ANSF APPLIED AND NATURAL SCIENCE FOUNDATION

Journal of Applied and Natural Science
15(1), 306 - 313 (2023)
ISSN : 0974-9411 (Print), 2231-5209 (Online)
journals.ansfoundation.org

Research Article

An assessment of seasonal, monthly and diurnal variations of ambient air quality in the Gurugram city (Haryana)

Neha Bhadauria
Amity Institute of Environmental Sciences, Amity University, Noida (Uttar Pradesh), India
Abhishek Chauhan*
Amity Institute of Environmental Toxicology, Safety and Management, Amity University, Noida (Uttar Pradesh), India
Rajnish Ranjan
E- Learning and Disaster Management, National Institute of Disaster Management, Delhi, India
Tanu Jindal
Amity Institute of Environmental Toxicology, Safety and Management, Amity University, Noida (Uttar Pradesh), India

*Corresponding author Email: akchauhan@amity.edu

Article Info
https://doi.org/10.31018/jans.v15i1.4142
Received: November 3, 2022
Revised: February 17, 2023
Accepted: February 27, 2023

How to Cite
Bhadauria, N. *et al.* (2023). An assessment of seasonal, monthly and diurnal variations of ambient air quality in the Gurugram city (Haryana). *Journal of Applied and Natural Science*, 15(1), 306 - 313. https://doi.org/10.31018/jans.v15i1.4142

Abstract
Gurugram is emerging as one of India's most advanced cities. The combined impact of industrial and vehicular emissions makes the environment toxic. Recently, Gurugram has experienced severe air quality. In the present work, an assessment of seasonal, monthly, and diurnal variations of ambient air quality was carried out in Gurugram during the period of March 2021 to 2022 February. Seasonal and monthly concentrations of key air pollutants like particulate matter ($PM_{2.5}$), nitrogen dioxide (NO_2), carbon monoxide (CO) and ozone (O_3) were examined at Vikas sadan, Gwal Pahari and Teri Gram in Gurugram city to study the most polluted seasons and months. Significantly higher mean concentrations of Particulate matter $PM_{2.5}$ (406.94 μgm^{-3}) and NO_2 (353.96ppb) were seen during the colder months and seasons. O_3 showed a consistent trend with variations during the year, with the highest concentration in winter (106.35$\mu g/m^3$). $PM_{2.5}$ and NO_2 concentrations during the night were greater for all seasons when compared to diurnal values. O_3 concentrations displayed diurnal tendencies that were the opposite of those of NO_2 concentrations. The highest concentrations of ambient $PM_{2.5}$, NO_2, and CO were observed at the Vikas Sadan Monitoring Station. While the NISE Gwal Pahari station showed greater O_3 values. The findings highlight the necessity of efficient air pollution control in Gurugram. To prevent public exposure to air pollutants, preventive measures like green spaces, using public transport, etc. must be adopted. The study contributes to a better understanding of air pollution by seasonal, monthly and diurnal assessment in the city of Gurugram.

Keywords: Air Quality, Diurnal, Gurugram, Monthly, Seasonal, Variations

INTRODUCTION

Air pollution is one of city's biggest threats to human health. In 2016, around 4.2 million premature deaths were recorded worldwide due to severe air quality (https://apps.who.int/iris/bitstream/handle/10665/250141/9789241511353-eng.pdf) (WHO, 2016). Due to breakneck urbanization in metropolitan cities, air pollution has become a critical threat to the environment, human health, and the quality of life in urban areas in India (Kumar *et al*., 2013). In most Indian cities, air pollution is a serious problem. Larger metropolitan centers, as well as other urban areas, frequently experience hazardous and unclean conditions as a result of poor air quality. Every year, 1.2 million individuals are killed by air pollution globally (Soga, 2019). Thus, air pollution is a crucial issue that needs to be addressed to safeguard human health and the country's economy (Kanawade *et al*., 2020).

Gurugram is one of the cities with the poorest air quality. According to World Air Quality Report (2018) by IQAir AirVisual, Gurugram was the most polluted city in the world. The World Air Quality Report (2019) from IQ Air Visual ranked Gurugram as the 7th most polluted city in the world. Most developing cities around the globe are experiencing ambient air pollution levels that exceed National ambient air quality standards (NAAQS) and World Health Organization (WHO) guidelines (Gurjar *et al.,* 2008; Hopke *et al.* 2008; Amato *et al*. 2016; Behera *et al.* 2015). Vehicles, factories, thermal power plants, DG sets and houses are a few of the main contributors to air pollution. Construction projects and road dust are two additional factors causing air pollution in Gurugram.

Malik *et al.* (2014) reported the negative impacts of vehicular pollution on ambient air quality in Gurugram City. Limited studies have been conducted which discuss the exceeding levels of ambient air pollutants in Gurugram, wherein assessment of prevailing concentrations of total suspended particles, PM_{10}, SO_2 and NO_2 (Kaushik *et al.,* 2006),correlation between weather conditions and air quality (Devara *et al.,* 2016), regression analysis between particulate pollutants and meteorological factors (Sharma and Sharma, 2016), use of geo-spatial techniques to assess air pollutants (Manjeet *et al.,* 2022) over Gurugram, Haryana, has been discussed. Thus, the present study aimed to assess the seasonal, monthly and diurnal fluctuation in air pollutant concentrations ($PM_{2.5}$, NO_x, CO, and O_3) in Gurugram City based on a year's worth of data (2021–2022) in light of the city's pollution levels, potential emission sources, and weather patterns.

MATERIALS AND METHODS

Study area

Gurugram city is situated around 20 miles southwest of New Delhi and its total population is approximately 1,514,432 (Census, 2011). The Gurugram district is located in the southernmost part of Haryana. It is located between latitudes of 27° 39' and 28° 32'25' and longitudes of 76° 39' 30' and 77° 20' 45'. Due to its proximity to the states of Rajasthan and Delhi, Gurugram is a significant strategic location. It is bordered on its north by the Jhajjar District and the Delhi State, while on its east is the Faridabad District. Mewat District is its neighbour to the south, and Rewari District is its neighbour to the west.

Sampling sites

Table1 shows the air quality monitoring stations at the following locations: NISE Gwal Pahari, TERI Gram, and Vikas Sadan. In this study, three monitoring stations have been highlighted. The Central Pollution Control Board (CPCB), New Delhi, continually monitors and updates (online) these locations for the measurement of various air quality metrics.

Methodology and data analysis

The Continuous Ambient Air Quality Monitoring (CAAQM) repository of CPCB, New Delhi, India, provid-

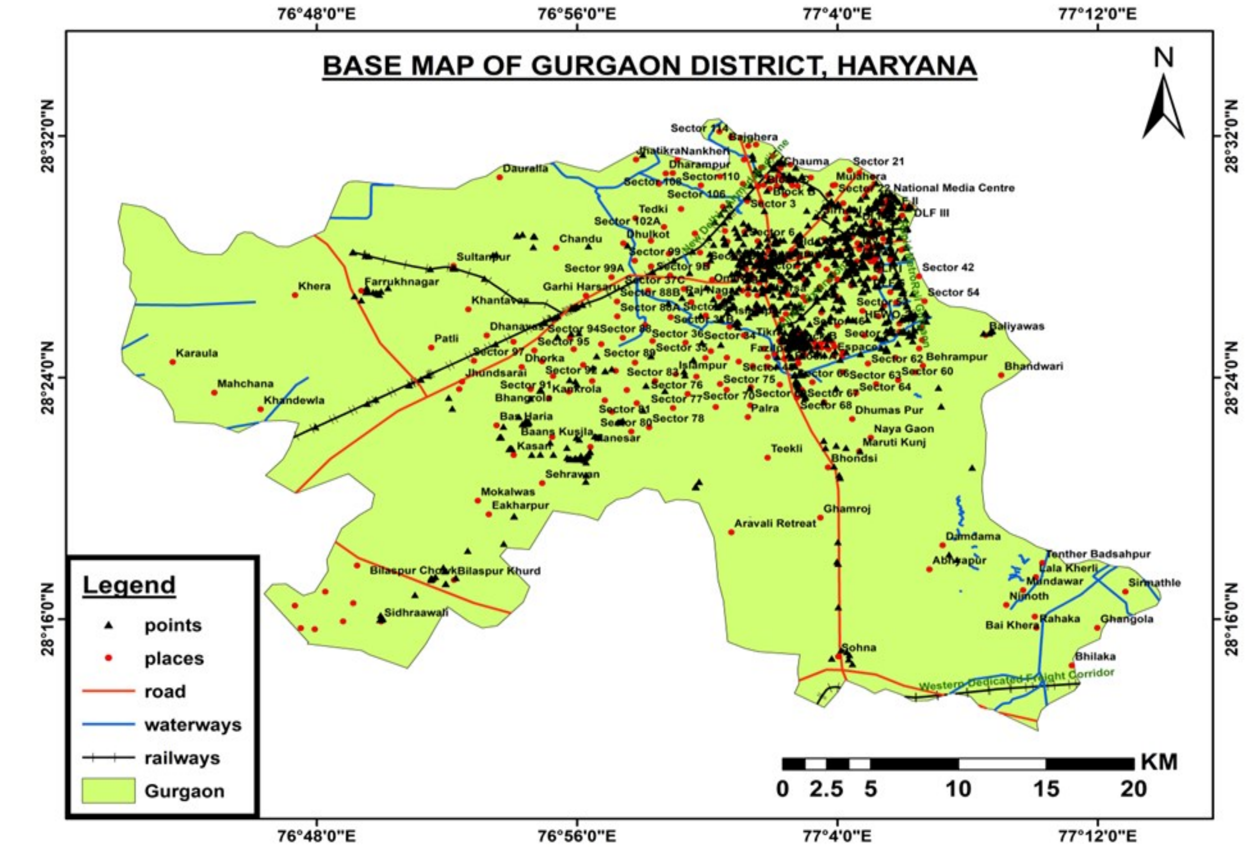

Fig. 1. *Map showing study area of Gurgaon*

Table 1. Air quality monitoring stations at Gurugram

Station Name	Latitude	Longitude	Location
Vikas Sadan, Gurugram – HSPCB	28.4501238	77.0263051	Shanti Nagar, Shivaji Nagar, Sector 11, Gurugram, Haryana- 122001
NISE Gwal Pahari, Gurugram – IMD	28.422681	77.148944	19th Milestone, Faridabad Road, Institutional Area, Gwal Pahari, Gurugram, Haryana- 122003
Teri Gram, Gurugram – HSPCB	28.4275	77.1465	Faridabad Gurgaon Rd, Opposite Pathways School, Gwal Pahari, Gurugram, Haryana- 122102

ed continuous records for levels of fine particulate matter ($PM_{2.5}$), nitrogen oxides (NO_2), carbon monoxide (CO), and ozone (O_3) from March 2021 to February 2022. Instead of directly getting averaged values, these daily concentration measurements were assessed and plotted as their monthly mean to produce high-quality findings. By taking into account the monthly mean of 24 -hour daily data, levels of a few specific ambient air pollutants over the years 2021 and 2022 were analysed in the current work. The four separate seasons of summer (March to May), monsoon (June to August), post-monsoon (September to November), and winter (December to February) were analysed in the current study for Gurugram city. The hourly $PM_{2.5,}$ NO_2, CO, and O_3 concentrations were collected from the stations between March 1, 2021 and February 28, 2022. The $PM_{2.5}$, NO_2, and O_3 values were analyzed using Origin software based on the NAAQS criteria. There were three separate air quality monitoring stations (AQMSs) where the air pollutants were measured. It is to be noted that COVID-19 lockdown was prevalent in the study area only during the first four months of the study and even during this period, all industrial and public activities were partially open. For the rest of the eight months of the study, all the activities were similar to the pre-covid period. Thus, the COVID-19 lockdown was not significant during the study duration.

RESULTS AND DISCUSSION

Seasonal and monthly variation of air pollutants

Seasonal and monthly concentrations of all ambient air pollutants were examined in Gurugram between 2021 and 2022 to more accurately identify the seasons and months that are the most polluted. Four seasonal periods were evaluated based on the Data of Indian Meteorological Department (IMD), and they were as follows: summer (March-May), monsoon (June-August), post-monsoon (September-November), and winter (December- February). IMD adheres to the four separate seasons of winter, summer, monsoon, and post-monsoon despite the fact that there is a wide variation of meteorological conditions in India from east to west and north to south (Hama *et al.,* 2020. The seasonal change of the climate significantly impacts the dispersion of air pollution in the city (Olise *et al.* 2020). In the present study, there were statistically significant seasonal and monthly fluctuations for all ambient air contaminants (Fig. 2). Colder seasons and months showed considerably higher mean concentrations of ambient $PM_{2.5}$, NO_2 and CO except O_3. $PM_{2.5}$ showed the highest values during post-monsoon (406.94μg/m^3), followed by winter (310.35μg/m^3), summer (216μg/m^3), and monsoon (98.62μgm^{-3}). While the highest concentrations of NO_2 were recorded in winter (353.96ppb) followed by post-monsoon (214.81ppb) and summer (123.45ppb) and the lowest concentration of NO_2 was recorded in monsoon season (77.42ppb). O_3 displayed the constant trend with some fluctuations for all seasons. Ozone concentrations depend on photochemical reactions with its precursors (sunlight, NO_x, and Volatile Organic Compounds (VOCs). Seasonal variations of CO revealed the highest concentrations in post-monsoon and winter seasons while minimum concentrations were observed in summer and monsoon seasons. A combination of unfavourable meteorological conditions, such as stagnant weather, reduced horizontal and vertical wind speed decreased sunshine hours, temperature inversion, and a lower boundary layer during the coldest seasons and months compared to summer and spring months can be blamed for the observed seasonal and monthly patterns for $PM_{2.5}$, NO_2, CO, and O_3 (Yousefian *et al*., 2020).The present results were also found to align with another study conducted in Delhi National capital region where concentration of air pollutants, namely, NO_2, O_3 , SO_2 and CO were found to be considerably higher in winters except for O_3 as compared to summer and monsoon months (Hama *et al.,* 2020).

Fig. 3. shows the monthly variations in air pollutants at different monitoring stations installed in Gurugram at the following locations: NISE Gwal Pahari, TERI Gram, and Vikas Sadan. For $PM_{2.5}$ of all three monitoring stations, the lowest to less than 100 μg/m3 concentrations have been observed in May, June, July, August, September, and October. The highest $PM_{2.5}$ concentration (above 200 μg/m^3) was observed in the month of November. During post-monsoon and winter months highest $PM_{2.5}$ concentrations were recorded, while minimum concentrations were found in summer and mon-

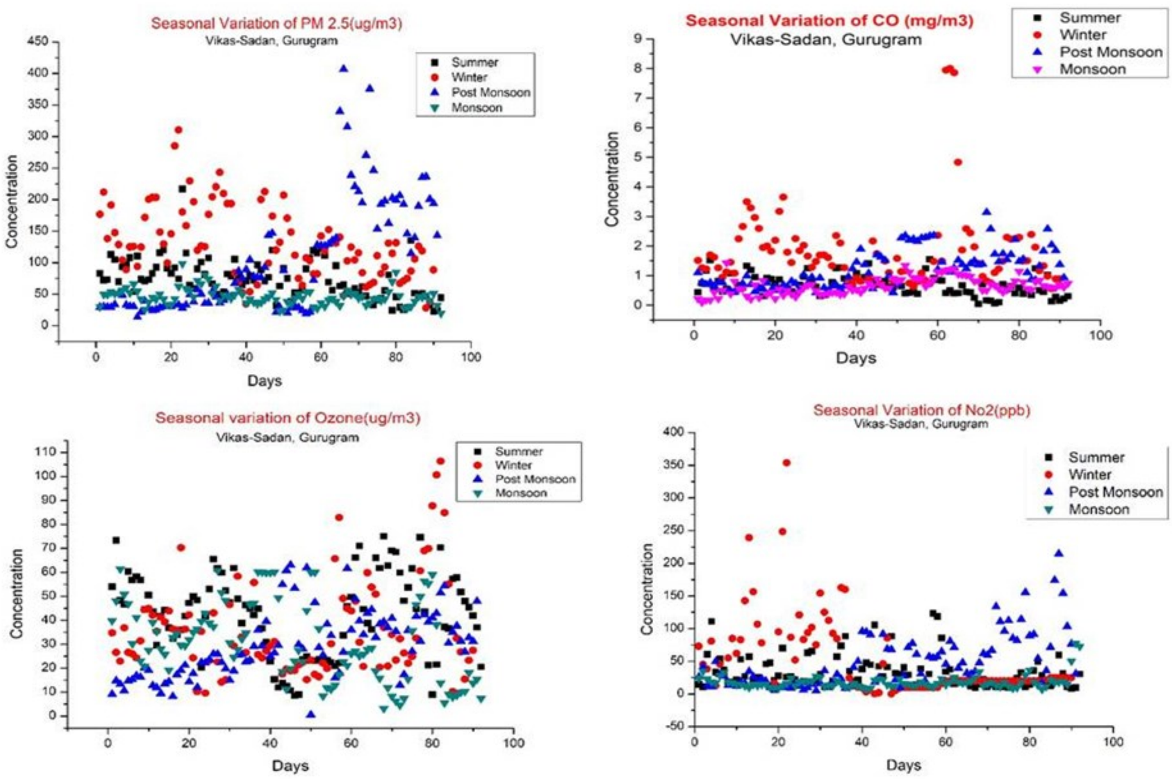

Fig. 2. *Seasonal Variations in $PM_{2.5}$, CO, NO_2 and O_3*

soon months. The increased burning of coal and biomass during the colder months results in greater $PM_{2.5}$ concentrations (Nagpure *et al*., 2015). Additionally, because of the low temperatures, lower boundary layer height, and decreased wind speed during the winter, weather conditions have a significant role in the buildup of $PM_{2.5}$ (Dumka *et al*., 2017 Guo *et al*., 2017, He *et al*.,2017). For NO_2 concentrations, the monthly variations were not so poor as $PM_{2.5}$ but with a similar trend, the winter months have the highest values of NO_2 concentrations due to combined emissions of primary emissions from traffic and domestic heating (Yin *et al*., 2019) and weak photochemical reaction and adverse diffusion condition (Ran *et al*., 2014; Zhou *et al*., 2015), while summer months have the lowest NO_2 concentration.

The highest NO_2 concentrations were observed at TERI Gram (34.17 μgm^{-3}) and Vikas Sadan (34.75 μgm^{-3}) monitoring stations followed by NISE Gwal Pahari (22.69 μgm^{-3}) in the month of February and November, respectively. For CO concentrations, monthly averaged air pollution in the winter months was recorded as higher as compared to the rest of the months for all the three monitoring stations. Vikas Sadan Monitoring Station recorded the highest concentrations of ambient $PM_{2.5}$ (234.42 μg/m^3) and CO (2.29mgm^3). While higher concentrations of O_3 (59.68μg/m^3) were recorded at NISE Gwal Pahari station. The lowest concentrations of $PM_{2.5}$ (8.12μg/m^3) and CO (0.4mgm^3) were recorded at NISE Gwal Phari in summer and monsoon respectively. In summer and winter, the lowest concentrations of NO2 (4.3 ppb) and ozone (4.26 μgm/3) were recorded at Teri gram station. This may be due to that in winters, the air pollutants emitted from numerous sources are confined in the boundary layer due to persistent temperature inversions and other conditions such as fewer wind speeds, lower temperatures (Suresh *et al*., 2020) and lack of rainfall decreased surface vertical mixing which results in less dispersion of air pollutants (Bodor *et al*., 2020). In general, air molecules are less lively and enforce consolidation and stability in the weather throughout the winter because of the low temperatures, which leads to less dispersion of air contaminants. As a result, pollution levels rise in all of the cities (Song *et al*. 2019).

Diurnal variation of $PM_{2.5}$, NO_2, and ozone

Diurnal variation of $PM_{2.5}$

$PM_{2.5}$ diurnal variation of ambient air quality is shown in Fig.4. When compared with the diurnal concentrations, $PM_{2.5}$ showed higher concentrations during the night for all the seasons as compared to daytime. The highest concentration of $PM_{2.5}$ (207.01μgm^{-3}) was observed at night time in December, while the lowest concentration was found in the daytime in June (19.09μgm^{-3}). Nighttime increase in $PM_{2.5}$ concentrations is associated with household emissions (Han *et al*., 2015; Yadav *et al*., 2017) and also depends on variation in the boundary

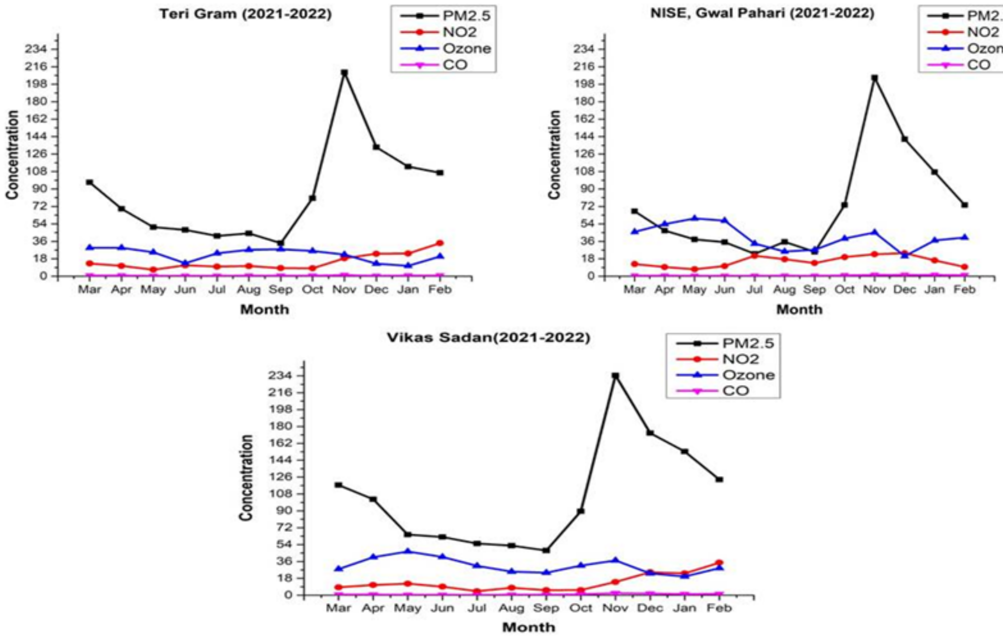

Fig. 3. *Monthly variations in $PM_{2.5}$, CO, NO_2 and O_3 at NISE Gwal Pahari, Teri Gram and Vikas Sadan monitoring stations*

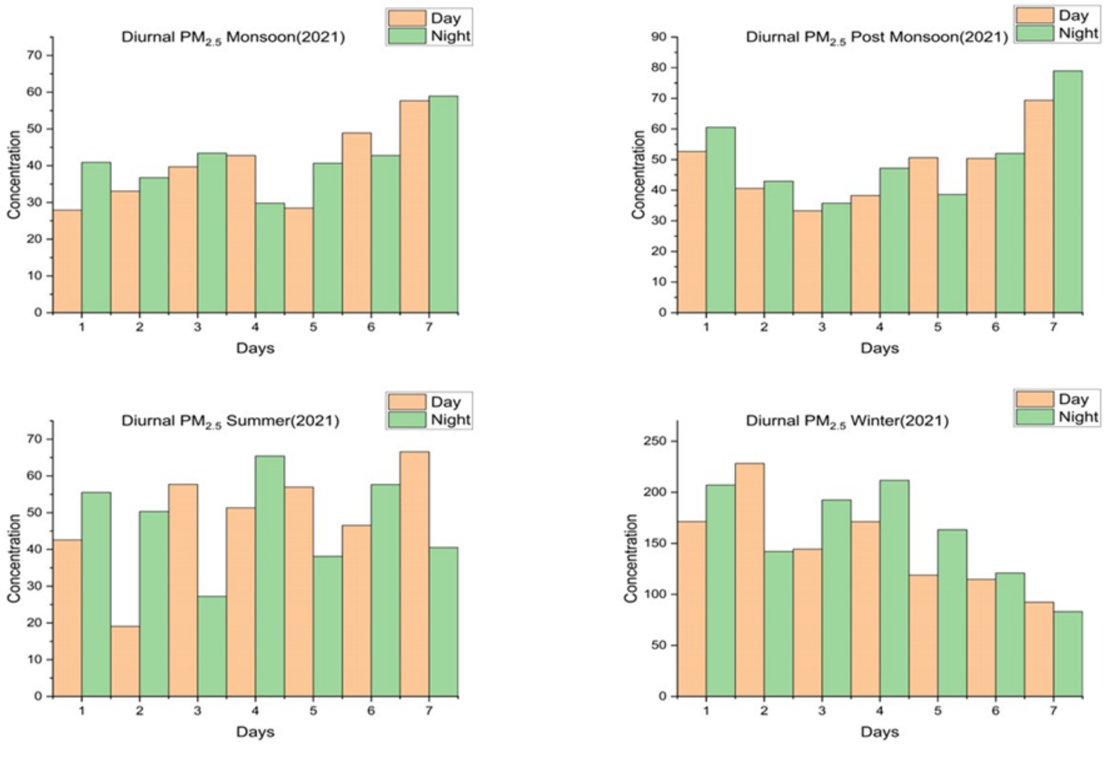

Fig. 4. *Diurnal Variation in $PM_{2.5}$ at Vikas Sadan Monitoring Station*

layer height (BLH). The boundary layer created during the daytime, which is supported by the negative correlation between the solar insolation and $PM_{2.5}$ concentration, was the main cause of the $PM_{2.5}$ concentration changes after sunrise. This can be explained by possible linkage between scattered radiation and AQI through the value of visibility (Luo *et al*., 2019). An increase in BLH accommodates more surface for dispersing air pollutants, which reduces the $PM_{2.5}$ concentrations in daytime and summer (Liu *et al*., 2015).

Diurnal variation of O_3 and NO_2

NO_2 and O_3 diurnal variations of ambient air quality have been shown in figure5. The diurnal variations of

NO_2 concentrations are completely different from ozone but similar to $PM_{2.5}$. The lowest concentrations of NO_2have been found in the daytime and nights have the highest concentrations. The highest concentrations of NO_2 (124.64 μgm^{-3}) were observed in December, while the lowest concentration (11.53 ppb) was recorded in June. Diurnal variations of ozone concentrations were recorded as lowest in the nighttime and winter, while highest concentrations were observed in daytime and summer, with maximum concentrations of 77.67 $\mu g/m^3$in June.

O_3concentrations showed opposite diurnal trends to those of NO_2 concentrations. Higher ozone concentrations in the daytime were mainly the result of photochemical reactions in the presence of intense solar radiation, resulting in the consumption of NO_2 concentrations. These large seasonal variations in the ozone concentrations are due to the impact of variations in climatic factors and various emission sources. The lower concentrations in winter may be due to the lesser daylight period and the lower solar insolation (Wang and Hao, 2012). NO_2 is the primary precursor of ozone;

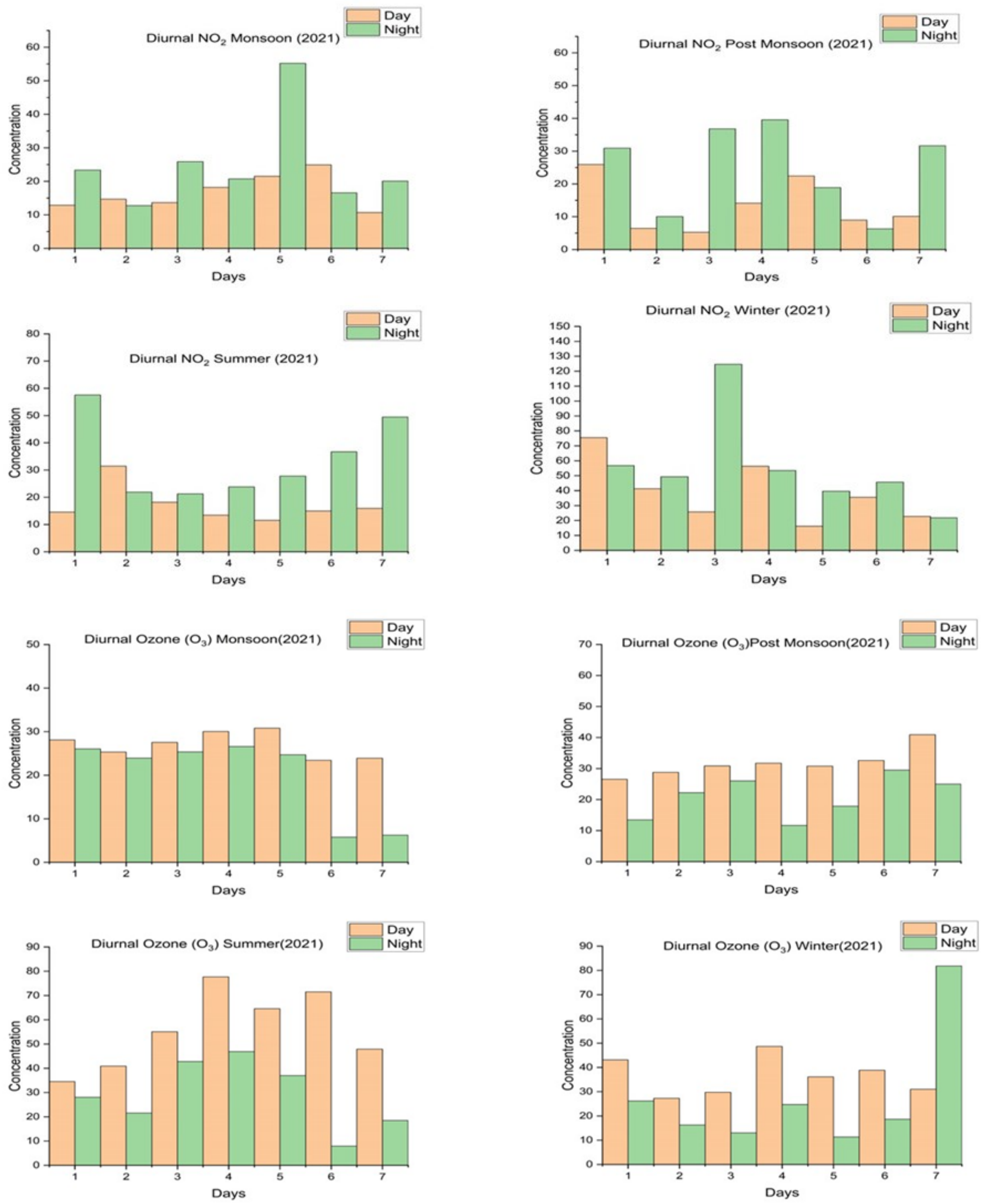

Fig. 5. *Diurnal variations in NO_x and ozone at Vikas Sadan Monitoring station*

therefore, the diurnal variation of O_3 depends on NO_2. The diurnal trend of O_3 firmly follows a negative correlation with that of NO_2 (Bhadauria *et al*., 2021). The diurnal variability of the NO_2 implicates higher levels during the night, and then it declines in the daytime. NO_2 involves a photo dissociation cycle where ozone formation and destruction occur (Singh *et al*., 2020). While NO_2 assists in the photochemical formation of ozone during the daytime, it produces NO, oxidizes hydrocarbons, and scavenges O_3 during nighttime (Brown *et al*., 2006). Moreover, the photochemical chemistry of pollutants near the surface may also contribute to the direct removal of O_3 (Jacob, 2000).

Conclusion

The assessment of seasonal, monthly and daily variations of ambient air quality carried out in Gurugram during 2021-2022 showed that colder seasons and months has considerably higher mean concentrations of ambient $PM_{2.5}$, NO_2 and CO, except O_3. A combination of unfavorable meteorological conditions, such as stagnant weather, reduced horizontal and vertical wind speed, decreased sunshine time, temperature inversion, and lower boundary layer during the coldest seasons and months compared to summer and spring months can be blamed for the observed seasonal and monthly patterns for $PM_{2.5}$, CO, and O_3 and NO_2. The highest concentrations of ambient $PM_{2.5}$, NO_2, and CO were recorded in Vikas Sadan Monitoring Station, while higher concentrations of O_3 were recorded at NISE Gwal Pahari station. While the lowest concentrations of ambient $PM_{2.5}$ and CO were recorded in NISE Gwal Pahari station and of NO_2 and O_3 were recorded at Teri Gram. Thus, Vikas Sadan Monitoring Station was found to be the most polluted of all the monitoring sites. The findings of the present study highlight the necessity of efficient air pollution control in Gurugram. The study advances knowledge of the levels of air pollutants in the fast-expanding urban metropolitan area. To prevent public exposure to air pollutants and to reduce pollution, preventive measures like increasing green cover, more usage of public transport and electric vehicles must be adopted.

Conflict of interest

The authors declare that they have no conflict of interest.

REFERENCES

1. Airon, A., Kumar, R. & Saifi, R. (2022). Temporal and spatial impact of lockdown during COVID-19 on air quality index in Haryana, India. *Scientific Reports*, *12*(1), 20046. https://doi.org/10.21203/rs.3.rs-1595823/v1.
2. Behera, S. N., Sharma, M., Mishra, P. K., Nayak, P., Damez-Fontaine, B. & Tahon, R. (2015). Passive measurement of NO2 and application of GIS to generate spatially-distributed air monitoring network in urban environment. *Urban Climate*, *14*, 396-413. https://doi.org/10.1016/j.uclim.2014.12.003.
3. Bhadauria, N., Chauhan, A., Ranjan, R. & Jindal, T. (2022). Variation in aerosol optical depth (AOD), NO2 and tropospheric ozonecolumn during the lockdown period amid COVID-19 pandemic over India. *Asian Journal of Chemistry, 34*(5), 1105-1112. https://doi.org/10.14233/ajchem.2022.23544.
4. Bodor, Z., Bodor, K., Keresztesi, Á. & Szép, R. (2020). Major air pollutants seasonal variation analysis and long-range transport of PM 10 in an urban environment with specific climate condition in Transylvania (Romania). *Environmental Science and Pollution Research*, *27*, 38181-38199. https://doi.org/10.1007/s11356-020-09838-2.
5. Brown, S. S., Ryerson, T. B., Wollny, A. G., Brock, C. A., Peltier, R., Sullivan, A. P. & Ravishankara, A. R. (2006). Variability in nocturnal nitrogen oxide processing and its role in regional air quality. *Science*, *311*(5757), 67-70. https://doi.org/10.1126/science.1120120.
6. Devara, P. C. S., Sharma, P. B., Joshi, M., Alam, M. P., Dumka, U. C., Tiwari, S. & Srivastava, A. K. (2016). Impact of Road-space-rationing method on regional air quality. *Indian Aerosol Science and Technology*, 10-20.
7. Dumka, U. C., Tiwari, S., Kaskaoutis, D. G., Soni, V. K., Safai, P. D. & Attri, S. D. (2019). Aerosol and pollutant characteristics in Delhi during a winter research campaign. *Environmental Science and Pollution Research*, *26*, 3771-3794. https://doi.org/10.1007/s11356-018-3885-y.
8. Guo, H., Kota, S. H., Sahu, S. K., Hu, J., Ying, Q., Gao, A. & Zhang, H. (2017). Source apportionment of PM2. 5 in North India using source-oriented air quality models. *Environmental Pollution*, *231*, 426-436. https://doi.org/10.1016/j.envpol.2017.08.016.
9. Gurjar, B. R., Butler, T. M., Lawrence, M. G. & Lelieveld, J. (2008). Evaluation of emissions and air quality in megacities. *Atmospheric environment*, *42*(7), 1593-1606. https://doi.org/10.1016/j.atmosenv.2007.10.048.
10. Hama, S. M., Kumar, P., Harrison, R. M., Bloss, W. J., Khare, M., Mishra, S. & Sharma, C. (2020). Four-year assessment of ambient particulate matter and trace gases in the Delhi-NCR region of India. *Sustainable Cities and Society*, *54*, 102003. https://doi.org/10.1016/j.scs.2019.102003.
11. Han, Y., Qi, M., Chen, Y., Shen, H., Liu, J., Huang & Y.,Tao, S. (2015). Influences of ambient air PM2. 5 concentration and meteorological condition on the indoor PM2. 5 concentrations in a residential apartment in Beijing using a new approach. *Environmental Pollution*, *205*, 307-314. https://doi.org/10.1016/j.envpol.2015.04.026.
12. He, J., Gong, S., Yu, Y., Yu, L., Wu, L., Mao, H. & Li, R. (2017). Air pollution characteristics and their relation to meteorological conditions during 2014–2015 in major Chinese cities. *Environmental pollution*, *223*, 484-496. https://doi.org/10.1016/j.envpol.2017.01.050.
13. Hopke, P. K., Cohen, D. D., Begum, B. A., Biswas, S. K., Ni, B., Pandit, G. G. & Markowicz, A. (2008). Urban air quality in the Asian region. *Science of the Total Environment*, 404(1), 103-112. https://doi.org/10.1016/j.scitote

nv.2008.05.039.

14. Jacob, D. J. (2000). Heterogeneous chemistry and tropospheric ozone. *Atmospheric Environment*, *34*(12-14), 2131 -2159. https://doi.org/10.1016/s1352-2310 (99)00462-8.
15. Kanawade, V. P., Srivastava, A. K., Ram, K., Asmi, E., Vakkari, V., Soni, V. K. & Sarangi, C. (2020). What caused severe air pollution episode of November 2016 in New Delhi?. *Atmospheric Environment*, *222*, 117125. https://doi.org/10.1016/j.atmosenv.2019.117125.
16. Kaushik, C. P., Ravindra, K., Yadav, K., Mehta, S. Haritash, A. K. (2006). Assessment of ambient air quality in urban centres of Haryana (India) in relation to different anthropogenic activities and health risks. *Environmental monitoring and assessment*, *122*, 27-40. https://doi.org/10.1007/s10661-005-9161-x.
17. Kumar, A. & Goyal, P. (2013). Forecasting of air quality index in Delhi using neural network based on principal component analysis. *Pure and Applied Geophysics*, *170*, 711-722. https://doi.org/10.1007/s00024-012-0583-4.
18. Liu, Z., Hu, B., Wang, L., Wu, F., Gao, W. & Wang, Y. (2015). Seasonal and diurnal variation in particulate matter (PM 10 and PM 2.5) at an urban site of Beijing: analyses from a 9-year study. *Environmental Science and Pollution Research*, *22*, 627-642.: https://doi.org/10.1007/s11356-014-3347-0.
19. Luo, H., Han, Y., Lu, C., Yang, J. & Wu, Y. (2019). Characteristics of surface solar radiation under different air pollution conditions over Nanjing, China: observation and simulation. *Advances in Atmospheric Sciences*, *36*, 1047-1059. https://doi.org/10.1007/s00376-019-9010-4.
20. Malik, D. (2014). *Assesment of impact of vehicular pollution on ambient air quality: a case study of Gurgaon city* (Doctoral dissertation, College of Engineering, University of Petroleum & Energy Studies).
21. Nagpure, A.S., Ramaswami, A. & Russell, A. (2015) “Characterizing the spatial and temporal patterns of open burning of municipal solid waste (MSW) in Indian cities,” *Environmental Science & Technology*, 49(21), 12904–12912. https://doi.org/10.1021/acs.est.5b03243.
22. Olise, F. S., Ogundele, L. T., Olajire, M. A. & Owoade, O. K. (2020). Seasonal Variation, pollution indices and trajectory modeling of bio-monitored airborne particulate around two smelting factories in Osun State, Nigeria. *Aerosol Science and Engineering*, *4*, 260-270. https://doi.org/10.1007/s41810-020-00070-6.
23. Ran, L. L. W. L., Lin, W. L., Deji, Y. Z., La, B., Tsering, P. M., Xu, X. B. & Wang, W. (2014). Surface gas pollutants in Lhasa, a highland city of Tibet–current levels and pollution implications. *Atmospheric Chemistry and Physics*, *14* (19), 10721-10730. https://doi.org/10.5194/acp-14-10721-2014.
24. Sharma, R. C. & Sharma, N. (2016). Influence of some meteorological variables on PM10 and NOx in Gurgaon, Northern India. *American Journal of Environmental Protection*, *4*(1), 1-6.
25. Singh, V., Singh, S., Biswal, A., Kesarkar, A. P., Mor, S. & Ravindra, K. (2020). Diurnal and temporal changes in air pollution during COVID-19 strict lockdown over different regions of India. *Environmental Pollution*, *266*,115368. https://doi.org/10.1016/j.envpol.2020.115368.
26. Suresh, A., Chauhan, D., Othmani, A., Bhadauria, N., Aswin, S., Jose, J. & Mejjad, N. (2020). Diagnostic Comparison of Changes in Air Quality over China before and during the COVID-19 Pandemic. https://doi.org/10.21203/rs.3.rs-30482/v1.
27. Takemura, T., Nakajima, T., Dubovik, O., Holben, B. N. & Kinne, S. (2002). Single-scattering albedo and radiative forcing of various aerosol species with a global three-dimensional model. *Journal of Climate*, *15*(4), 333-352. https://doi.org/10.5194/acp-16-3289-2016.
28. Wang, S., & Hao, J. (2012). Air quality management in China: Issues, challenges, and optons. *Journal of Environmental Sciences*, *24*(1), 2-13. https://doi.org/10.1016/s1001-0742(11)60724-9.
29. Yadav, R., Sahu, L. K., Beig, G., Tripathi, N. & Jaaffrey, S. N. A. (2017). Ambient particulate matter and carbon monoxide at an urban site of India: influence of anthropogenic emissions and dust storms. *Environmental Pollution*, *225*, 291-303. https://doi.org/10.1016/j.envpol.2017.01.038.
30. Yin, X., de Foy, B., Wu, K., Feng, C., Kang, S. & Zhang, Q. (2019). Gaseous and particulate pollutants in Lhasa, Tibet during 2013–2017: Spatial variability, temporal variations and implications. *Environmental Pollution*, *253*, 68-77. https://doi.org/10.1016/j.envpol.2019.06.113.
31. Yousefian, F., Faridi, S., Azimi, F., Aghaei, M., Shamsipour, M., Yaghmaeian, K. & Hassanvand, M. S. (2020). Temporal variations of ambient air pollutants and meteorological influences on their concentrations in Tehran during 2012–2017. *Scientific reports*, *10*(1), 1-11. https://doi.org/10.1038/s41598-019-56578-6.
32. Zhao, S., Yu, Y., Yin, D. & He, J. (2015). Meteorological dependence of particle number concentrations in an urban area of complex terrain, Northwestern China. *Atmospheric Research*, 164, 304-317.https://doi.org/10.1016/j.atmosres.2015.06.001.