Temporary reduction in VOCs associated with health risk during and after COVID-19 in Maharashtra, India

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Abstract
A novel coronavirus has affected almost all countries and impacted the economy, environment, and social life. The short-term impact on the environment and human health needs attention to correlate the Volatile organic compounds (VOCs) and health assessment for pre-, during, and post lockdowns. Therefore, the current study demonstrates VOC changes and their effect on air quality during the lockdown. The findings of result, the levels of the mean for total VOC concentrations were found to be 15.45 ± 21.07, 2.48 ± 1.61, 19.25 ± 28.91 µg/m³ for all monitoring stations for pre-, during, and post lockdown periods. The highest value of TVOCs was observed at Thane, considered an industrial region (petroleum refinery), and the lowest at Bandra, which was considered a residential region, respectively. The VOC levels drastically decreased by 52%, 89%, 80%, and 97% for benzene, toluene, ethylbenzene, and m-xylene, respectively, during the lockdown period compared to the previous year. In the present study, the T/B ratio was found lower in the lockdown period as compared to the pre-lockdown period. This can be attributed to the complete closure of non-traffic sources such as industries and factories during the lockdown. The Lifetime Cancer Risk values for all monitoring stations for benzene for pre- and post lockdown periods were higher than the prescribed value, except during the lockdown period.

Keywords TVOCs · Lockdown · T/B ratio · Lifetime cancer risk

1 Introduction
SARS-CoV-2, a novel coronavirus well known as COVID-19, was first reported in Wuhan, China in late December 2019 (Sohrabi et al., 2020; Cui et al., 2020; WHO, 2020a, b). These global spread viruses have affected over 252 million people worldwide and impacted the international economy, industrial production, and social life of all people. (Singh et al., 2022b) In order to flatten the curve for COVID-19, many state governments and ultimately central governments have taken measures to control the pandemic by generating
social distancing among the people (Kerimray et al., 2020; Yunus et al., 2020; Pradhan et al., 2020) and declared country-wide lockdowns (Jain & Sharma, 2020; Hasan et al., 2021). These measures witnessed the reduction of air pollutants and increased air quality across the world due to the complete closures of industries, transport, and construction works (Anjum, 2020; Chen et al., 2020; Dutheil et al., 2020; Navinya et al., 2020; Vithanage et al., 2022). At the same time, in many studies, there was reported an emission reduction in the primary pollutants such as particulate matter (PM), carbon monoxide (CO), nitrogen dioxide (NO2), Sulfur dioxide (SO2), and Volatile organic compounds (VOCs) whereas the precursors of secondary pollutants ozone (O3) was amplified during the lockdown period (Siciliano et al., 2020; Tobias et al., 2020; Wang et al., 2020; Kandari & Kumar, 2021; Pal et al., 2021; Lal et al., 2021; Singh et al., 2021a). VOCs are important precursors of surface ozone and PM2.5 (Atkinson et al., 2006), but variations of VOCs concentration caused by lockdown are still unclear till now (Wang et al., 2021). The VOC concentration will directly relate to the determination of the O3 accumulation level (Zhang & Stevenson, 2022).

In the past decades, ambient VOCs pollution has become a serious environmental problem in urban areas, especially in developing countries such as China, India, Iran, Malaysia, Philippines, Vietnam, and Thailand (Cui et al., 2018; Sahu et al., 2016; Hazerati et al., 2016; Hosaini et al., 2016; Do et al., 2015, Carlsen al., 2018). Due to various harmful effects on human health and the environment, ambient VOC pollution has attracted wide attention from the public, policymakers, industrial managers, and the scientific research community (Wang et al., 2016; Churkina et al., 2017; Tran et al., 2018; Kumar & Singh, 2015).

In tropospheric chemistry and photochemical air pollution, Volatile organic compounds (VOCs) and nitrogen oxides play a major and key central role (Dantas et al., 2020). Various studies reported that the majority of oxygenated volatile organic compounds are oxidized in the atmosphere through chemical reactions in the gas phase (Calvert et al., 2011; Mellouki et al., 2003). The degradation of saturated oxygenated VOCs is largely initiated by their reaction with hydroxyl radicals (OH). In addition, the photolysis of carbonyls such as aldehydes and ketones can also play a significant role in their atmospheric degradation. The oxidation of unsaturated oxygenated compounds may be initiated by a reaction with ozone, nitrate (NO3), and hydroxyl radicals. Many precursors to PM2.5 and ozone formation include VOCs, which were emitted by various sources, including vehicular emissions, hazardous wastes, and solvent use possessing their own toxicity (Yan et al., 2021). Many substances are included in the category of Volatile Organic Compounds (VOCs), benzene (C6H6), toluene (C7H8), ethylbenzene (C8H10), and (o-, m-, p-) xylenes (C8H10) and are compounds known as the BTEX groups combinedly. BTEX pollutants sources include plastics, paints, resins, rubber, adhesives, lubricants, and detergents (Allahabady et al., 2022). Up to, 60% of non-methane VOCs (NMVOCs) which were released into the atmosphere are contributed by only BTEX species (Pakkatil et al., 2020). Another study shows that aerosols of heated tobacco products (HTP), and aerosols of e-cigarettes also lead to the source of VOCs (Lu et al., 2022). According to Zhao et al. (2017), transportation and industry were considered the two major contributors to ambient VOCs, and transportation and fuel combustion were also significant contributors to VOC pollution (39–51%) of the source of VOCs emissions (Wang et al. 2020). Another study indicated that industrial (38.5%) and traffic (32%) were the two dominant sources of VOCs in the urban areas, while residential and biogenic sources contributed 13.8% and 1.8%, respectively (Sun et al., 2021). Apart from anthropogenic VOCs, Biogenic VOCs are important for atmospheric chemistry and play a significant role in the oxidative capacity of the atmosphere (Andreae et al., 1997; Fuentes et al., 2000). BVOCs; including isoprene, terpenes
(monoterpenes, sesquiterpenes), and oxygenated VOCs (alcohols, aldehydes, ketones, and acetates) are important for atmospheric chemistry since they contribute to secondary organic aerosol formation.

Many studies have shown that long-term airborne VOCs exposure leads to short- and long-term effects like allergy, nausea, headache, visual disorders, memory impairment, damage to kidney and liver, asthma, nose, and sore throat discomfort, and even cancer also (Yoon et al., 2010; Kharel et al., 2021, Ulker et al., 2021). Several studies reported that the BTEX class is considered a highly carcinogenic, mutagenic, and genotoxic agent. (Alghamdi et al., 2014, Cerón-Bretón et al., 2015). It is mostly seen that VOCs have an important role in global ecological integrity and human health (Monteno—Montoya et al., 2018; Sakunkoo et al., 2021). These compounds play a crucial role in forming secondary pollutants on account of their active participation in photochemical reactions (Alghamdi et al., 2014; Cerón Bretón et al., 2015; Miri et al., 2016). In the formation of particulates and ozone, which further forms smog, VOCs play an important and major role (Singh et al., 2014). VOCs also play a crucial role in Photochemical reactions in the atmosphere then lead to the formation of a wide range of important secondary pollutants, including ozone (O3) and secondary inorganic and organic aerosol (Nelson et al., 2021).

During the period of COVID-19 lockdown, many studies reported the impact of different pollutants on the ambient air quality, but little research was carried out on VOCs. A study found that the level of average VOCs was reported 26.9 ppb during the COVID-19 lockdown (Wang et al., 2021). Due to complicated sources of VOCs, including vehicle exhaust, vegetation emission, biomass burning, and the use of many volatile chemical products like (solvents, pesticides, coatings, personal care products, and cleaning agents) determined VOC emission and its photochemical processing very complicated for furthermore studies (Gao et al., 2021).

The Maharashtra Pollution Control Board released a report (MPCB), indicating that VOC (toluene) at Mehul and Ambapada villages reported ranging from 15.3 to 41.0 µg/m³ during the year 2014 which were linked with major health risks. None of the previous studies have focused on a detailed analysis of VOCs for pre-, during, and post-lockdown in India. This study allowed the development of a critical understanding of VOCs for the year 2019 to 2021, including pre-, during, and post-lockdown. Moreover, permitting the phase-wise relaxation in lockdown explored potential factors that influence divergent variations in different monitoring stations in Maharashtra.

Hence, the present study aims to characterize BTEX compounds and TVOCs in different lockdown periods for pre-, during, and post-lockdown periods. Furthermore, we compared the concentration of VOCs for pre-, during, and post-lockdown periods. In addition to exploring the potential factors through the T/B ratio that could influence divergent variations in different monitoring stations. The present study also calculated the health risk of cancer for pre-, during, and post-lockdown periods.

### 2 Materials and methods

#### 2.1 Study area

This study was carried out in selected monitoring stations in western India, which is considered subtropical monsoon climate. The five biggest cities of Maharashtra were selected
for VOC pollutants: Bandra, Aurangabad, Chandrapur, Thane, and Nashik. The details for each monitoring station of latitudes, longitude, and description have presented in Table 1. Monsoon climate (including due, frost, and hail) in these cities starts in the first week of September with rainy (June–September), summer (March–May), and winter season (November–February). Hill stations are also not that cool (Singh et al., 2022a). This part of Maharashtra receives a maximum of 22° C—39° C during summers and a minimum of 12° C – 34 °C during winters. Rainfall in Maharashtra varies from district-to-district; Thane receives heavy rain of about 200 cm annually, and Pune gets less than 50 cm annually; other than this, central Maharashtra, including Bandra, Aurangabad, and Chandrapur, receives lesser rainfall (Fig. 1).

2.2 Data and source

Data of different VOCs species were obtained from the central pollution control board (CPCB) on an hourly and daily basis. The data for BTEX (benzene, toluene, ethylene, and xylene) were considered in this paper on an hourly (24 hs.) and daily basis. Few of the hourly and daily data were missing from the particulate monitoring station. These data were replaced with a mean substitution, the mean value of a variable was used in place of the missing data value for that same variable. The daily average of measurements was calculated 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 stations in Maharashtra. Some of the erroneous data were considered as outliers and removed from the analysis. The CPCB database provides data quality assurance (QA) or quality control (QC) programs by establishing strict procedures for sampling, analysis, and calibration (Gurjar et al., 2016). Several previous studies reported that the CPCB provides data quality assurance and quality control (QA/QC) programs and detection limits of each BTEX species through rigorous sampling, analysis, and calibration (Singh & Kumar, 2021; Singh et al., 2021b; Pakkattil et al., 2021).

2.3 Measures

There were three phases of the pandemic pre-lockdown, lockdown, and post-lockdown. The time between March 24, 2019 – May 31, 2019, was referred to as the ‘pre-lockdown period’, the time between March 25, 2020, and May 31, 2020, was referred the ‘during lockdown period, whereas the time between March 25, 2021, and May 31, 2021, was referred the ‘post lockdown period to examine relative and temporal changes in BETX concentration in atmosphere quality (https://app.cpcbcr.com/cct/#/caaqm-dashboard-all/caaqm-landing).

2.4 Human health assessment

HHRA (human health risk assessment) is a method that is used to identify the impact of different pollutants on a population’s health due to long- and short-term exposure to it (Pinthong et al., 2022). For example, it assessed the possible health risks from BTEX exposure (benzene, toluene, ethylene, and xylene) using the US Environmental
| Serial No | Monitoring station | Latitude  | Longitude | Background |
|-----------|--------------------|-----------|-----------|------------|
| 1         | Bandra             | 19.05° N  | 72.82° E  | Bandra is an upscale coastal suburb located in the Mumbai (Bombay) area of the Konkan division, Maharashtra, India |
| 2         | Aurangabad         | 19.87° N  | 75.34° E  | Located on a hilly upland terrain in the Deccan Traps, Aurangabad is the fifth-most populous urban area in Maharashtra, with a population of 1,175,116 |
| 3         | Chandrapur         | 19.96° N  | 79.29° E  | The city sits at the confluence of the Erai River and Zarpat river. The area around the city is rich in coal seams. Hence, Chandrapur is also known as the "black coal city." |
| 4         | Thane              | 19.21° N  | 72.97° E  | Located on the north-western side of the state of Maharashtra, the city is an immediate neighbor of Mumbai city and a part of the Mumbai Metropolitan Region |
| 5         | Nashik             | 19.99° N  | 73.78° E  | Nashik is one of the fastest-growing cities in India. It has been a major industrial center in the automobile hub. The city houses companies like Atlas Copco, Robert Bosch GmbH, CEAT Limited, Crompton Greaves, Graphite India, |
Protection Agency’s (EPA) human health risk assessment framework. The HHRA is a tool used by regulatory agencies to assist in the formulation of policies that protect public health against the harmful effects of air pollution (OECD, 2008). By current literature studies it was found that it can further be subdivided into four components—on the bases of identification of hazardous substances; dose–response assessment by analyzing the pollutant taken up by the human body as a function of concentration and duration of exposure; the exposure assessment depends on amount and timeline of exposure to hazard.

2.4.1 Hazard identification

Hazard identification is a procedure to identify the pollutant in an ambient environment that is likely to induce harmful effects on human health (Sone et al., 2020). The identification of different VOCS, including BTEX, which are of high risk to human health, was performed through a literature review.
2.4.2 Dose–response assessment

The Dose–response assessment estimates are based on the amount of the pollutant taken into the body and exposure length (Rostami et al., 2021). Therefore, the Dose–response assessment is not estimated in the current study. Rather, the present study compares the measured ambient concentration of pollutants in the study area with the South African National Ambient Air Quality Standard (NAAQS), which serves as the benchmark (NAAQS, 1994).

2.4.3 Exposure assessment

Exposure assessment (EA) was calculated to examine the duration and magnitude of the population based on different parameters. In the present study, the inhalation route is the major route of exposure to the identified pollutants. We estimated the daily and annual readings for normal and acute exposure periods for different age groups, namely male (70 years), female (60 years), and children (36 years). The values of the parameters used in the health risk assessment model are presented in Table 2.

\[
EC\left(\frac{\mu}{m^3}\right) = \frac{CA\left(\frac{\mu}{m^3}\right) \times ET\left(\frac{h}{day}\right) \times EF\text{year} \times ED\left(\frac{day}{year}\right)}{AT\text{(year)} \times 365\left(\frac{day}{year}\right) \times 24\left(\frac{h}{day}\right)}
\]

(1)

\[
EDI\left(\frac{mg}{kg\cdot day}\right) = \frac{CA\left(\frac{\mu}{m^3}\right) \times \left(\frac{1}{1000}\right)\left(\frac{mg}{ug}\right) \times IR\left(\frac{m^3}{day}\right) \times ET\left(\frac{h}{day}\right) \times EF\text{year} \times ED\left(\frac{day}{year}\right)}{AT\text{(year)} \times 365\left(\frac{day}{year}\right) \times 24\left(\frac{h}{day}\right) \times BW(kg)}
\]

(2)

\[
HQ = \frac{EC}{RfC}
\]

(3)

\[
ILCR = CDI \times SF
\]

(4)
Here, EC (µg m$^{-3}$) = exposure concentration;
CA (µg/m$^3$) = VOC (the average concentration of benzene, toluene, ethylene, and xylene);
ET (h/d) = exposure time;
EF (d/y) represents exposure frequency;
ED (y) = exposed length of working,
AT (h) = average exposure time, during the carcinogenic assessment, the average lifetime (per capita life expectancy × 365 d/y × 24 h/d) was adopted, and during the non-carcinogenic assessment, the average period of exposure cycle (ED × 365 d/y × 24 h/d) was adopted;
HQ (µg/m$^3$) = hazard quotient;
RfC = reference concentration of inhalation toxicity;
SF (kg d mg$^{-1}$) = carcinogenic slope factor.

A hazard quotient is the ratio of the potential exposure to a material and the measure at which no detrimental results are predicted. “ILCR” (Incremental Lifetime Cancer Risk) means the incremental possibility of an individual establishing cancer over a lifetime as an outcome of exposure to a contaminant. A slope factor is defined as an upper bound, approximating a 95% confidence limit, on the escalated cancer crisis from a lifetime exposure to a chemical.

### 2.4.4 Risk characterization

Risk assessment from different VOC can be calculated by using Eq. (5)

$$ EC = \frac{CA \times ET \times EF \times ED}{AT} $$

(5)

For non-carcinogenic health risk assessment, Eq. (6) is used

$$ HQ = \frac{EC}{RfC} $$

(6)

$$ LCR = E_L \times SF $$

(7)

For VOCs having a non-carcinogenic effect on the human health value of HQ should be less than or equal to 1. The value of HQ is directly proportional to the toxicity of VOCs i.e., the higher the value HQ > 1 it can create a potential risk to human health. For carcinogens, VOCs risk factor HQ between $10^{-4} – 10^{-3}$ can be considered the normal range for human health protection. In reality, populations may be exposed to the same constituents from other sources which are unknown or not considered in this study. Therefore, it is obvious to assume that the estimated carcinogenic risk is well below the $10^{-6}$ limited level to allow for a reasonable margin of protectiveness for populations at potential risk. In spite of this, if a calculated cancer risk exceeds the $10^{-6}$ limit, there is a serious need for taking the right steps and applying the management in this direction for overall population health.
3 Results and discussion

3.1 Total VOCs levels in the pre-, during and post lockdown periods

The present study focused on determining the significant changes in air pollutants, especially the total Volatile organic compounds (TVOCs) concentrations, during the COVID-19 pandemic in India, especially its western part. The VOC concentrations significantly declined during the lockdown period in 2020 as compared to the corresponding period in 2019 at all of the monitoring stations in Maharashtra. The main factors behind the significant decline in VOC concentrations during the lockdown were near-total restrictions on transport, industrial activities, and the opening of marketplaces. The average VOCs are referred to as the average of BTEX species in the current study. As a result, the levels of the mean for total VOC concentrations were found to be 15.45 ± 21.07, 2.48 ± 1.61, 19.25 ± 28.91 µg/m³ for all monitoring stations for pre-, during, and post lockdown periods. The high standard deviations for all years were noticed due to high values reported at the Thane monitoring station as compared to other monitoring stations. The TVOCs concentrations for all monitoring stations ranged between 0.47 µg/m³ (Bandra) and 51.69 µg/m³ (Thane), 0.44 µg/m³ (Chandrapur), and 4.39 µg/m³ (Nashik), and 2.33 µg/m³ (Bandra) and 77.04 µg/m³ (Thane) respectively for pre-, during, and post-lockdown periods (Fig. 2).

The maximum and minimum levels of TVOCs for all three years were observed in Thane and the Bandra monitoring stations, respectively. The trend of TVOCs for among all the monitoring stations was observed to be in order Thane > Nashik > Chandrapur > Bandra during the lockdown period, whereas Thane > Aurangabad > Chandrapur > Bandra for the pre-lockdown and Thane > Aurangabad > Nashik > Chandrapur > Bandra for the post lockdown periods. The TVOCs concentration declined by ~84% compared to the levels observed in the previous year. In India, all the passenger trains, metro, and flight services were canceled from 25th March 2020 (Press Information Bureau, Government of India, 2020). Transportation for non-essential services is prohibited, and only essential personnel and service providers are allowed to travel. According to Pawer et al., (2020) about 41% of commuters stopped traveling during the transition to the lockdown phase, 51.3% were using the same mode of transport and 5.3% of commuters shifted from public to private
mode. A report released by the Motor Vehicle Department of Maharashtra, (2022) claimed that the number of inspected vehicles declined gradually during the pandemic as the corresponding year 2019 in Maharashtra. The total number of inspected vehicles were reported as 13.34, 10.86, and 9.41 million for the year 2018–19, 2019–20, and 2020–21 respectively. The present study agrees with this report and finds that traffic volumes decreased during COVID-19 in Maharashtra.

After the lifting of the lockdown, TVOCs gradually increased along with the re-opening of various industries and transport services. This could also be related to the use of private transportation (including private cars and taxis) as people continued practicing social distance and resuming their jobs (Huang et al., 2020). The highest value of TVOCs was observed at Thane, considered an industrial region, and the lowest at Bandra, which was considered a residential region, respectively. The highest TVOCs at Thane may be attributed to the petroleum refinery and chemical industries. On the other hand, the reduction percentages for TVOCs have not observed a similar trend during the lockdown periods. This can be generally explained by the changes in the contribution of both solvent use and vehicle exhaust (Qi et al., 2021). In a study conducted at different zones in Delhi, the average values of TVOC and $\sum$BEXT were reported highest (518.9 $\mu$g/m$^3$) in heavy traffic density areas during the rush and non-rush hours (Singh et al., 2016) which was much higher than the present study.

### 3.2 Identification of VOCs characteristic pollutants for pre-lockdown period

The BTEX concentration for all monitoring stations was presented in Fig. 3 for pre-, during, and post-lockdown periods. The BTEX concentration for all monitoring stations was
presented in Fig. 3 for pre-, during, and post-lockdown periods. The mean levels of VOC species for pre-lockdown periods were found to be 2.32 ± 3.45, 15.47 ± 17.48, 3.15 ± 2.47, and 6.32 ± 5.38 µg/m³ for benzene, toluene, eth-benzene, and mp-xylene, respectively. For pre-lockdown periods, the average VOCs varied from 0.23 to 8.30 µg/m³ for benzene and 1.35 to 40.09 µg/m³ for Toluene at Chandrapur and Thane monitoring stations, respectively. Benzene, toluene, and MP-Xylene's average VOCs were 8.30, 40.09, and 13.78 at Thane. The maximum VOCs for benzene, toluene, eth-benzene, and mp-xylene were 30.15, 112.20, 108.0, and 9.63 µg/m³ for Thane during the year 2019, whereas the minimum that was observed was 0.23, 1.35, and 1.32 at Chandrapur for the year 2019.

The average trend was found to be in order Thane > Bandra > Aurangabad > Chandrapur for Benzene and Thane > Aurangabad > Chandrapur for Toluene, whereas a similar trend was also observed for MP-Xylene during the year 2019. A high level of VOCs was reported at Thane due to the area-defined buffer zone between hazardous industries and residential quarters. Ravendiran et al. (2019) claimed that transport was the most significant contributor to VOCs in ambient air; other sources such as industries and petrol pumps also contributed significantly. Furthermore, several studies reported that the major emission sources that were contributing to VOCs were solvent-related emissions, renovations, household products, paints, glues, polishes, waxes, and pesticides (Batterman et al., 2007; Schlink et al., 2010; Dunagan et al., 2011; Jia & Batterman, 2010; Chin & Batterman, 2012; Chin et al., 2014).

3.3 Identification of VOCs characteristic pollutants during lockdown periods

The mean levels of VOC specie for all monitoring stations were calculated to be 1.12 ± 1.07, 1.63 ± 1.19, 0.62 ± 0.51, and 0.19 ± 0.13 µg/m³ for benzene, toluene, eth-benzene, and mp-xylene, respectively during the lockdown period. The average Benzene concentration varied from 0.06 µg/m³ (Chandrapur) to 2.58 µg/m³ (Bandra), whereas for toluene it varied from 0.19 µg/m³ (Chandrapur) to 3.06 µg/m³ (Nashik) during the lockdown period. The VOCs at all stations were recorded below the prescribed limit by CPCB (5 µg/m³) during the lockdown period. The average values reported during the lockdown were minimum due to complete transport and industrial activities restrictions, which are significant sources of primary VOC emissions.

The average trend of benzene was found to be in order Chandrapur > Nashik > Bandra, whereas a similar trend was also observed for toluene during the lockdown period. The maximum values that were calculated were 9.37 µg/m³ (Bandra), 0.16 µg/m³ (Chandrapur), and 1.69 µg/m³ (Nashik) for benzene, 1.05 µg/m³ (Chandrapur), and 8.69 µg/m³ (Nashik) for toluene during the lockdown period. The levels of VOC were reported higher at Chandrapur as compared to other stations due to the presence and continued operation of the Super Thermal Power Station which contributed a significant portion of VOCs during the lockdown period. Power plants were functional during the lockdown period but at a reduced scale due to the decline in electricity demand in industrial and commercial units (Sathe et al., 2021). The values of VOC for all monitoring stations were observed to be lower during the lockdown period than the corresponding period in 2019. The major factors behind the decline in emissions during lockdown have been found to be complete restrictions on activities such as transportation (including road, rail, and air), construction, and industries, except essential services such as medical facilities and electricity. In contrast, a slight increase in VOC was noticed during the second and third phase of the lockdown (April 15 – May 3, 2020) due to conditional relaxation to certain businesses,
including agricultural businesses, cargo transportation, trucks, trains, and planes, to operate which were significant sources for VOCs.

### 3.4 Identification of VOCs characteristic pollutants for post-lockdown periods

The mean levels of VOC specie for all monitoring stations were $3.38 \pm 1.19 \, \mu g/m^3$, $28.54 \pm 32.30 \, \mu g/m^3$, and $1.68 \pm 1.78 \, \mu g/m^3$ for benzene, toluene, and mP-xylene, respectively during the post-lockdown period. The average VOCs for all stations varied from 2.33 (Bandra) to 5.33 (Thane) for benzene, 3.28 (Nashik) to 74.14 (Thane) in the post-lockdown period. The average levels for VOCs were found to be the highest at Thane, followed by Aurangabad, Chandrapur, and Nashik. The benzene concentration for Thane was recorded quite high, even above the standard limits, while in Bandra, Chandrapur, and Nashik, the levels were also found to be over the standard limits. The trend for benzene was observed in the order Thane > Chandrapur > Bandra > Nashik, whereas, for toluene, the order was Thane > Aurangabad > Nashik (Supplementary Figure 1).

The maximum VOCs varied from 2.85 (Bandra) to 18.04 (Thane) for benzene and 8.85 (Aurangabad) to 219.20 (Thane) for toluene. The maximum values of VOCs have been observed at Thane, possibly due to this area experiencing the movement of heavy-duty vehicles (Srivastava et al., 2006). Emissions from the refinery and transportation of raw material and products through heavy vehicles in Thane contributed to TVOCs there. Traffic emissions were one of the significant sources at Thane, which is situated within 2 km of the major highways.

### 3.5 Comparative analysis for pre-, during, and post-lockdown period

The average levels of VOCs for benzene varied from 0.23 to 8.30, 0.06 to 2.58, and 2.33 to 5.38 $\mu g/m^3$ for all stations for pre-, during, and post lockdown periods, respectively. The VOCs levels drastically decreased by 52%, 89%, 80%, and 97% for Benzene, Toluene, Ethylbenzene, and M-xylene, respectively during the lockdown period compared to the corresponding period in 2019. A similar study conducted in metro cities in India indicated a decrease of about $80 \pm 13\%$, $75 \pm 20\%$, $88 \pm 7\%$, and $80 \pm 16\%$ for benzene, toluene, ethylbenzene, and xylene, respectively, during the first phase of lockdown when compared to the values prior to this time (Pakkattil et al., 2021).

The maximum changes were observed -76%, -86%, and -87% for Benzene, Toluene, and M-Xylene respectively at Chandrapur during the lockdown period. On the other hand, the average VOCs for the post lockdown period were recorded much higher at 3.02, 17.5, and 9.05 times than those during the lockdown period. These higher values recorded for post-lockdown periods were attributable to the relaxation in lockdown by the government of Maharashtra to activities such as transport (public and private), industrial and construction work, and commercial shops (Patil et al., 2021). On the other hand, a slight increase in VOC emissions can be expected, especially in COVID-19, like the situation when the use of sodium hypochlorite solution as a spraying agent in community disinfection practices (Chatterjee, 2020), and frequent mass use of sanitizers were followed rigorously within the cities to control the spread of the disease (Sathe et al., 2021).

The average changes in TVOCs for all stations declined by 84% during the lockdown period as compared to the corresponding period in the previous year. The TVOCs were observed (2.48 $\mu g/m^3$) below the prescribed limit during the lockdown period, whereas
for pre (15.45 µg/m³) and post (19.25 µg/m³), they were observed higher than the CPCB prescribed limit.

### 3.6 Source identification of VOCs

The ratio of Toluene and Benzene ratio (T/B) has been widely used to evaluate the influence of traffic and non-traffic sources for vehicle exhaust contribution to aromatics (Nelson & Quigley, 1984; Shi et al., 2015). Emissions from vehicles are the primary source for both Benzene and Toluene, but benzene is also a well-known marker for vehicular exhaust (Miller et al., 2012). A value of less than 2 for T/B indicated that vehicular emissions significantly influenced aromatic emissions (Wang et al., 2016). Several previous studies have reported that ratios lower than 2 indicated a high traffic source contribution (Tiwari et al. 2010; Yurdakul et al., 2013; Jaars et al., 2014; Miller et al., 2012; Barletta et al., 2008), whereas higher ratios indicated non-traffic sources and much higher ratio could also show the influence of other industrial activities (Ho et al., 2004; Simpson et al., 2020; Kang et al., 2022).

In the present study, the T/B ratio was calculated to be 21.19, 5.22, and 4.83 for Aurangabad, Chandrapur, and Thane, respectively, which indicated that non-traffic sources were major contributors during 2019. A higher T/B ratio was also attributed to other sources such as industrial emissions and petrol pumps in 2019 (Gaur et al., 2016). The highest toluene to benzene ratio was observed at Aurangabad station, which may indicate higher average temperatures and higher incident solar radiations and other sources along with the traffic emissions to have contributed to higher levels of VOCs.

The T/B ratio during the lockdown period varied between 3.19 and 4.33 in Chandrapur and Nashik stations, respectively, indicating traffic and transportation (under the essential activities) as sources of emissions. In the present study, the T/B ratio was found lower in the lockdown period as compared to the pre-lockdown period. This can be attributed to the complete closure of non-traffic sources such as industries and factories during the lockdown. For the post-lockdown period, the T/B ratio was found to be in the range of 1.22 (Nashik) and 13.8 (Thane). Similar studies claimed that the T/B ratios were nearly equal to 2 or less, which indicates the predominance of traffic emission sources (Carlsen et al., 2018). This result was similar to that study in Izmir, Turkey (1.81) (Hartmann et al., 1997), Bari, Italy (2.0) (Caselli et al., 2010), Delhi, India (2.54) (Hoque et al., 2008), Sakaka city, Saudi Arabia Kingdom (1.95–6.07) (El-Hashemy & Ali, 2018), Orleans city, France (2.63–2.88) (Jiang et al., 2017), and in Doha, Qatar, (2.41–3.55) (Alfoidy et al., 2019), which reported that mobile sources were the significant potential source of VOCs. A higher T/B ratio was recorded for the post-lockdown period as compared to the lockdown period. A higher T/B ratio also indicated the influence of the resumption of industrial activities and factories. Similar studies were reported for a higher ratio of T/B such as Taiwan (5.2–9.4) (Hsieh et al., 2011), and Japan (6.2–6.5) (Tiwari et al., 2010), which reported that industrial sources were a major potential source of VOCs.

### 3.7 Correlations between the monitoring stations

To find out the relationship between VOCs during the lockdown periods, the correlations of VOCs in each monitoring station were analyzed. The Pearson correlation
The coefficient was used to calculate the correlation coefficient for daily average VOC concentrations during the lockdown period. According to Akoglu, 2018, the Interpretation of the Pearson’s and Spearman’s correlation coefficients has defined as very strong correlation (Pearson coefficient: 0.8–1.0), strong correlation (Pearson coefficient: 0.6–0.8), moderate correlation (Pearson coefficient: 0.4–0.6), weak correlation (Pearson coefficient: 0.2–0.4), or irrelevance (Pearson coefficient: 0–0.2). The present study revealed significantly strong correlations between Thane and Bandra monitoring stations for pre-lockdown period (0.73). However, moderate correlations were noticed for the rest of the monitoring stations during the same periods (Table 3). Positive weak correlations were noticed (0.02 to 0.09) between the different monitoring stations during the post-lockdown periods which indicated that the source of pollution was not similar in these monitoring stations. Furthermore, indicated that variable sources of pollution could be established by reopening transport, industries, and other anthropogenic sources.

### 3.8 Health risk Assessment

This study calculated the health risk assessment for daily exposure, effective yearly exposure, effective lifetime exposure, hazard quotient, and lifetime cancer risk for the pre-, during, and post-lockdown periods. Several published reports have classified the toxicological profile of 20 VOCs by the ATSDR, and the National Toxicology Program (NTP) of the U.S., Department of Health and Human Services (DHHS), U.S. Environmental Protection Agency (EPA), Texas Commission on Environmental Quality (TCEQ), National Research Council (NRC) of the National Academies, and the IARC (CDC, 2016; ASTDR, 2012; Phillips & Haney, 2017; IARC, 1994) Exposure to the VOCs in the present study indicate acute and chronic health hazards. Many studies claimed that the human health effects of VOCs can be categorized as non-cancer and cancer risks (He et al., 2015; Li et al., 2019). It has been reported that non-cancer risk is mainly associated with chronic damage to the liver and kidney (Rumchev et al., 2007; Singh et al., 2021a, b, c; Singh et al., 2021c), and cancer risk is primarily reflected in

| Correlations 2019 | Banda | Aurangabad | Chandrapur | Thane |
|------------------|-------|------------|------------|-------|
| Banda            | 1     |            |            |       |
| Aurangabad       | -.417* | 1          |            |       |
| Chandrapur       | .436*  | -.390*     | 1          |       |
| Thane            | .738*  | -.448*     | .490*      | 1     |

**. Correlation is significant at the 0.01 level (2-tailed)

| Correlations 2021 | Banda | Aurangabad | Chandrapur | Nashik | Thane |
|-------------------|-------|------------|------------|--------|-------|
| Banda             | 1     |            |            |        |       |
| Aurangabad        | -.164 | 1          |            |        |       |
| Chandrapur        | -.058 | -.149      | 1          |        |       |
| Nashik            | .092  | .022       | -.131      | 1      |       |
| Thane             | -.224 | .069       | -.119      | -.098  | 1     |

**. Correlation is significant at the 0.01 level (2-tailed)
the lung, blood, and brain cancer due to specific exposure (Straif et al., 2009). Several studies reported the health risk assessment of PAHs in different aquatic environments in India (Ambade & Sethi, 2021; Ambade et al., 2021a, b, c; Kurwadkar et al., 2022a, b; Kurwadkar et al., 2022a).

Various organizations such as the WHO and the USEPA have established guideline values for BTEX compounds and recommended the limit of LCR (USEPA, 2009). LCR values are considered an indicator of risk; an LCR with a value of 10^{-6} indicates that the potential cancer risk in individual cases will be one person per million people (Habeebullah, 2015). Sexton et al. (2007) proposed different levels to determine the risk from air pollutants in the ambient environment. These levels are classified as follows: compounds with a CR value greater than 10^{-4} can be defined as a “definite risk”, a value of 10^{-5}-10^{-4} as a “probable risk”, and a value of 10^{-5}-10^{-6} as a “possible risk”.

At all monitoring stations, the present study calculated LCR values for pre-, during, and post lockdown periods for benzene, toluene, and MP-xylene. LCR values of Benzene for pre-, during and post lockdown periods varied from 2.03 \times 10^{-6} to 3.56 \times 10^{-5}, 2.62 \times 10^{-7} to 1.11 \times 10^{-5}, and 9.99 \times 10^{-6} to 2.3 \times 10^{-5} for males whereas from 2.37 \times 10^{-6} to 4.15 \times 10^{-5}, 3.06 \times 10^{-7} to 1.29 \times 10^{-5}, and 1.17 \times 10^{-5} to 2.69 \times 10^{-5} for females and from 3.95 \times 10^{-6} to 6.92 \times 10^{-5}, 5.1 \times 10^{-7} to 2.15 \times 10^{-5}, and 1.94 \times 10^{-5} to 4.48 \times 10^{-5} for children, respectively for all monitoring stations (Table). The highest LCR values at all monitoring stations were calculated at Thane for the post lockdown period, and the lowest was at Chandrapur during the lockdown period.

LCR values of Toluene for pre-, and during lockdown periods were varied from 5.81 \times 10^{-6} to 1.72 \times 10^{-4}, and 8.36 \times 10^{-7} to 3.18 \times 10^{-4} for male whereas from 6.77 \times 10^{-6} to 2.01 \times 10^{-4}, and 9.75 \times 10^{-7} to 3.71 \times 10^{-4} for females and from 1.13 \times 10^{-5} to 3.34 \times 10^{-4} and 3.73 \times 10^{-5} to 6.85 \times 10^{-5} for children, respectively for all monitoring stations. The LCR values for pre-, during, and post lockdown periods were recorded to be the highest for Thane station, whereas the lowest values were recorded for Chandrapur station among males, females, and children. The LCR values for pre lockdown period varied from 5.64 \times 10^{-6} to 5.91 \times 10^{-5}, 6.58 \times 10^{-6} to 6.89 \times 10^{-5}, and 1.1 \times 10^{-5} to 1.1 \times 10^{-4} for male, female, and children respectively. The LCR values were recorded to be the highest for Thane station and the lowest for Chandrapur station. A value of LCR for the pre-lockdown period was found to be similar 2.15 \times 10^{-5} and 2.05 \times 10^{-5} for male and female residents respectively in China, which indicated a noticeable higher carcinogenic risk for male and female residents. (Qin et al., 2022). The LCR values for all monitoring stations for benzene for pre-, during, and post-lockdown periods were higher than the prescribed value (1 \times 10^{-6}), except during the lockdown period, a guideline limit value in some circumstances (Dutta et al., 2009; Ramírez et al., 2012). The LCR values for males, females, and children were similar to Delhi (Kumar et al., 2014). Many studies estimated cancer risk in various cities and reported similar results (Guo et al., 2004; Hoddinott & Lee, 2000).

## 4 Conclusion

The temporary change in Volatile organic compounds (VOCs) was investigated at five different monitoring sites in Maharashtra (Bandra, Chandrapur, Aurangabad, Thane, and Nashik) for pre-, during, and post lockdown period (the year 2019–2021). The VOCs data for five monitoring stations were obtained from the Central Pollution Control Board
(CPBC). As a result, the levels of total VOC (TVOC) concentrations were found to be 15.45, 2.48, 19.25 µg/m³ for all monitoring stations for pre-, during, and post lockdown periods. The average changes in TVOC level declined 84% during the lockdown period as the corresponding year 2019. The highest value of TVOCs was observed at Thane, considered an industrial region, and the lowest at Bandra, which was considered a residential region, respectively. The highest TVOCs at Thane may be attributed to the petroleum refinery and chemical industries. During the lockdown period, the average VOC concentrations were recorded below the standard limits prescribed by CPCB (5 µg/m³). The levels of VOC were reported higher at Chandrapur as compared to other stations due to the presence and continued operation of the Super Thermal Power Station, which contributed a significant portion of VOCs during the lockdown period. On the other way, the average VOCs for the post-lockdown period for Benzene, Toluene, and M-Xylene respectively were recorded much higher at 3.02, 17.5, and 9.05 times than those during the lockdown period. These higher values recorded for post lockdown periods were attributable to the relaxation in lockdown by the government of Maharashtra to activities such as transport (public and private), industrial and construction work, and commercial shops.

In the present study, the T/B ratio was calculated to be 21.19, 5.22, and 4.83 for Aurangabad, Chandrapur, and Thane, respectively, which indicated that non-traffic sources were major contributors during 2019. The T/B ratio during the lockdown period varied between 3.19 and 4.33 in Chandrapur and Nashik stations, respectively, indicating traffic and transportation (under the essential activities) as sources of emissions. A higher T/B ratio for post lockdown indicated the influence of the resumption of industrial activities and factories.

The LCR values for pre-, during and post lockdown periods were the highest for Thane station, whereas the lowest values were recorded for Chandrapur station among males, females, and children. The LCR values for all monitoring stations for benzene for pre-, during, and post-lockdown periods exceeded the threshold level (1 × 10⁻⁶), and significant health threats to people except during the lockdown period.

Further, the study aims to increase the scientific rigor of research in this area. However, some of the limitations of the current manuscript required access to have a more comprehensive study in the coming future; it is necessary to expand the scope of the analysis with the measurements of more monitoring sites along with the meteorological parameters and also lack of individual VOC data for few monitoring stations. This study could persuade a closer look at reduction strategies to limit the health effects of VOC emission from various sources from the viewpoint of human health; the government should introduce more stringent legislation toward reducing source emissions in India.

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Data availability The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethical approval Not applicable.

Consent to participate All authors have agreed to authorship, read and approved the manuscript.

Consent for publication All the authors have given consent for publication.

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