Variation and correlation between ultraviolet index and tropospheric ozone during COVID-19 lockdown over megacities of India

Biswajit Bera1 · Sumana Bhattacharjee2 · Pravat Kumar Shit3 · Nairita Sengupta4 · Soumik Saha2

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Abstract
Worldwide spread out of COVID-19 in a short-time has brought a significant decline of road traffic, tourist flow and industrial ventures. During this emergency period, the restricted human dealings with nature have appeared as blessing for health of the total environment. The variation of atmospheric O3 may modulate the range of UV index (UVI) at any region of the earth. The objective of the study is to examine the variation of UV index over the megacities of India with respect to tropospheric O3 level modification during COVID-19 lockdown. The meteorological or environmental data (temperature in °C, gust in km/h, wind speed km/h, relative humidity in %, air pressure in mb and cloud cover in okta) of four selective megacities of India (Kolkata, Chennai, Delhi, Mumbai) during and pre lockdown period have been obtained to comprehend about the variation of UV index and tropospheric O3. The descriptive statistical applications i.e. standard deviation, standard errors and K-means clustering have been done through standard statistical software. In the present study, t-test has been used to understand level of significance of surface O3 and UVI during pre-lockdown (2019) and lockdown (2020) phase. The result shows that the four major megacities in India namely New Delhi, Mumbai, Kolkata and Chennai have experienced the vibrant diminution in terms of the concentration of UV index with slightly increasing the tropospheric O3 level during the lockdown phase. The higher accumulation of O3 during the lockdown in the lower atmosphere of four megacities does not exceed the permissible limit. The excess amount of O3 has remarkably contributed to trap the harmful UV radiation which has lowered the UVI in these worst polluted megacities of India. In the meantime, the prominent reduction of NOx during the lockdown period decreases the titration impact to O3 and this mechanism helps to revitalize the ozone concentration level. The uniqueness of the current study is highlighted the ground reality regarding reduction of UV index and amplification of tropospheric O3 concentration during lockdown phase. This study definitely assists to make new environmental policy, act and law for recover the health of the total environment.

Keywords COVID-19 · UV index · Concentration of O3 · Lockdown phase

1 Introduction
The brutal hit of novel coronavirus (COVID-19) modifies the systematic tempo of global social, political, economic, cultural arena as well as the global citizens are bounded to encounter the dreadful tremor of COVID-19. On 30th January 2020, the World Health Organization (WHO) announced COVID-19 disease as sixth Public Health Emergency of International Concern considering its devastating consequences all over the world (Wee et al. 2020; WHO 2020a). COVID-19 emerged from novel coronavirus SARS-CoV-2 and it has been designated as pandemic on 11th March 2020 by WHO (WHO 2020b). After detecting the first confirmed case in December 2019 at Wuhan city in China (Huang et al. 2020a, b; Zhou et al. 2020; Zhu et al. 2020), the fatal contagion is gushed speedily through physical contacts. In this regard, maintenance of social isolation is highly required to prevent the deadly impacts of this noxious infectious disease and worldwide almost all governments have imposed this social distancing norms to combat the disastrous outbreak of COVID-19 (Huang et al. 2020a, b; Zhang et al. 2020; Bera et al. 2021). India holds the leading position in the list of world’s worst affected countries with 46,188 deaths and 23,28,405 confirmed cases as of 11th August, 2020 (https://www.covid19india.orgcovid19india.org). In India, social distancing rules and
lockdown has been strictly imposed from 25th March 2020 and then it has been extended up to 31st May 2020 into four phases to fight with the menace of coronavirus during this acute crisis period.

During the lockdown period, the halting of transport movement, industrial activities and power generation ensure the cleanliness of atmosphere, refurbishment of ozone layer and purification of the total environment (Chakraborty and Maity 2020; Chakraborty et al. 2021a, b). Although, the health and economic sectors must fight against the noxious effects of COVID-19 while the pausing of anthropogenic activities restrains the magnitude of pollution (Dutheil et al. 2020). It must be remarkable that the global atmospheric quality as well as health of total environment has been restored at a certain limit because of restricted burnings of fuels, partly shut down of industrial production and transportation activities (Muhmmad et al. 2020). The usage of energy resources and consumption of materials is effectively dwindled due to the imposition of long-term lockdown (Jribi et al. 2020). It must be stated that the alteration of NO2 level is remarkably prominent over Asian countries during COVID-19 lockdown while in India NO2 is sharply reduced by 70% amidst this global emergency (Gautam 2020). The previous study has pointed out that the concentration of SO2, NO2, CO2, O3, PM10 and PM2.5 has been investigated over the 22 cities of India during the month of March and April, 2020 in comparison with the identical time frame during 2017 and this assessment depicts the cheering picture in terms of air quality up gradation during lockdown period (Sharma et al. 2020). In this context, it must be mentioned that ozone (O3) is a significant parameter for examining the air quality modifications. During COVID-19 lockdown phase, O3 accumulation is substantially amplified over Yangtze river delta area in China (Li et al. 2020) and Sao Paulo in Brazil (Nakada and Urban 2020) which is considered as a positive sign for ecological wellbeing. In Kolkata Metropolitan city (India), SO2, NO2, CO, PM2.5 and PM10 has been amazingly lowered during lockdown period while concentration of O3 is magnified to some extent compared with the pre-lockdown period (Bera et al. 2020). In the atmosphere, O3 has a crucial contribution in the aspect of physicochemical mechanisms over troposphere, nevertheless it plays a vital role to intensify the oxidizing capability of the lower atmosphere. The surface O3 may exert detrimental impacts for natural vegetation, agricultural yields along with animal community and mankind (Bates 1994; Finlayson-Pitts and Pitts 1997; Hogset et al. 1997; Wang et al. 2003; Garcia et al. 2005; Jerreett et al. 2009; Nishanth et al. 2014) and its presence exceeds the permissible limit (200 μg/m3 or 0.2 mg/m3 or 0.1 ppm) in the troposphere (Bera et al. 2020). The tropospheric O3 is categorised as secondary air pollutant and its origin is related with the composite photochemical procedures in the existence of volatile organic compounds (VOC), nitrogen oxides (NOx) and carbon monoxide (CO) which regulate the balance of surface O2 (Fishman and Crutzen 1977, 1978; Garcia et al. 2005). Several previous research reports highlighted that maximum accumulation of O3 had been recorded during the ending phase of autumn and entire winter season and this phenomenon is continued over the month of May in India (Varshney and Aggarwal 1992; Lal et al. 2000; Naja and Lal 2002; Nair et al. 2002; Jain et al. 2005; Beig et al. 2007; Ghude et al. 2008).

It must be stated that O3 is such an atmospheric constituent only which has the competency to captivate solar ultraviolet ray (UVR) within the range of 2000—3000 Å and this phenomenon expressively guards the biota of the earth from life-threatening exposure to the noxious UV ray (Brasseur and Solomon 1986). Ultraviolet radiation is divided into three categories i.e. UV-A (315–400 nm), UV-B (280–315 nm) and UV-C (200–280 nm). Atmospheric ozone has the potentiality to engross all types of UV-C rays and the captivation capacity of O3 has been augmented in terms of the reduction in wavelength of UV-B radiation (Fioletov et al. 2010). UV radiation is the principal and highly avoidable threat for skin cancer of innumerable people globally. This harmful radiation can weaken the human immunity system and it is severely injurious for eyes and skin (Meves et al. 2003). Ultraviolet or UV index (UVI) had been introduced to estimate the diurnal magnitude of UVR at a certain point of time and space in a consistent manner (Gies et al. 2018). The UV index had been propounded during 1992 in Canada and it had accepted by the Environmental Protection Agency (EPA) and United States National Weather Service (NWS) along with the World Health Organization (WHO) and World Meteorological Organization (WMO) during 1994. This concept was first documented during 1995 and later it had been revised during 2002 to modify its effectiveness as a means of rising peoples’ consciousness about the probable troubles regarding UVR (World Health Organization, World Meteorological Organization, United Nations Environment Programme International Commission on Non-Ionizing Radiation Protection 2002). Fundamentally, the Global Solar Ultraviolet Index (UVI) defines the intensity of ultraviolet ray upon the surface of the earth and the high range of UVI indicates the speedy and acute damaging impact on human health (World Health Organization, World Meteorological Organization, United Nations Environment Programme International Commission on Non-Ionizing Radiation Protection 2002). The UVI assists to analyse the ultraviolet related morbidities and contributes to develop a robust perception among human being about their vulnerability towards the risk of UVR (Gies et al. 2018). The magnitude of UVI is generally
persisted at higher range over the tropical regions compared with the poles. The highly populous megacities of India are not the exception in this aspect as they also register the greater range of Solar Ultraviolet Index. The fact is noteworthy that the variation in atmospheric O$_3$ level may modulate the range of UVI at any region of the earth surface. In this context, it must be stated that the four major megacities in India namely Delhi, Mumbai, Kolkata and Chennai have experienced the vibrant modifications in terms of the toxic air pollutants concentration including O$_3$ during the lockdown phase (Central Pollution Control Board (CPCB) 2020; Sharma et al. 2020; Lau et al. 2020; Bera et al. 2020). The significance of the study is brought the variation and correlation between tropospheric O$_3$ and UVI and how the meteorological or environmental factors played a significant role for slight reduction of the concentration of UV index. The current study shows that the consumption of O$_3$ is declined due to restrict of NO release and it recovers the accumulation status of O$_3$ in the troposphere. Such study will definitely assist to policy makers for sustainable management of the health of the total environment. Despite the positive sides of the scientific study, some limitations have been experienced like micro level data unavailability and lack of laboratory facilities during pandemic situation. The main objectives of the study are (1) to examine the variation of UV index (in New Delhi, Mumbai, Kolkata and Chennai) and (2) to comprehend the correlation between tropospheric O$_3$ and UVI index during COVID-19 lockdown compared with the preceding year along with role of meteorological or environmental factors.

2 Methods and material

2.1 Data sources and data acquisition

In the present study, the variation of UV index has been analysed in the presence of the altered surface ozone accumulation during lockdown phase. The four important megacities of India such as New Delhi, Mumbai, Kolkata and Chennai have been selected for this purpose and the time span from 25th March to 31st May of 2019 and 2020 has been determined to examine the changing pattern of UVI and surface O$_3$ concentration during and pre lockdown period. The monthly average surface ozone concentration throughout the time frame of the year 2020 and 2019 has been obtained from NASA Earth Observatory (NEO) hub (https://neo.sci.gsfc.nasa.gov/) for comparative analysis of tropospheric ozone accumulation over the selective four megacities during and pre lockdown session (Earth Observatory Hub and (NEO) 2020). The spatiotemporal data of UVI, tropospheric O$_3$ concentration along with UVI intensity data over the major megacities of India (New Delhi, Mumbai, Kolkata, and Chennai) during the sampling period have been extracted from Tropospheric Emission Monitoring Internet Service (http://www.temis.nl/index.php) (Tropospheric Emission Monitoring Internet Service (TEMIS) 2020). The diurnal climatological data (temperature in °C, gust in km/h, wind speed km/h, relative humidity in %, air pressure in mb and cloud cover in okta) of four selective megacities of India (Kolkata, Chennai, Delhi, Mumbai) during and pre lockdown period have been obtained from world weather online (https://www.worldweatheronline.com/).

2.2 Data analysis

2.2.1 Statistical analysis along with RS and GIS techniques

The diurnal and monthly average as well as the percentage of tropospheric O$_3$ and UVI has been determined individually for each selective megacity during and pre lockdown period to identify changing trend of the two variables during the sampling period in 2020 compared with the previous year. The relevant statistical applications are used to deduce the proper inter-relation and consistency level among the selected variables (Bera et al. 2019). In this study, Pearson correlation coefficient (R) and coefficient of determination (R$^2$) have been applied on the Grapher 13 software platform to determine the strength of the correlation and association among the two selective variables i.e. surface O$_3$ and UVI over four megacities during the sampling periods of the year 2019 and 2020. Moreover, the descriptive statistical applications i.e., standard deviation, standard errors have been estimated to identify the temporal variation of surface O$_3$ and UVI over New Delhi, Mumbai, Kolkata and Chennai (Table 1). Here, the hierarchical cluster analysis has been done on the basis of pre-lockdown and lockdown data that can discriminate the datasets on the basis of their characteristics. In the current study, t-test has been applied to comprehend level of significance of surface O$_3$ and UVI during pre-lockdown (2019) and lockdown (2020) phase (Table 4). Here, the authors mainly used the paired sample t-test because to compare mean of the same variables (UVI and O3) in different time period (pre lockdown year and lockdown year). The t-test has been performed here to measure if there is a substantial variation between the two variables. Here, the statistical significant is the mathematical method that can give results us the difference among variables which are statistically proved, more reliable and a exit a true relationship not by chance and it mainly reflects the confidence level. The important steps ("t-test") are given below.
\[ t = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{s^2 \left( \frac{1}{n_1} + \frac{1}{n_2} \right)}} \]  
(1)

\[ s^2 = \frac{\sum_{i=1}^{n_1} (x_i - \bar{x}_1)^2 + \sum_{j=1}^{n_2} (x_j - \bar{x}_2)^2}{n_1 + n_2 - 2} \]  
(2)

where \( \bar{x}_1 \) and \( \bar{x}_2 \) = sample average of different groups. \( s^2 \) = sample variance where as \( n_1 \) and \( n_2 \) = sample sizes of variables.

Moreover, K-means clustering technique has been used to find out the similarities among the four selective megacities in terms of ground-level O3 and UVI concentration during (2020) and pre lockdown (2019) period. K-means clustering is a simplest unsupervised machine learning algorithm which is applied in this study through statistical software. It also attempts to develop the intra cluster data points as similar as possible. The process of k-means clustering is called the Expectation Maximization. K-means clustering also calculates the values of iterates and centroids until the researches can find the value of optimal centroid. Here, the total no. of clusters is specified by the algorithm on the basis of number of data points. After that it will calculate the cluster centroids. Next, the sum of square distance has been calculated between the centroids and also the data points. After that the cluster has been assigned to the each data point on the basis of closeness of centroids. Subsequently, two parameters have been selected here such as the tropospheric ozone and UVI for two different years like pre lockdown (2019) and lockdown (2020). Here, two is the value of k and the result
of the k-means cluster analysis is very much significant because the p values of the cluster are highly significant with 0.004 (first cluster) and 0.009 (Second cluster) respectively. Criterion of iteration is an iterative approach that mainly helps and improved the quality of the classification of this unsupervised machine learning algorithm by removing, dividing and re-clustering methods. This process is also known as iterative k-means minus-plus. The main objective of the K-means clustering is to make a partition on the datasets into the defined number of clusters on the basis of clusters centroids. It can give us clear divisions of the data set. K-means clustering also applied here for the partitioning of the UVI and O3 data into different clusters. K-means clustering is following as-

Assignment step (It means to divide the observations according to Voronoi diagram)

\[
S_i^{(t)} = \left\{ x_p : \frac{1}{|S_i|} \sum_{x_j \in S_i} x_j \right\}
\]

Update step (Centroids for the observations)

\[
m_i^{t+1} = \frac{1}{|S_i^{(t)}|} \sum_{x_j \in S_i^{(t)}} x_j
\]

Alongside, the graphical representations have been accomplished based on the average value of O3 and UVI during the sampling time frame in 2019 and 2020 using Grapher 13 software. The correlation matrix (according to Pearson’s method) has also been applied to determine the interrelationship of ultra violet index and O3 with various climatological criteria. Furthermore, relevant digital thematic maps have been produced on the basis of the monthly average tropospheric ozone concentration data with the help of ArcGIS 10.3 software.

### 3 Results

#### 3.1 Variation of tropospheric O3 concentration during and pre-lockdown phase

The present study illustrates that the concentration of O3 is slightly amplified over the selected four megacities in India
during lockdown session (25th March to 31st May) 2020 compared with the pre lockdown year, 2019 (Fig. 1). Concurrently, reduction of the UV index has been registered over these particular regions amidst the same time period in the year 2020. During the lockdown phase, the highest average accumulation of tropospheric O$_3$ (302.54 du) has been recorded over New Delhi in the month of April, 2020 whereas in this megacity, the O$_3$ concentration level was 278.48 du during the identical month of pre lockdown scenario, 2019. It must be noticeable that the modification of surface O$_3$ level over New Delhi, Mumbai, Kolkata and Chennai has been varied within the range of 47.93—52.07% during the quarantine session in 2020 (Table 2; Fig. 2). In Mumbai, the O$_3$ concentration was recorded around 48.21% within 25th March to 31st March, 2019 during pre-lockdown scenario whereas it has been risen up to 51.79% in the same time frame of 2020 during lockdown period. The average monthly presence of surface O$_3$ is improved by 2.28% over Kolkata in April during lockdown phase in comparison with the same month of 2019. It must be noteworthy that the increasing rate of surface O$_3$ is substantially declined in May, 2020 in comparison with April, 2020 over New Delhi (1.58%), Mumbai (0.9%) and Kolkata (1.94%) while Chennai has exceptionally witnessed the decreasing trend of O$_3$ (0.18%) in the month of May, 2020 (275.8 du) compared with May, 2019 (274.83 du) during pre-lockdown stage (Table 2; Fig. 2).

### 3.2 Variations of UV index over four major megacities

On the other side, the present study portrays that the UV index has been diminished at a significant rate in terms of the magnification of O$_3$ in lower atmosphere over the four important megacities of India during lockdown period compared with pre-lockdown. The dropping of UVI during the quarantine session in 2020 has been distinctly depicted in different pockets of India (Fig. 3). During the lockdown scenario, the UV index is prominently altered within the range of 9.2 to 13.84 which vividly indicates about 1.3% to 5.72% lessening of UVI over New Delhi, Mumbai, Kolkata and Chennai in comparison with the previous year, 2019 (Table 3; Fig. 4). In New Delhi during the month of April 2020, the UV index is decreased around 9.99 from 11.2 in April, 2019 whereas UVI has been diminished by 4.84% in Mumbai during March (25th March to 31st March) of 2020 compared with the identical time period during pre-
lockdown phase in the year 2019. In another vital megacity of India i.e. Kolkata, the minimum value of UVI (11.13) has been registered in March, 2020 while the highest declining rate of UVI (3.12) has been identified in April, 2020 during the lockdown scenario. The notable fact is that during COVID-19 lockdown, the maximum reduction of UVI (13.18) has been estimated in Chennai in the month of April (2020) and the lowest index value of solar ultraviolet radiation (9.2) has been recorded in March over New Delhi (Table 3; Fig. 4). In this context, the negligible increase of UV index (0.24) in Chennai during May, 2020 compared with the same time period during pre-lockdown session is considered as an exceptional issue.

3.3 Assessment of surface O3 and UVI level using statistical techniques

The correlation coefficient analysis (R) and coefficient of determination (R²) have been done to comprehend the inter-relationship between tropospheric O3 and UV index over the four major megacities in India. In case of New Delhi, the correlation coefficient between surface O3 and UVI proved the strong negative relation during March 2019 which was R = −0.9730. Whereas the coefficient of determination on that time was R² = 0.9467, which indicates a strong association among O3 and UVI. In March 2020, the correlation coefficient was R = −0.8591 and coefficient of determination was R² = 0.7381. In April 2019, the correlation coefficient was R = −0.8696 and coefficient of determination was R² = 0.7563. Whereas in May the correlation coefficient was R = −0.9667 and −0.9862, similarly the coefficient of determination was R² = 0.9346 and 0.9727 for the year 2019 and 2020 respectively. Here, it showed strong negative relation and good association among O3 and UVI except April 2020 in New Delhi. It has experienced poor association (R² = 0.3596) and poor coefficient of correlation (R = −0.5996) respect to others (Fig. 5). In case of Kolkata, the almost similar scenario has been depicted through coefficient correlation (R) and coefficient of determination (R²) analysis. Here, the moderate negative correlation between the two variables has been exceptionally established in April during lockdown period (R = −0.6660) and coefficient of determination was (R² = 0.4436). While the statistical assessment represents the strong inverse relationship and high association between variables O3 and UVI in March and May during and pre-lockdown phase and the month of April, 2019 (Fig. 6).

Moreover, Mumbai has also witnessed the strong inverse correlation (R) and good association (coefficient of determination) between O3 concentration and UVI. In March correlation coefficient was R = −0.9444 and −0.9795 whereas coefficient of determination was R² = 8919 and R² = 0.9595 in the year 2019 and 2020 respectively. Similarly, in the month of May correlation coefficient was R = −0.9980 and −0.9902 whereas the coefficient of determination was R² = 0.9961 and 0.9806 in the year 2019 and 2020 respectively. During lockdown and pre-lockdown, the moderate inverse relation between the two above-said criteria has been determined for April in both years. The correlation coefficient was R = −0.7651 and −0.8047, simultaneously the coefficient of determination was R² = 0.5855 and 0.6477 respectively in the year 2019 and 2020 respectively. The study identifies that the coefficient of determination value (R²) is varied within the range of 0.8069 to 0.9912 and the correlation coefficient varies from −0.8927 to −0.9956 in Chennai during the sampling period amidst pre-lockdown and lockdown phase which demonstrates strongly negative
correlation and association between tropospheric O$_3$ accumulation and UV index over this important megacity in southern India (Fig. 8).

In the aspect of tropospheric O$_3$ concentration, the value of mean and SE is 274.14 and 0.634 individually during 2019 while the value of mean and SE is 284.20 and 0.722 respectively with t (271) = -11.932 and p < 0.05 during 2020 (Tables 1, 4). Therefore, it has been demonstrated that the concentration of tropospheric O$_3$ is magnified amidst the lockdown session that is statistically tested or significant. Beside this, in case of UVI during 2019 the value of mean and standard error mean (SE) is 12.5789 and 0.06506 respectively whereas in the year of 2020 the value of mean and SE is 11.9913 and 0.06960 correspondingly.
with $t(271) = 11.661$ and $p < 0.05$ (Tables 1, 4). The dendrogram also discriminates the year-wise data of different megacities. The dendrogram depicts us the major variation in the above-mentioned parameters and it mainly generates two major distinct groups like pre-lockdown (2019) and lockdown (2020) that can easily show the variability in the datasets (Fig. 9). It has been verified that the intensity of UVI is declined during the lockdown period which has been statistically tested or significant. Thus, statistical analysis established that the lockdown system has a notable impact upon the modification of tropospheric $O_3$ and UVI index. Similarly, the K-means clustering method has portrayed a prominent similarity in the context of ground-level $O_3$ accumulation and UVI range over the selective megacities during lockdown scenario in 2020. On the other side, during the pre-lockdown session in the year 2019 the concentration status of the two parameters over the four megacities illustrates the completely

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**Fig. 5** Correlation between tropospheric $O_3$ and UV index over New Delhi during the sampling periods in the year 2019 and 2020.
distinct scenario. The K-means cluster algorithms have grouped New Delhi, Mumbai, Kolkata and Chennai in two separate clusters individually for lockdown and pre-lockdown phase. The K-means clustering algorithm can be subdivided the dataset of different megacities of different years into distinct homogeneous groups. That can categorize the data into different parts (pre lockdown and lockdown) and can improve the data variability of different periods (Table 5).

The correlation matrix has been used to represent the correlation of the UVI and O₃ with the climatic variables (temperature, wind speed, gust, relative humidity, cloud and air pressure) over the selective megacities of India during and pre lockdown phase (Figs. 10, 11). During the lockdown period (2020), UVI has a positive correlation with the climatic factors i.e., wind speed, gust and relative humidity in most of the megacities whereas only New Delhi has a slightly negative correlation between UVI and relative humidity. Air pressure has a negative correlation
with UVI but there is an exception in case of Chennai during lockdown period (2020). During lock down period most of the megacities have a positive correlation between temperature and UVI but in case of Chennai, it showed a slightly negative correlation between UVI and temperature. Moreover, the distinct correlation between climatic variables and $O_3$ has been notified over the four megacities during lockdown period (2020). In the aspect of Chennai and Mumbai, a slightly positive correlation has been identified among $O_3$ and temperature, wind speed, gust and cloud; whereas a negative interrelationship among $O_3$ and temperature, wind speed and gust have been observed over Kolkata and New Delhi amidst the lockdown phase. During the pre-lockdown period (2019), a different trend of interrelation has been witnessed among the climatic factors and UVI and $O_3$. A positive correlation between climatic factors (except air pressure) and UVI over Kolkata has been noticed amidst pre-lockdown period. Alongside, there is no correlation between few climatic factors and $O_3$ while slightly negative correlation has been identified between other climatic factors and $O_3$ over Kolkata during the same time frame. Relative humidity and air pressure have

![Fig. 7 Correlation between tropospheric $O_3$ and UV index over Mumbai during the sampling period in the year 2019 and 2020](image_url)
Fig. 8 Correlation between tropospheric O₃ and UV index over Chennai during the sampling period in the year 2019 and 2020

Table 4 Paired sample test for tropospheric O₃ and UVI during the sampling period of 2019–2020

| Sampling period | Selective variables | Paired differences | t | df | Sig. (2-tailed) |
|----------------|---------------------|--------------------|---|----|----------------|
|                |                     | Mean              | Standard deviation | Standard error mean | 95% Confidence interval of the difference | Lower | Upper |
| 2019–2020      | O₃                  | –10.060           | 13.905              | 0.843             | –11.720 – 8.400 – 11.932 | 271   | 0.000 |
|                | UVI                 | 0.58757           | 0.83103             | 0.05039           | 0.48837 0.68677 11.661 | 271   | 0.000 |
established a negative relationship with UVI and a slightly positive relationship between O₃ and climatic factors have been observed over New Delhi. Over Mumbai no correlation along with slightly negative correlation has been seen between UVI and climatic factors whereas relative humidity and wind speed have a positive relation with O₃ during pre-lockdown period.

4 Discussions

The solar spectrum is characterized with 100 nm to 400 nm wavelengths and it is demarcated as ultraviolet radiation (Hu et al. 2007). The unprecedented exaggeration of UV radiation penetration in the earth surface is an issue of serious concern as the UV ray exerts dreadful effects on every sphere of natural environment. The range of UV index is accentuated with the increase of altitude while the diurnal maximum concentration of UV ray is recorded at noon due to the perpendicular angle of solar radiation. Seasonally, the highest intensity of UV ray is measured during spring and summer whereas the minimal presence of UV radiation is registered during winter. The wavelength of UV ray which invades to the surface of the earth is varied within 290 nm to 400 nm (Chadys̆iene et al. 2005). The entire UV-A radiation reaches to the earth’s surface as there is no incident of UV-A absorption by atmospheric ozone (Tan et al. 2018) while UV-C is wholly engrossed by ozone and oxygen in the upper and middle portion of the atmosphere (Chandra and Mcpeters 1994). Stratospheric ozone can absorb UV-B very effectively though about 10% radiation falls upon the earth’s surface (Madronich et al. 1998; Hu et al. 2007). In the current study, it must be noteworthy that in the lower part of the atmosphere with the higher intensity of ozone concentration can oscillate the range of UV index over the tropical region like India.

During the COVID-19 lockdown period, the strengthening of tropospheric ozone over New Delhi, Mumbai, Kolkata and Chennai has been instigated to drop the UV index compared with the preceding year, 2019. Commonly, the natural presence of surface O₃ is confined around 0.04 parts per million (ppm) which is not injurious for human
health (Bera et al. 2020). The fact is notable that higher accumulation of O$_3$ during the lockdown phase in the lower atmosphere of four megacities did not cross the permissible limit. The excess amount of O$_3$ absorbed the harmful UV radiation and as a result, the UVI has been reduced in these worst polluted megacities of India. During lockdown, the partial halting of industrial activities, vehicle movement, constructional works, burning of fuels markedly dwindle the concentration of lethal air pollutants like NO$_2$, NO, CO and VOC in the atmosphere of these tremendously polluted cities (Central Pollution Control Board (CPCB) 2020; Sharma et al. 2020). Different anthropogenic activities like burning of fossil fuel, heating activities in industrial furnace, diesel combustion expand the accumulation of air pollutants like nitrogen oxides (NO$_x$) over extremely polluted cities (Barck et al. 2005; Carslaw 2005; Carslaw and Beevers 2004a, b). Generally, the concentration of CO and NO$_2$ is significantly dropped in the major megacities of India due to the restricted industrial and transport activities during the quarantine phase compared with the pre-lockdown phase (Central Pollution Control Board (CPCB) 2020; Bera et al. 2020). In the atmosphere, around 90% of nitrogen is released as nitric oxide (NO) while <10% nitrogen is produced in the form of nitrogen dioxide (NO$_2$). The existence of surface O$_3$ is dependent on the share of production and annihilation of NO as O$_3$ has the competency to speedily react with nitric oxide (Vellingiri et al. 2015). The consumption of O$_3$ is reduced due to curtail of NO emission and it improves the accumulation status of O$_3$ in the troposphere (Andrade et al. 2017; Tobías et al. 2020). Meanwhile, the prominent reduction of NO$_x$ during the lockdown period brings the titration impact to O$_3$ and this mechanism helps to revitalize the ozone concentration level in the atmosphere (Li et al. 2020).
participating components of surface \( \text{O}_3 \) generation, i.e., VOC is also curtailed in the lower atmosphere over Indian cities due to the closure of its human-induced sources like yield of petroleum and natural gas (Gilman et al. 2013; Petron et al. 2012), transport activities (Russo et al. 2010), wood combustion (Kansal 2009), industrial production (Gilman et al. 2009) during lockdown session (Central Pollution Control Board (CPCB) 2020). As the above-mentioned pollutants (\( \text{NO}_x, \text{VOC}, \text{CO} \)) are regarded as the chief responsible ingredients in the formation process of surface \( \text{O}_3 \) and their lesser existence promotes to rejuvenate \( \text{O}_3 \) level in the lower atmosphere over the four selective megacities of India during the lockdown period in comparison with pre-lockdown state. In this context, the fact must be mentioned that the changing pattern of various meteorological elements like temperature, pressure, relative humidity, wind speed and direction can modify the creation and destruction process of surface \( \text{O}_3 \) (Dueñas et al. 2002; Elminir 2005; Satsangi et al. 2004). The meteorological factors like relative humidity, wind speed and wind direction have diverse effects on ozone concentration at the ground level of the atmosphere. Present study showed that ground level ozone concentrations expand the increase of temperature; though, it is not significantly connected to relative air humidity. Nevertheless, the wind direction has the great influence on the deviation of ozone concentrations.

As a result, sometimes ground-level \( \text{O}_3 \) may be slightly decreased instead of the steady decline of \( \text{NO}_x, \text{VOC}, \text{CO} \) in the lower atmosphere and this exceptional phenomenon has been recorded at Chennai in the month of May during lockdown. On the other side, the notable fact is that the UVI over the four major megacities in India is fluctuated between the range of 9 and 13 during the lockdown phase in 2020 and it showed very high to extreme risk of damage.
from uncovered solar exposure. But the intensity of UV radiation coming to the earth surface is markedly dropped as a consequence of ground-level O₃ amplification over the selective megacities amidst lockdown period in compared with pre-lockdown year. It is an important provisional incident for the health of the total environment.

5 Conclusion

In general, the concentration of UV ray is persisted comparatively higher over the tropical regions except the winter season. The matter is mostly remarkable that amidst the unusual and unpleasant situation during COVID-19 lockdown, the accumulation of various air pollutants such as NO₂, NO, CO, SO₂, PM₁₀, PM₂.₅ and O₃ have been considerably altered due to the temporary pausing of industrial function, transportation activities and several man-made actions and this air quality modifications assist to eradicate the fatal impurities in the atmospheric arena. The study demonstrates that satisfactory changes in air quality standard accentuate the surface ozone concentration within the desirable limit which influences to cut down the UV index to some extent in different corners of India during lockdown phase. Although the excessive amount of ground-level ozone is undoubtedly hazardous for living organisms including human-beings and it is labelled as “bad ozone”. But it plays crucial role to diminish UV index level and it is highly appreciable for nourishing environmental health if the O₃ concentration is confined within the permissible limit. In this context, it must be opined that the lockdown system is definitely accountable for the massive devastation in global economic and socio-cultural aspects; however the glimpse of total environmental restoration has been brightened specifically during this unfamiliar quarantine session. Worldwide the fact is highly admitted that the excessively populous as well as worst polluted cities and countries including Indian megacities momentarily reclaim their environmental transparencies and ecological stability during the lockdown period. Then, the environmentalists and scientists have opined to initiate the partial lockdown as the sacred blessings towards every spheres of environment. More scientific research and development are highly required regarding the variation and spatiotemporal concentration of UVI and tropospheric ozone for the protection of humans from hazardous UV radiation. So, it is fact that the effectiveness of short-term lockdown system should be recognized to ensure the long-term sustainable environmental management as well as ecological renovation for the extremely polluted megacities of India.

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Declarations

Conflict of 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.

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Authors and Affiliations

Biswajit Bera1 · Sumana Bhattacharjee2 · Pravat Kumar Shit3 · Nairita Sengupta4 · Soumik Saha2

1 Department of Geography, Sidho-Kanho-Birsha University, Sainik School, Ranchi Road, P.O., Purulia 723104, India
2 Department of Geography, University of Calcutta, 35, Ballygunge Circular Road, Ballygunge, Kolkata 700019, India
3 Department of Geography and Environment Management, Raja Narendralal Khan Women’s College, Gope Palace, P.O. Vidyasagar University, Paschim Medinipur 721102, India
4 Department of Geography, Diamond Harbour Women’s University, Sarisha 743368, India