18%) and lung cancer (7%) and every year approximately 7 million people die due to air pollution. Currently, particulate pollution is one of the grave environmental challenges to human health in India, especially Lucknow. This city is one of the most urbanized and fast-growing cities in India which has resulted in a worsening of the air quality in Lucknow city. According to World AQ Report 2019, Lucknow had 11th rank in the world for poor air quality and in 2020 9th place among the top 10th most polluted cities in the global.

In 2020, to prevent the COVID-19 outbreak, the Government of India declared a complete (25th March to 31st May 2020) and partial (1st June to December 2020) Lockdown for both outbound and inbound traffic. During this nationwide Lockdown,

all anthropogenic activities were completely were prohibited except essential services. The entire Lockdown has negative impacts on economy of the nation, however, this led to a dramatic reduction in air pollution due to limited transport and the economic activities. So, the most polluted Indian cities, especially Lucknow need to be addressed with the most sincerity.

❖ **Therefore, in the present study we have performed the following work:**

- ➢ To study the variation in atmospheric particulate matters, Physicochemical characterization, their sources and health risk on living society during two successive years 2019-(Unrestricted anthropogenic activities) and 2020-(Restricted anthropogenic activities due to COVID-19 Lockdown) in Lucknow, India.
- ➢ To study the variation in air quality during Lockdown and Post-Lockdown with respect to Pre-Lockdown in the most polluted cities of India (viz., Ghaziabad, Delhi, Noida, Greater Noida and Lucknow.
- ➢ To study the variation in air quality during Pre-Diwali, Diwali and Post Diwali due to firecracker on Diwali festival for four successive years 2019 to 2022 in India's most polluted city Lucknow.

❖ **The key finding of the entire study after critical evaluation and interpretation of the experimental data are as follows:**

5.1. Variation in air quality with respect to PM_{10} and $PM_{2.5}$ at different areas of Lucknow city

The annual concentration of PM_{10}* and $PM_{2.5}$ were 282 ±19, 312 ±13, 328 ±11 and 341 ±17* and 154 ±8, 164 ±7, 177 ±11 and 180 ±12 μg/m^3 in 2019 and 152 ±78, 178 ±88, 189 ±94 and 205 ±104* and 83 ±48, 94 ±53, 100 ±56 and 108 ±59 μgm^3 in 2020 at BBAU, Gomti Nager, Indira Nagar and Hazratganj respectively. The annual concentration of PMs (PM_{10} & $PM_{2.5}$) was found to be more than 4 times higher in 2019 and 2-3 times higher in 2020 than annual standards prescribed by NAAQS (PM_{10}: 60 & $PM_{2.5}$: 40) and 3 times higher in 2019 and 1-3 higher in 2020 with respect to 24-hrs standards (PM_{10}: 100 & $PM_{2.5}$: 60). This sharp reduction in PMs (PM_{10} & $PM_{2.5}$) in 2020 with respect to 2019 at each location can be attributed due to the restricted anthropogenic activities, especially VEs because of the COVID-19 pandemic Lockdown. The annual concentration of PM_{10} and $PM_{2.5}$ were found to be lowest in Institutional area (BBAU) with respect to residential (Gomti Nagar), semi-commercial (Indira Nager) and commercial area (Hazratganj) during 2019 and 2020. The lower concentration of PMs at Institutional area indicates lighter traffic density compared to residential, semi commercial and commercial area. However, the highest concentration of these pollutants (PM_{10} & $PM_{2.5}$) were recorded in commercial area followed by semi-commercial, residential and Institutional area. The prime sources of pollution in the commercial sector are the intense commercial activities and very heavy traffic density. But concentration of PMs at residential and semi commercial sites was found to be much higher probably due to nearby highway where re-suspension of vehicle diesel and road dust are key source of particulate pollution.

5.1.1. Variations in concentration of particulate matter in Lucknow city during 2019 and 2020

The average concentration of atmospheric PM_{10} and $PM_{2.5}$ during 2019* and 2020** were found in the range of 294-342 (316 ±13) and 157-184 (169 ±8)* $\mu g/m^3$ and 65-317 (181 ±90) and 28-178 (96 ±54)** $\mu g/m^3$ respectively. The levels of atmospheric PM_{10} and $PM_{2.5}$ were observed higher in 2019 in relation to 2020. The decline levels of PM_{10}* and $PM_{2.5}$** in 2020 were found -42%* and -43%** respectively with regard to 2019. The concentrations of both PM_{10} and $PM_{2.5}$ exceeded the NAAQS more than three times in 2019 and in 2020, 3 times higher (January and February months), one higher in March, below of NAAQS (April to August) and 1-2 higher than the NAAQS limit (September to December). The likely reason for the dominance of PM_{10} and $PM_{2.5}$ pollutants in 2019 are active anthropogenic activities. However, in 2020 (April to August), a sharp decline was observed due to the anthropogenic emissions switch-off. Because to curb the outbreak of COVID-19. The complete nationwide Lockdown was implemented from 25th March to 31st May and all anthropogenic activities were completely prohibited, excluding essential services. After the complete Lockdown, the partial Lockdown was applied from 1st June to 31st December in India. The return of traffic on the roads, because of excess relaxation in traffic and other activities during partial Lockdown, due to this the level of both the PMs started increasing again (September to December). However, the maximum level of both PMs (PM_{10} and $PM_{2.5}$) were detected in the month of November in 2019 and January in 2020. In 2019, the Diwali festival was celebrated on 27 October, and bursting of crackers in large amounts along with unrestricted anthropogenic activities usually could be responsible for the high levels of air pollution in the month of November. Whereas in 2020 unlimited anthropogenic activities, especially the additional road traffic in Lucknow may be responsible for the higher level of PMs in the month of January.

5.1.2. Meteorological Impact on concentration of Particulate Matter during 2019 and 2020

The fluctuations in R_H, VW_S, T_{EMP} and W_S were detected 30-93 (71 ±20) %, 0.04-0.12 (0.06 ±0.02) m/s, 10-34 (22 ±8) °C and 0.31-0.51 (0.41 ±0.05)* m/s and 43-91 (69 ±13) %, 0.05-0.19 (0.10 ±0.04) m/s, 14-30 (24 ±5) °C and 0.42-0.58 (0.45 ±0.04)** m/s during 2019* and 2020** respectively. The W_S, T_{EMP} and VW_S were observed higher in 2020 with respect to 2019, whereas R_H was higher in 2019. The optimistic effect meteorological parameters (lowest W_S, T_{EMP} and VW_S and highest R_H) along with the AAs, especially high traffic loads, also had a positive effect on the increased levels of air pollution in atmospheric air in 2019. However, in 2020, high W_S, VW_S and T_{EMP} and low R_H in the context of 2019, as well as long-term restricted anthropogenic activities had an optimistic effect on the dispersion of air pollutants. Consequentially, the accumulation of air pollutants in the atmosphere was found lower, especially during Lockdown period. In 2019, about 92.70% of the wind remained to calm i.e., <0.5 m/sec and 7.30% of wind blowing between 0.5 to >=11 m/sec. However, in 2020 almost 85.15% of W_S was calm (<0.5 m/sec) and 14.85% times found between 0.5 to >=11 m/sec. In both 2019 and 2020, the wind was mostly blowing from the southeast direction. The southeast direction of Lucknow is surrounded by the Raebareli District and the state borders Bihar (Patna). The key sources of air pollution in Raebareli and Bihar are vehicular exhaust, industrial units, construction activities, brick kilns and waste/biomass burning. The long-distance transport of air pollutants from the point source may be responsible for the high level of PMs in 2019. The outcome of the current study, indicates that the metrological parameters (W_S, W_D, VW_S, R_H, T_{EMP}) are extremely influential factors along with anthropogenic activities to determine the concentration of air pollutants in an outdoor environment.

5.2. Air quality status during Lockdown in India's most polluted cities

The concentrations of atmospheric PM_{10} and $PM_{2.5}$ in selected cities were found in range during Pre-Lockdown*, Lockdown** and Post-Lockdown*** at Delhi 134-260 (211±67)*, 109-142 (125±16)**, 58-127 (88±35)*** and 62-174 (122±56)*, 47-58 (52±5)**, 26-50 (36±12)***; Ghaziabad 1136-254 (208±63)*, 131-156 (143±12)**, 58-142 (96±42)*** and 67-175 (125±45)*, 49-59 (53±5)**, 22-152

(69±71)***; Noida 120-247 (194±66)*, 110-134 (123±12)**, 54-138 (89±43)*** and 56-170 (115±57)*, 46-50 (48±2)**, 24-49 (36±12)***; Greater Noida 141-275 (260±70)*, 120-140 (133±11)**, 59-151 (97±47)*** and 55-163 (111±54)*, 42-45 (43±1)**, 19-49 (31±15)*** and Lucknow 197-331 (283±74)*, 102-134 (119±16)**, 68-155 (99±48)*** and 91-186 (149±51)*, 48-59 (54±6)**, 30-118 (59±50)*** respectively. The concentrations of atmospheric PM_{10} and $PM_{2.5}$ were found to be higher during Pre-Lockdown in relation to Lockdown and Post-Lockdown periods in all selected cities, as there was no restriction on any activity in any city during Pre-Lockdown. However, the Lockdown and Post-Lockdown periods show significant declines in the levels of atmospheric PM_{10} and $PM_{2.5}$ with respect to Pre-Lockdown in all selected cities. Due to the COVID-19 pandemic national Lockdown, the restriction on anthropogenic sources. The drastic reduction in the levels of both PMs coarse and fine particles resulted in significant improvement in poor air quality.

5.2.1. Monthly variation in concentrations of PM_{10} and $PM_{2.5}$ during Lockdown in India's most polluted cities

During the Pre-Lockdown period the concentrations of both PM_{10} and $PM_{2.5}$ pollutants were found to be higher in the month of January in all cities. The concentrations of both PMs particles were found to be more than 2-3 times the permissible limit of NAAQS in the months of January. As all anthropogenic sources were active in India in the months of January and there was no restriction on any activity in any cities. In Lockdown period, the levels of PM_{10} were found to be above the NAAQS and levels of $PM_{2.5}$ were found below the NAAQS limits in all months across all the cities. In post-Lockdown period, the concentration of PM_{10} and $PM_{2.5}$ was found to be the lowest in the month of August across all the cities. In Aug month the concentrations of both pollutants were found below the NAAQS limits. Due to anthropogenic emissions switch-off during Lockdown and Post-Lockdown both pollutants showed a sharp decline in all months of the Lockdown period and Post-Lockdown with respect to Pre-Lockdown in all cities.

5.2.2. Variation in average concentrations of PM_{10} and $PM_{2.5}$ during Lockdown in India's most polluted cities

Average concentrations of both the particles were found to be more than twice the NAAQS in Pre-Lockdown period in all cities. Among the selected cities the maximum concentrations of both particles were found in Lucknow. The most significant sources of atmospheric PMs in Lucknow are automobiles. However, in Post-Lockdown period, the concentrations of both the particles were found below the NAAQS limits in all cities. In Lockdown period, the concentrations of PM_{10} were found to be more than the NAAQS limit and $PM_{2.5}$ found below the NAAQS limit in all cities. In this section, we found that the average concentrations of both the particles were showed a sharp decline in Lockdown and Post-Lockdown period as a comparison to Pre-Lockdown in all selected cities. We also found that both the pollutants were showed significant differences at the level of $p < 0.05$ in all selected cities as compared to the Pre-Lockdown period, except Ghaziabad and Noida for PM_{10} in Lockdown and $PM_{2.5}$ Post-Lockdown period in Ghaziabad. As a result, the concentrations of both the particles significantly improved during the Lockdown and Post-Lockdown period. Since all major sources of atmospheric pollutants were prohibited during complete Lockdown and Post-Lockdown (partial lockdown).

5.2.3. Percentage change in atmospheric PM_{10} and $PM_{2.5}$ during Lockdown in India's most polluted cities

The Percentage change was found in concentrations of PM_{10} and $PM_{2.5}$ at selected cities; Delhi -40.78*, -58.42** and -57.60**, -70.11***: Ghaziabad -31.20**,

-53.91*** and -57.29**, -44.82***; Noida -36.59**, -53.95*** and -58.36**, -68.49***; Greater Noida -39.39**, -55.75*** and -61.07**, -71.56***; LKO -57.95**, -65.01*** and -63.31**, -59.95*** respectively (where ** represent Lockdown Period, and *** indicate Post-Lockdown). Among the selected top five most polluted cities of India, Lucknow showed maximum reduction in PM_{10} during both period Lockdown and Post-Lockdown and also in $PM_{2.5}$ during Lockdown and Greater Noida showed maximum reduction in $PM_{2.5}$ during Post-Lockdown period. Based on analysis of air quality data, this study suggests: decreasing levels of PMs pollutants during the Lockdown and Post- Lockdown period have had a positive impact on the overall environment including humans and ecosystems. Therefore, the COVID-19 pandemic can be considered a ‘blessing in disguise’, for sustainable environmental and human health.

5.3. Temporary variations in the level of atmospheric pollutants during the Diwali episode

The levels of PM_{10}, $PM_{2.5}$, SO_X and NO_X on Diwali day were found in 2019-(1.51, 1.59, 1.66 and 139), 2020-(1.65, 1.75, 1.24 and 1.28), 2021-(1.56, 1.65, 1.53 and 137) and 2022-(1.53, 1.58, 1.45 and 1.42) times higher concerning Pre-Diwali during four successive years. However, the level of PM_{10}, $PM_{2.5}$, SO_X and NO_X were found in 2019-(1.60, 1.21, 0.98 and 0.98), 2020-(1.03, 1.18, 0.92 and 0.88), 2021-(1.07, 1.15, 0.99 and 0.96) and 2022-(1.06, 1.15, 1.01 and 0.98) times higher during Post-Diwali compared to Pre-Diwali. The levels of $PM_{2.5}$ and PM_{10} in Diwali and Post-Diwali were found to be highest every year than Pre-Diwali. However, the level of gaseous pollutants was found higher on Diwali and lower in Post-Diwali as compared to Pre-Diwali of each year. These changes in air quality are attributed to the bursting of fireworks on Diwali, resulting in massive amounts of air pollutants rising and accumulating in atmospheric air for several hrs/days after the celebration of Diwali. The mean levels of $PM_{2.5}$, PM_{10}, SO_X and NO_X pollutants on Diwali day were recorded as 1.44, 1.21, 1.52 and 1.37*, 1.29, 1.12, 1.35 and 1.17** and 1.38, 1.15, 1.44 and 1.31 times lower in 2020 with respect to 2019*, 2021** and 2022 respectively. The decline in mean levels of these pollutants was observed in 2020 due to the complete Lockdown (25^{th} March to 31^{st} May) and partial Lockdown (1^{st} June to 31^{st} December).

5.3.1. Impact of Meteorology on Air Quality during the Diwali episode

The average value of W_S, VW_S, R_H, and T_{EMP} were detected as 0.62 ±0.14*, 0.91 ±0.13**, 0.88 ±0.17*** and 0.76 ±0.06 **m/s**, 0.12 ±0.003*, 0.53 ±0.10**, 0.39 ±0.13*** and 0.48 ±0.12 **m/s**, 79 ±9*, 68 ±12**, 79 ±10*** and 82 ±11 **%** and 21 ±3*, 27 ±2**, 21 ±2*** and 22 ±3 **°C** during 2019*, 2020**, 2021*** and 2022 respectively. In 2019, 2021 and 2022, the lower average values W_S, VW_S and $T_{EMP,}$ and high R_H were observed with respect to 2020 Diwali days. The adverse meteorological parameters is not favorable to the rapid disposal of atmospheric pollutants and able to trap in the tropospheric (lower) layer of the atmosphere.

5.3.2. Interspecies correlation and linear regression analysis of air pollutants during the Diwali episode

These outcomes of the current study evidently indicate that there is a very strong association between $PM_{2.5,}$ SO_X and NO_X with PM_{10} pollutant and vice-versa. The value of R^2 indicates that gaseous pollutants were directly dependent on PMs during Diwali days.

5.4. Morphological and elemental characterization of PMs particles during 2019 and 2020

SEM-EDX result, highlight the physico-chemical aspects of particulate matters (PM_{10} and $PM_{2.5}$) which show a wide disparity during 2019 and 2020. The key morphological and elemental components of **PM_{10} particles** were showing **in 2019:**

Aluminosilicate (**irregularly aggregated**) originates from earth crust/soil; **Lead** (**spherical**) attributed due to high vehicular exhausts and **Cadmium (crystalline)** source of heavy traffic. **In 2020: Biological particles** (**capsule/oval**) originate from fungi, bacteria, viruses and agriculture activities; **O-rich particles (no typical morphology**) represents a pollution-free air due to Lockdown and **Soot particles** (**spherical/cluster**) due to vehicle movement. However, **$PM_{2.5}$ particles** displayed major morphological and elemental constituents **in 2019: Ca-rich/cement particles (amorphous clusters**) emitted from construction activities and resuspended dust; **Chlorine rich particles (agglomerate-crystallin**) emitted from coal combustion/biomass burning and **Carbon particles** (**spherical porous-surface**) discharge from vehicular exhaust and combustion of fossil fuels. **In 2020: Biomass burning particles (elongated symmetrical**) originate from the burning of agricultural waste and biomass burning; **O-rich particles (no specific morphology**) and **Vehicle exhaust** (**slight-spherical**) due to vehicular movement as there was more relaxation in traffic and other activities in the unlocked phases of Lockdown.

5.5. Health risk assessment of Particulate Matters

5.5.1. Spatiotemporal variation in AQI and associated human health risks during 2019 and 2020

The mean AQI value were found in the range of 328-349 (338)* and 65-345 (209)** during 2019* and 2020** in Lucknow city which is unhealthy for living society. The very poor category **(338)** of AQI has serious health hazards on human health and is capable of causing respiratory illness, heart and lung diseases. The poor category **(209)** may cause breathing discomfort and heart disease in people. The significant decline in AQI levels in 2020 was found 38% compared to 2019*. This sharp decline in AQI might be due to nationwide Lockdown. In current study, $PM_{2.5}$ and PM_{10}

are the key contributors of elevated level of AQI which indicates the serious health hazards on human health.

5.5.2. Temporal variation in AQI and associated human health risks during Diwali Festival

The mean AQI value were detected as 498, 368, 437 and 457 in 2019, 2020, 2021 and 2022 respectively during the Diwali festival in Lucknow. The AQI was recorded in the severe category during the Diwali festival in 2019, 2021 and in 2020, in the very-poor category. The very-poor/severe category of AQI has serious health consequences on human health like respiratory illness, lung and heart diseases. The significant decline in average AQI levels were recorded as 26%, 15% and 19% in 2020 with respect to 2019*, 2021** and 2022 respectively. This reduction might be due to nationwide Lockdown, because all AAs were entirely or partially prohibited in 2020.

5.5.3. $PM_{2.5}$ and PM_{10} human exposure levels

In the current study, annual mean exposure levels of atmospheric PMs (PM_{10} and $PM_{2.5}$) in Lucknow city were critically higher than the AQG levels recommended by the WHO during two successive years 2019 and 2020. The mortality rate was 85.7% (8.6 per 10 $\mu g/m^3$) time higher due to annual mean exposure level of PM_{10} and 91.07% (9 per 10 $\mu g/m^3$) because of $PM_{2.5}$ in 2019 in regard to AQG level. However, in 2020, the mortality rate was 75% (7.5 per 10 $\mu g/m^3$) and time higher due to annual exposure level of PM_{10} and 72.22% (7.2 per 10 $\mu g/m^3$) due to annual exposure of $PM_{2.5}$ in reference of AQG.

5.5.4. Long-term effects of PM_{10} and $PM_{2.5}$

However, RR values in 2019 and 2020 were found to be 2.83 and 1.67 respectively for post-neonatal mortality due to annual/chronic exposer of PM_{10}. The RR value in 2020 was observed as 40.98 times lower as compared to 2019. Whereas, the

RR values were found 2.39 and 1.46 in 2019 and 2020 respectively due to exposure of $PM_{2.5}$ pollution for all-cause mortality. The RR value dropped to 38.91 in 2020 than 2019. It is also interesting the decline values of these cases show a significant reduction in the health impact in 2020 compared to 2019.

5.6. Trace metal associated with particulate matter in Lucknow City

The outcome of current study revealed that the total 21 Heavy Metals and Metalloid Particles (HMMP) were found. The decreasing order of these metals was Fe > Al > Ca > Na > Ba > Zn > Pb > Ti > Cu > K > Mg > Ni > Sb > Li > Sr > Co > Mn > Cr > Hg > Cd > As found in 2019 and Al > Na > Ca > Fe > Zn > Ba > Cu > Mg > Ti > Pb > K > Ni > Mn > Co > Sr > Li > Sb > Cd > Cr > Hg > As found in 2020. The highest concentration of Fe and Al was found in 2019 and 2020, respectively and lowest of As was found in both years 2019 and 2020.

5.7. Human health risk assessment of heavy metals associated with atmospheric particulate matters during 2019 and 2020

In current study, the ADDE was used to assess the carcinogenic and non-carcinogenic threat of each heavy metals (Al, As, Cd, Co, Cr, Cu, Fe, Hg, Mn, Ni, Pb and Zn) associated with PM_{10} and $PM_{2.5}$ for adults and children through different exposure pathways viz. ingestion, inhalation and dermal contact.

5.7.1. Non-carcinogenic risk

Non-carcinogenic health risk assessment of PM_{10} and $PM_{2.5}$ are also estimated in terms of HQ and HI for both years 2019 and 2020. The HQ and HI values of each toxic metal except Al through HQing and HI for children were found to be <1, indicating that the non-carcinogenic health risk is within the permissible limits during both the consecutive years. The HQing and HI values of Al metal for PM_{10} and $PM_{2.5}$

during 2019* and 2020 (HQing: 2.34E+00 and 1.91E+00; HI: 2.35E+00 and 1.91E+00)* and (HQing: 1.97E+00 and 1.38E+00; HI: 3.95E+00 and 1.39E+00) respectively were found to higher than the safe level (1) for children, indicating potential noncarcinogenic health risks.

5.7.2. Carcinogenic risk

In present study, carcinogenic health risk assessment of PM_{10} and $PM_{2.5}$ for both years 2019 and 2020 was calculated for As, Cd, Cr, Ni and Pb in terms of CR and LCR for adults and children. The CR associated with the toxic metal present in both particles was found to be below the tolerable limit (1.0E-04) for both adult and children through three exposure routes during both consecutive years, except Pb for Children in PM_{10}-(CR_{inh} and CR_{ing}) during 2019 and 2020, and $PM_{2.5}$-(CR_{inh}) in 2019. In 2019, the LCR value of each toxic metals associated with PM_{10} was found to be higher than the acceptable limits for both adults and children, excluding the LCR value of Cd for adults in PM_{10}. In 2020, LCR values of Cr, Ni and Pb associated with PM_{10} were found to be above the tolerable limits for both adults and children, except the As and Cd. In $PM_{2.5}$, LCR value for adult and children of Ni (4.83E-06 and 1.47E-05) and Pb (5.86E-05 and 1.52E-04) respectivally and As (children: 1.05E-06) were found higher than the threshold limit in 2019. Whereas, in 2020 the LCR value of Cr (3.56E-06 and 8.31E-06), Ni (7.83E-06 and 2.05E-05) and Pb (4.31E-05 and 1.06E-04) respectivally for adult and children were found higher than the threshold limit.

5.8. Source apportionment of atmospheric PMs by Enrichment Factor analysis of trace metals

The Enrichment Factors (EFs) of heavy metal associated with PMs have been divided into four (4) groups in the present study. **Greatest Enrichment,** the EFs values (>**1000)** of heavy metals (Hg, Sb, Cd, Ti and Pb) were mainly generated from strong anthropogenic activities such as traffic activity, waste incineration and biomass burning. **Highly Enrichment,** the EFs values **(≥100)** of heavy metals (As, Zn, Cu, Co, Li and Pb) were attributed by diverse anthropogenic activities like, mixed traffic emissions, fossil fuels burning, agricultural residue burning and construction activities. **Moderately Enrichment,** the EFs values **(≤100)** of heavy metals (Ni, Ba, Cr, Sr, Mn, Co and Li) were originate from both natural as well as anthropogenic activities such vehicular emission and re-suspension of road dust. **Slightly Enrichment,** the EFs values **(<10)** of heavy metals (K, Mg, Na, Ca, Fe, Al, Mn and Sr) were mainly occurred from natural crust or soil dust.

5.9. Source apportionment of atmospheric particulate matters during 2019 and 2020 using PMF model

The PMF model was applied to examine the sources of PM_{10} and $PM_{2.5}$ particles for both successive years 2019 and 2020.

5.9.1. Factor or source identification

In present study, four (4) main factors/sources of PM_{10} and $PM_{2.5}$ were identified for both successive years 2019 and 2020 in Lucknow City. **(1) Vehicular emissions, factor-1** is mainly characterized by high loadings of Pb, Co, Cd, Hg, Cu, Ni, Ba, Mn, Zn, OC and EC which mainly generated by the vehicular emissions. This sector contributed significantly to total PM_{10}* and $PM_{2.5}$ for 2019-(60%* and 52%) and 2020-(33%* and 34%) in Lucknow city. **(2) Soil/Crustal Dust**, **2nd factor** contains considerable amounts of elements such as Al, Fe, K, Mg, Ti Ca and Mn that occur due to soil/crustal dust. This factor is significantly responsible for total PM_{10}* and $PM_{2.5}$ for 2019-(17%* and 20%) and 2020-(54%* and 53%) in LKO city. **(3) Industrial emissions, 3rd factor** was influenced by species like As, Cd, Pb, Sb, Cr, Al and Zn which are mostly produced by industrial source. This sector accounting for total PM_{10}*

and $PM_{2.5}$ in 2019-(13%* and 20%) and 2020-(8%* and 7%) in LKO city. **(4) Construction Activity, 4th factor** the most prominent elements like Ca, Cr, Cu, K, Ni, Na, Pb, Ti and Zn were identified as construction activity. This activity contributed to the total PM_{10}* and $PM_{2.5}$ for 2019-(10%* and 8%) and 2020-(5%* and 6%) in the LKO city.

Finally, the overall results of this study indicate that traffic emissions (factor 1) were the major source of Pb, Co, Cd and Hg. Soil dust (Factor 2) was the main source of Al, Fe, K, Mg and Mn. Industrial emission (Factor 3) was the key source As, Cd, Pb, Sb and Cr and construction activity (Factor 4) of Ca, Cr, Cu, K and Pb (Fig. 5.18). The leading source of air pollution in the LKO city during 2019 was AAs, especially traffic emissions because of active anthropogenic activities. However, in 2020 the natural source (Soil Dust) main contributor of air pollution, as all AAs was complete or partial restricted in India as well as worldwide because of pandemic covid-19 situation. The present study concludes that source apportionment of PMF model reveals that the vehicular sector is the major contributor to air pollution in Lucknow city. Therefore, this study will be helpful for the policy makers and concerned authorities in proper implementation of pollution management strategies to reduce this phenomenon.