Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

Elsevier hereby grants permission to make all its COVID-19-related research that is available on the COVID-19 resource centre - including this research content - immediately available in PubMed Central and other publicly funded repositories, such as the WHO COVID database with rights for unrestricted research re-use and analyses in any form or by any means with acknowledgement of the original source. These permissions are granted for free by Elsevier for as long as the COVID-19 resource centre remains active.
COVID-19 lockdown: Effects on selected volatile organic compound (VOC) emissions over the major Indian metro cities

Anoop Pakkattil, M. Muhsin*, M.K. Ravi Varma

Department of Physics, National Institute of Technology Calicut, Calicut 673601, Kerala, India

ARTICLE INFO

Keywords:
COVID-19
Volatile organic compound (VOC)
BTEX
HCHO
TROPOMI

ABSTRACT

Due to the COVID-19 pandemic, many countries across the world, including India, have imposed nationwide lockdowns to contain the spread of the virus. Many studies reported that the air quality had improved much due to the lockdown. This study examines the variation of Volatile Organic Compounds (VOCs) over the Indian metropolitan cities during the lockdown period by using ground-based and satellite observations. Ground-based BTEX (Benzene, Toluene, Ethylbenzene, and Xylenes) measurements from various metropolitan cities have shown a drastic drop of about 82% in the first phase of lockdown when compared with the pre-lockdown period. Whereas the spatial distribution of formaldehyde (HCHO), obtained from the TROPOspheric Monitoring Instrument (TROPOMI) onboard Sentinel-5P satellite, did not show any significant variation due to COVID-19 lockdown, indicating the major source of HCHO is biogenic or pyrogenic. The BTEX ratios were evaluated for a better understanding of the source and photochemical age of the air samples. The ozone forming potential of BTEX in all locations was found reduced; however, the corresponding decrease in ozone concentrations was not observed. The increase in ozone concentrations during the same period indicates alternative sources contributing to ozone formation.

1. Introduction

Volatile organic compounds (VOCs) are a collection of volatile hydrocarbons and organic air pollutants released into the atmosphere from both natural and anthropogenic sources. VOCs play a vital role in atmospheric chemistry by contributing to the formation of ground-level ozone, influencing hydroxyl radical (OH) and nitrogen oxides (NOx) concentrations. These contribute to harmful oxidents, which can adversely affect human health, the ecosystem, and the atmosphere (Atkinson, 2000). Globally, tropical and extratropical forests act as the largest VOCs sources, whereas vehicular emissions are the major contribution in urban areas (Atkinson and Arey, 2003; Ho et al., 2009).

Among the VOCs, a subset of mono-aromatic compounds like benzene, toluene, ethylbenzene, and xylene are collectively known as BTEX species that have drawn attention due to their impact on health (Alghamdi et al., 2014; Miller et al., 2011; Truc and Kim Oanh, 2007). Also, up to 60% of non-methane VOCs (NMVOCs) released into the atmosphere are contributed by BTEX species (Lee et al., 2002), and its ratios can be used as an effective tool to investigate various photochemical processes (Yassaa et al., 2006). These species are toxic air pollutants, with benzene being a well-known carcinogen. Gasoline-powered vehicles, industries, and biogenic sources contribute a significant part of these pollutants in the atmosphere (Mehta et al., 2019). Several studies have utilized the BTEX ratios...
(benzene/ toluene (B/T), toluene/ benzene (T/B), and xylene/ethylbenzene (Σ X/E)) as indicators of emission sources and photochemical age of the air parcel (Miller et al., 2011; Phuc et al., 2018). Formaldehyde (HCHO) is another abundant oxygenated VOC, predominantly formed by the photochemical oxidation of hydrocarbons such as methane (CH₄) and NMVOCs (Fu et al., 2007; Mahajan et al., 2015). HCHO is naturally released from vegetation, biomass combustion (Howard, 1989; Seco et al., 2007) and is present in most organisms as a part of its metabolism. However, fuel combustion, industrial and consumer products can also emit the pollutant to the atmosphere.

Most of the VOCs react with nitrogen dioxide (NO₂) molecules to produce ozone, which in the troposphere is a harmful secondary air pollutant. Several studies have found that the reason for the high ozone level in the urban atmosphere is from the emitted VOCs, and its control is essential for the safety of living beings (Liao et al., 2014; Ryerson et al., 2003; Suthawaree et al., 2012). Different types of VOCs in the atmosphere have different reaction mechanisms and rates and hence have a significant difference in their ozone formation potential (OFP) (Atkinson, 1990; Carter, 1994).

COVID-19 lockdown gave a peculiar opportunity to examine the source, variations, and impacts of various atmospheric pollutants, including VOCs, over the Indian region. The sudden and complete restrictions on anthropogenic activities, which usually contribute to a significant part of atmospheric air pollution, allowed the scientific community an opportunity to study various atmospheric dynamics. Due to the COVID-19 epidemic, restriction measures have been implemented across different parts of India since mid-March 2020, and a 14 h voluntary curfew was imposed on March 22, which leads to a complete nationwide lockdown on March 24th (Phase 1, L1). While the first phase of the lockdown ended on April 14, subsequent phases were imposed on April 15 (L2), May 4 (L3), and May 18 (L4), with conditions being relaxed progressively. However, the complete lockdown was imposed only in phases 1 and 2, with the near-total shutdown of transport and industrial sectors (Pathakoti et al., 2020). Later more relaxations were granted when unlock phases are imposed at the beginning of each month, starting from the 1st of June (U1-U4).

Several studies have used the ground-based and satellite-based measurements (like ESA operated Tropospheric Monitoring Instrument (TROPOMI) onboard Sentinel-5P satellite, and NASA operated Ozone Monitoring Instrument (OMI) onboard AURA satellite) to study the variations of numerous trace pollutants as a part of COVID-19 lockdown in different parts of the world. As a result of this, many studies have reported a significant reduction in pollutants mainly related to traffic and industrial emissions like Particulate matter, NO₂, CO, and Black carbon (Otmani et al., 2020; Pathakoti et al., 2020; Sarfraz et al., 2020; Sharma et al., 2020; Tobías et al., 2020; Chauhan and Singh, 2020; Singh and Chauhan, 2020). Whereas amid its importance, few studies have been carried out on VOC variations in relation to COVID-19 lockdown (Huang et al., 2020; Pei et al., 2020). Due to the unavailability of VOC measurements, Cazorla et al. (2020) used VOCs derived from CO (one of the tightly linked pollutants to VOC) measurements in their O₃ model calculations in lockdown studies over Quito, Ecuador (Cazorla et al., 2020). Pei et al. used satellite-based HCHO measurement as a proxy to VOC variations to correlate high O₃ variations during lockdown over China (Pei et al., 2020). And, the HCHO exhibited a small decrease and returned to normal levels quickly.

The present study examines the variation of VOCs due to lockdown over the Indian metropolitan cities by using ground-based and satellite measurements. Section 2 describes the data and methodology used for this study. Section 3 discusses the major results and Section 4 summarises the results from this study.

Fig. 1. Major cities in the Indian region used for ground-level BTEX sample analysis.
2. Data and methodology

The present study used in-situ measurements and satellite observations to investigate the influence of the COVID-19 lockdown on VOCs over the Indian region. Due to the limitations in real-time monitoring of VOCs, the study is limited to BTEX and Formaldehyde. Of those observations, BTEX concentrations were obtained by in-situ measurements at various metropolitan cities. BTEX ratios are used to derive some insight into the source and photochemical age of the air mass. OFP of BTEX compounds at major cities were investigated both before and during the lockdown periods for a better understanding of its impact on photochemical activities of the selected VOCs. The daily averaged data of BTEX measurements at a station in 6 metropolitan cities (Mumbai, Bengaluru, Delhi, Kolkata, Hyderabad, and Chennai) from 1st January to 15th September 2020 was acquired from CAAQMS (Continuous Ambient Air Quality Monitoring System) located across India (https://app.cpcbccr.com/ccr/#/caaqm-dashboard-all/caaqm-landing) to represent the variation of urban VOCs. Fig. 1 shows the location of selected cities in India. The daily average of measurements was taken for ease of analysis at every station. The technical specifications of the measurements and instrument used can be found elsewhere (https://cpcb.nic.in/archivereport.php). The unavailability of continuous BTEX measurements restricted further studies in many other stations/cities in India. Some of the erroneous data were considered as outliers and removed from the analysis.

Formaldehyde (HCHO) data was obtained from TROPOMI (TROPOspheric Monitoring Instrument) onboard Sentinel-5 Precursor satellite, launched by the European Space Agency on 13th October 2017 (Kleipool et al., 2018). It is in a Sun-synchronous orbit at 824 km with an Equator crossing time of 13:30 local solar time. It has a comparatively higher spatial resolution as low as 7 × 3.5 km² in nadir. The primary objective of the satellite is to measure the column density of the trace gases and thereby monitor global air pollution. For the present analysis, HCHO level 2 data was downloaded from ESA’s Sentinels Scientific Data Hub website (https://s5phub.copernicus.eu/dhus/#/home) for a period of 1st January – 31st May of 2019 and 2020 and further gridded into 0.1° X 0.1° resolution over the Indian region (5° N - 35° N; 65° E - 95° E). The obtained data were further averaged for a duration of 1st January to 24th March (before lockdown) and 25th March to 31st May (during the lockdown) to obtain the spatial mean distribution of

Fig. 2. Variation of a)Benzene, b)Toluene, c)Ethylbenzene, and d)Xylene mixing ratios at various metropolitan cities during different phases of lockdown in India. Sudden fall in BTEX mixing ratios are observed immediately after the implementation of lockdown L1.
Ozone formation potential of BTEX at major cities during the two periods and the corresponding ozone levels at each station.

### Table 1

**Average concentrations of BTEX, NOx, and their ratios at major Indian cities during pre-lockdown and lockdown (1st phase) periods.**

| City    | Before LD (μg/m³) (Mean, 1st Jan-25 Mar) | LD (μg/m³) (Mean, 1st phase) |
|---------|-----------------------------------------|------------------------------|
|         | B | T | E | m,p,X | NOx | T/B | X/B | X/E | NO/NO2 | B | T | E | m,p,X | NOx | T/B | X/B | X/E | NO/NO2 |
| Mumbai  | 1.65 | - | 2.04 | 4.70 | 73.83 | - | 2.85 | 2.3 | 0.75 | 0.47 | - | 0.18 | 0.54 | 13.23 | - | 1.15 | 3.00 | 1.38 |
| Bengaluru | 0.99 | 1.96 | - | - | 23.79 | 1.97 | - | - | 0.36 | 0.32 | 0.53 | - | - | 4.77 | 1.66 | - | - | 0.16 |
| Delhi   | 6.08 | 20.88 | 4.43 | 8.43 | 63.33 | 3.43 | 1.39 | 1.90 | 0.65 | 0.38 | 0.97 | 0.35 | 0.31 | 16.52 | 2.55 | 0.82 | 0.89 | 0.74 |
| Kolkata | 19.13 | 36.41 | 7.18 | 6.86 | 104.81 | 1.90 | 0.36 | 0.96 | 0.55 | 3.37 | 14.49 | 1.47 | 1.93 | 15.81 | 4.30 | 0.57 | 1.11 | 0.10 |
| Hyderabad | 0.9 | 4.53 | - | 0.28 | 12.87 | 5.03 | 0.31 | - | 0.14 | 0.30 | 2.20 | - | 0.11 | 4.52 | 7.33 | 0.37 | - | 0.31 |
| Chennai | 0.18 | 0.06 | - | - | 27.19 | 0.33 | - | - | 0.78 | 0.11 | 0.003 | - | - | 13.82 | 0.30 | - | - | 0.39 |

HCHO over the Indian region. The mean spatial distribution of the HCHO during 2019 for the same periods of before and during lockdown were obtained for comparison purpose.

### 3. Results and discussion

The daily variation of BTEX concentrations from January to mid of September is depicted in Fig. 2, where the data were normalized for better representation and smoothed over seven days to reduce the noise in measurements. Mean concentrations of BTEX compounds found in major cities are given in Table 1. A dramatic decrease in the concentrations of all the BTEX species can be noticed immediately after the implementation of lockdown. An overall decrease of about 80 ± 13%, 75 ± 20%, 88 ± 7%, and 80 ± 16% were observed for benzene, toluene, ethylbenzene, and xylene, respectively, during the first phase of lockdown when compared to the values prior to this time. Unfortunately, the complete data from all the stations during previous years are not available for comparison. Individual variations of species are different in different cities and at various stages of lockdown. Apart from the nationwide lockdown, different states/regions have implemented several activities and movement restrictions locally.

T/B ratios are commonly used to determine the nature of the sources of BTEX. Low T/B ratios are, in general, observed when vehicular emissions act as a major BTEX source. This is because benzene is commonly emitted from mobile sources and toluene from both mobile and point sources (Miller et al., 2011). T/B ratios were found reduced during the first phase of lockdown at Bangalore, Delhi, and Chennai. In contrast, these ratios are increased in Kolkata and Hyderabad. A similar trend were observed for X/B ratios, though the values were missing at Chennai. In addition, X/B ratios were found reduced in Mumbai. One possible reason for the increase in T/B ratios is the presence of some nearby point sources, whose percentage contributions to the total BTEX increased during the restricted vehicular activities. At the same time, X/E ratios represent the photochemical age of air samples. Xylenes are more reactive than ethylbenzene, and hence higher X/E ratios represent better apportionment accuracies of emission sources (Ueda and Tomaz, 2011). Though remarkably reduced concentrations were noticed for xylene and ethylbenzene during the lockdown, the X/E ratios were found to have increased in Mumbai and Kolkata. In contrast, the ratio was decreased from 1.9 to 0.89 in Delhi. Apart from vehicular restrictions, all outdoor anthropogenic activities were restricted. Hence, detailed analysis at each station locally is necessary for correlating the changes in these ratios to possible emission sources.

During the lockdown 2020, several studies reported higher ozone mixing ratios. The ozone levels are increased by 24–27% in Nice and Turin, by 14% in Rome, and by 26% in Wuhan (Sicard et al., 2020). In India, the increased ozone mixing ratios during lockdown are reported by various studies (Bedi et al., 2020; Kumari and Toshniwal, 2020; Selvam et al., 2020). Several possible reasons are suggested for the increase in ozone mixing ratios during lockdown, which includes the reduction in its precursors (NOx and VOCs), reduction of NO emissions (reduces reaction with ozone to form NO2), and increased temperature during summer (Sicard et al., 2020; Tobías et al., 2020). However, most of the Indian cities are VOC limited (Bedi et al., 2020), which invites more attention to the variation of VOCs in an urban environment.

The ozone-forming potential (OFP) is widely used as a tool to describe the maximum potential of a VOC in ozone formation in urban air where, in general, the ozone formation is VOC limited. OFP of BTEX compounds were calculated by multiplying each species concentrations by its maximum incremental reactivity (MIR) scales (Alghamdi et al., 2014; Carter, 2010, 1994; Olajire and Azeez, 2014). Based on MIR scales, xylene has the highest potential among BTEX compounds in ozone formation. This is followed by toluene, ethylbenzene, and benzene. Table 2 shows the OFP of BTEX species during pre-lockdown and lockdown periods in major Indian cities. OFP at all the stations represented here has been found reduced considerably during the lockdown periods. The average OFP of BTEX during pre-lockdown periods at Delhi was 167.12 ± 152.02 μg/m³, which is comparable with a previously measured value of 207.51 ±

### Table 2

Ozone formation potential of BTEX at major cities during the two periods and the corresponding ozone levels at each station.

| VOC species | MIR | OFP (Before LD) | OFP (LD, 1st Phase) |
|-------------|-----|-----------------|---------------------|
|             | Mum | Ban | Del | Kol | Hyd | Chem | Mum | Ban | Del | Kol | Hyd | Chem |
| Benzene     | 0.72 | 1.19 | 0.71 | 4.384 | 17.37 | 0.65 | 0.13 | 0.34 | 0.23 | 0.27 | 2.43 | 0.22 | 0.01 |
| Toluene     | 4.00 | - | 7.84 | 83.52 | 145.64 | 18.12 | 0.24 | - | 2.12 | 3.88 | 57.96 | 8.80 | 0.01 |
| Ethyl benzene | 3.04 | 6.20 | - | 13.47 | 21.83 | - | 0.55 | - | 1.06 | 5.29 | - | - | - |
| m,p-Xylene | 7.80 | 36.66 | - | 65.75 | 53.51 | 2.18 | - | 4.21 | - | 2.42 | 15.05 | 0.86 | - |
| Ozone (μg/m³) | 35.13 | 33.53 | 34.22 | 38.91 | 26.68 | 13.01 | 35.42 | 58.84 | 54.23 | 26.68 | 13.01 |
Fig. 3. Spatial distribution of mean TROPOMI tropospheric HCHO vertical column densities over Indian region.
123.40 μg/m³ (Garg and Gupta, 2019). During the first phase of lockdown, this has been reduced to 7.63 ± 7.27 μg/m³. But the corresponding drop in ozone concentrations was not observed in Delhi. In fact, the ozone values at the representing station in Delhi have increased by 71.9%. A similar increase in ozone levels was observed in two other cities, except Chennai, where the ozone levels are reduced by 46.5%. Bangalore and Hyderabad showed an insignificant increase in ozone concentrations. The reason for such a dichotomy might be explained with the variation of NOx, and NO/NO2 values. Although NOx values are reduced at all the studied locations, maximum reduction was observed in Mumbai (~82%) and least in Chennai (~49%). However, NO/NO2 ratios are increased in Mumbai, Delhi, and Hyderabad. In contrast, Bengaluru, Kolkata, and Chennai showed a decrease in the ratio values. The decline in NO/NO2 ratio is associated with an increase in ozone concentrations and might be the reason for the increase in ozone levels in these cities. Unfortunately, total VOC values are not available at monitored locations to study VOC/NOx ratios. However, when we compared the same period in 2019, ozone values are increased during the targeted days, when compared to earlier months of that year by 67.4% in Delhi and 96.5% in Hyderabad. In contrast, negligible changes were observed in Bangalore, and around 40% decrease was observed in Chennai. This implies that the local meteorology, too, has played an important role in estimating the ozone mixing ratios. Despite all these factors, the reason for the increase in ozone mixing ratios in some cities are still not completely revealed. The most probable reason for this in a VOC limited environment is the presence of some unchanged/increased VOCs such as HCHO with high density regions. A similar result was recently reported over China during the COVID-19 lockdown (Pei et al., 2020). However, the argument of Siciliano et al. (2020) explained it in such a way, where the increase in ozone concentrations was associated with the increase in NMHC/NOx ratio in Rio de Janeiro.

Fig. 3 show the mean spatial distributions of formaldehyde (HCHO), another atmospherically relevant VOC, over the Indian region from 1st January to 24th March 2019 (corresponding to before lockdown period of 2020), 25th March to 31st May 2019 (corresponding to lockdown period of 2020), 1st January to 24th March 2020 (before lockdown), 25th March to 31st May 2020 (during lockdown) respectively. The temporal pattern of HCHO concentration exhibits uniform trends over the Indian region and is found elevated during April–May compared to the January–March period. This seasonal pattern is similar to the previous studies (Mahajan et al., 2015). Spatially, the concentrations are comparatively high over the west coast, Indo Gangetic Plain (IGP), and the northeast region of India. The broad-scale distribution of HCHO over India is consistent with the mean distribution of the Normalized Diffusive Vegetation Index (NDVI) (figure not shown). Also, it can be noted that the spatial distribution has inter-annual variations. Interestingly, Fig. 3 shows that there is no significant variation in HCHO concentration due to the COVID-19 lockdown. However, Chauhan and Singh (2021) reported a mixed behavior of HCHO at various Indian cities for 21 days of measurement. Generally, HCHO columns are related to local emissions of VOCs with a spatial spreading that increases with the VOC lifetime. Over India, HCHO has biogenic, pyrogenic, and anthropogenic sources. Precise quantifications of the proportions of biogenic, pyrogenic, and anthropogenic emissions of HCHO is not available. Since HCHO does not significantly vary due to the COVID-19 lockdown, its emissions may be inferred from the biogenic and pyrogenic sources in this region than anthropogenic industrial or vehicular activities. By observing the vertical column densities (VCD) of HCHO over indian region, large contribution from biogenic sources are reported in previous studies (Mahajan et al., 2015; Surl et al., 2018). This is also evident from the present study, as high VCDs are not observed over high urban density regions. A similar result was recently reported over China during the COVID-19 lockdown (Pei et al., 2020). However, the relationship between HCHO and ozone are already reported in several studies. The degradation of HCHO has a strong influence on ozone chemistry by enhancing the ozone formation rates (Carter, 1994; Vlasenko et al., 2010; Wang et al., 2017). HCHO is considered to be an important factor in ozone formation and accounts for nearly 27.6% and 20% of the total ozone formation potential in urban and rural areas of China (Wang et al., 2017; Xiaoyan et al., 2010). Our present study supports the NMHC/NOx argument of Siciliano et al. (2020) for the increased ozone concentrations as the HCHO values are increased, and NOx values are reduced when compared with the pre-lockdown period. The elevated HCHO during the April–May season must have very well influenced the ozone concentrations.

4. Conclusion

The present study estimates the changes in five volatile organic compounds in connection with the nationwide lockdown in India due to the COVID-19 pandemic. Variation in BTEX concentrations was analyzed at six major cities using ground-based measurements, and HCHO variations over the Indian region are studied using TROPOMI (TROPOspheric Monitoring Instrument), onboard Sentinel-5 Precursor satellite, observations. Daily averaged BTEX concentrations measured from 1st January to 24th March 2020 (Pre-lockdown) were compared to the first phase of lockdown. An overall decrease of about 80 ± 13%, 75 ± 20%, 88 ± 7%, and 80 ± 16% were observed for benzene, toluene, ethylbenzene, and xylene when compared with the pre-lockdown period. However, HCHO didn’t show any significant variation when compared with the same period of 2019. BTEX ratios are used to study the source and photochemical age of air mass, and it showed distinguished behavior in various cities during the transition to lockdown. Drop-in BTEX concentration during lockdown across the cities considerably reduced its ozone-forming potential; however, the actual ozone concentrations were found to have increased in most of the cities, indicating its forming and sustenance by alternate means.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.
Acknowledgments

The authors would like to thank the Central Pollution Control Board, India, for providing surface VOC measurements through their website [https://app.cpcbccr.com]. Formaldehyde data was downloaded from ESA’s Sentinels Scientific Data Hub website (https://s5hub.copernicus.eu/dhus/#/home). M. Muhsin was supported by the National Postdoctoral Fellowship grant PDF/2018/001128 from the Science & Engineering Research Board of the Department of Science and Technology (DST- SERB), India.

References

Alghamdi, M.A., Khodr, M., Abdelmaksoud, A.S., Harrison, R.M., Hussein, T., Li, X., Al-Jeelani, H., Al-Arifi, M., Almehmadi, F.M., Hyvarinen, A.-P., Hameri, K., 2014. Seasonal and diurnal variations of BTEX and their potential for ozone formation in the urban background atmosphere of the coastal city Jeddah, Saudi Arabia. Air Qual. Atmos. Health 7, 467–480. https://doi.org/10.1007/s11869-014-0263-x.

Atkinson, R., 1990. Gas-phase tropospheric chemistry of organic compounds: a review. Atmos. Environ. Part A. Gen. Top. 24, 1–41. https://doi.org/10.1016/0960-1686(90)90458-B.

Atkinson, R., 2000. Atmospheric chemistry of VOCs and NOx. Atmos. Environ. 34, 2063–2101. https://doi.org/10.1016/S1352-2310(99)00460-4.

Atkinson, R., Arey, J., 2003. Atmospheric Degradation of Volatile Organic Compounds.

Bedi, J.S., Dhaka, P., Vijay, D., Aulakh, R.S., Gill, J.P.S., 2020. Assessment of air quality changes in the four metropolitan cities of India during COVID-19 pandemic lockdown. Aerosol Air Qual. Res. 20, 2062–2070. https://doi.org/10.4209/aap.2020.05.0209.

Cazorla, M., Herrera, E., Palomeque, E., Saud, N., 2020. What the COVID-19 lockdown revealed about photochemistry and ozone production in Quito, Ecuador. Atmos. Environ. 219, 117508. https://doi.org/10.1016/j.atmosenv.2019.117508.

Chauhan, A.K., Singh, R.P., 2021. Effect of Lockdown on HCHO and Trace Gases over India during March 2020. AAQR (in press).

Chauhan, A.K., Singh, R.P., 2021. Effect of Lockdown on Ozone Reactivity scales for volatile organic compounds. Air Waste 44, 881–899. https://doi.org/10.1080/02757540.2013.844796.

Chauhan, A.K., Singh, R.P., 2021. Effect of Lockdown on HCHO and Trace Gases over India during March 2020. AAQR (in press).

Chauhan, A.K., Singh, R.P., 2021. Effect of Lockdown on Ozone Reactivity scales for volatile organic compounds. Air Waste 44, 881–899. https://doi.org/10.1080/02757540.2013.844796.

Czap, W.R., 2001. Development of ozone reactivity scales for volatile organic compounds. Air Waste 44, 881–899. https://doi.org/10.1080/02757540.2013.844796.

Czap, W.R., 2001. Development of ozone reactivity scales for volatile organic compounds. Air Waste 44, 881–899. https://doi.org/10.1080/02757540.2013.844796.

Czap, W.R., 2001. Development of ozone reactivity scales for volatile organic compounds. Air Waste 44, 881–899. https://doi.org/10.1080/02757540.2013.844796.

Czap, W.R., 2001. Development of ozone reactivity scales for volatile organic compounds. Air Waste 44, 881–899. https://doi.org/10.1080/02757540.2013.844796.

Czap, W.R., 2001. Development of ozone reactivity scales for volatile organic compounds. Air Waste 44, 881–899. https://doi.org/10.1080/02757540.2013.844796.

Czap, W.R., 2001. Development of ozone reactivity scales for volatile organic compounds. Air Waste 44, 881–899. https://doi.org/10.1080/02757540.2013.844796.

Czap, W.R., 2001. Development of ozone reactivity scales for volatile organic compounds. Air Waste 44, 881–899. https://doi.org/10.1080/02757540.2013.844796.

Czap, W.R., 2001. Development of ozone reactivity scales for volatile organic compounds. Air Waste 44, 881–899. https://doi.org/10.1080/02757540.2013.844796.

Czap, W.R., 2001. Development of ozone reactivity scales for volatile organic compounds. Air Waste 44, 881–899. https://doi.org/10.1080/02757540.2013.844796.

Czap, W.R., 2001. Development of ozone reactivity scales for volatile organic compounds. Air Waste 44, 881–899. https://doi.org/10.1080/02757540.2013.844796.

Czap, W.R., 2001. Development of ozone reactivity scales for volatile organic compounds. Air Waste 44, 881–899. https://doi.org/10.1080/02757540.2013.844796.

Czap, W.R., 2001. Development of ozone reactivity scales for volatile organic compounds. Air Waste 44, 881–899. https://doi.org/10.1080/02757540.2013.844796.
Siciliano, B., Dantas, G., Cleyton, M., Arbilla, G., 2020. Science of the Total environment increased ozone levels during the COVID-19 lockdown: analysis for the city of Rio de Janeiro, Brazil. Sci. Total Environ. 737, 139765. https://doi.org/10.1016/j.scitotenv.2020.139765.

Singh, R.P., Chauhan, A.K., 2020. Impact of lockdown on air quality in India during COVID-19 pandemic, air quality. Atmos. Health 13 (8), 921–928. https://doi.org/10.1007/s11869-020-00863-1.

Suri, L., Palmer, P.I., Gonzalez Abad, G., 2018. Which processes drive observed variations of HCHO columns over India? Atmos. Chem. Phys. 18, 4549–4566. https://doi.org/10.5194/acp-18-4549-2018.

Suthawaree, J., Tajima, Y., Khunchornyakong, A., Kato, S., Sharp, A., Kajii, Y., 2012. Identification of volatile organic compounds in suburban Bangkok, Thailand and their potential for ozone formation. Atmos. Res. 104–105, 245–254. https://doi.org/10.1016/j.atmosres.2011.10.019.

Tobías, A., Carnerero, C., Roche, C., Massagüé, J., Via, M., Minguillón, M.C., Alastuey, A., Querol, X., 2020. Changes in air quality during the lockdown in Barcelona (Spain) one month into the SARS-CoV-2 epidemic. Sci. Total Environ. 726, 138540. https://doi.org/10.1016/j.scitotenv.2020.138540.

True, V.T.Q., Kim Oanh, N.T., 2007. Roadside BTEX and other gaseous air pollutants in relation to emission sources. Atmos. Environ. 41, 7685–7697. https://doi.org/10.1016/j.atmosenv.2007.06.003.

Ueda, A.C., Tomaz, E., 2011. BTEX concentrations in the atmosphere of the metropolitan area of Campinas (São Paulo, Brazil). WIT Trans. Ecol. Environ. 147, 211–217. https://doi.org/10.2495/AR110191.

Vlasenko, A., Macdonald, A.M., Sjostedt, S.J., Abbatt, J.P.D., 2010. Formaldehyde measurements by proton transfer reaction – mass spectrometry (PTR-MS): correction for humidity effects. Atmos. Meas. Tech. 3, 1055–1062. https://doi.org/10.5194/amt-3-1055-2010.

Wang, C., Huang, X.-F., Han, Y., Zhu, B., He, L.-Y., 2017. Sources and Potential Photochemical Roles of Formaldehyde in an Urban Atmosphere in South China. J. Geophys. Res. Atmos. 122 (11) https://doi.org/10.1002/2017JD027266, 911-934,947.

Xiaoyan, W., Huixiang, W., Shaoli, W., 2010. Ambient formaldehyde and its contributing factor to ozone and OH radical in a rural area. Atmos. Environ. 44, 2074–2078. https://doi.org/10.1016/j.atmosenv.2010.03.023.

Yassaa, N., Brancareoni, E., Frattoni, M., Ciccioli, P., 2006. Isomeric analysis of BTEXs in the atmosphere using β-cyclodextrin capillary chromatography coupled with thermal desorption and mass spectrometry. Chemosphere 63, 502–508. https://doi.org/10.1016/j.chemosphere.2005.08.010.