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Variation and dispersal of PM$_{10}$ and PM$_{2.5}$ during COVID-19 lockdown over Kolkata metropolitan city, India investigated through HYSPLIT model

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1. Introduction

The outbreak of disastrous novel coronavirus (COVID-19) uncovered at the end of December 2019 and creates the massive disarray particularly in socio-cultural and economic pillars of the nations (Wang et al., 2020b). This unknown communicable disease was first recognized at Wuhan city (in China) on December 29, 2019 (Huang et al., 2020a). The lockdown system with social distancing norm has been imposed by Chinese Government and globally, there was no alternative technique to fight against deadly coronavirus pandemic (Huang et al., 2020b). Most of the people of the world have obligated to maintain their lives through these confined cubicles since the end of March 2020. Similarly, the lockdown system with social distancing has been imposed by the Government of India from March 24, 2020 and it is sustained up to May 31, 2020. Subsequently, the global economic growth and human health security are continuously facing the terrible effects of coronavirus whereas the global pollution level is slightly dropped due to restricted economic activities of humans (Dutheil et al., 2020). To a degree, the global air quality index along with different aspects of total environment is also improved for partially shutdown of economic sectors and limited usage of vehicles movement. WHO (2016) estimated that the enormous release of noxious pollutants smashed 4.2 million lives in early age worldwide (Cohen, 2020). As per the assessment of WHO (2016), almost seven million people have lost their lives every year due to acquaintance to particulate matter 2.5 which can cause chronic lung function disorder, cardiac arrest, lung cancer, respiratory problem, pneumonia, cardiovascular disease (Ng et al., 2019).
scientific studies have already established that the high rate of human death is due to the consequences of PM$_{2.5}$ and PM$_{10}$ in the lower atmosphere (Qi et al., 2020; Stafoggia and Bellander, 2020). Particulate matter 2.5 (PM$_{2.5}$) and 10 (PM$_{10}$) are the microscopic particulate matters with ≤ 2.5 μm and ≤ 10 μm diameter respectively. The anthropogenic PM$_{2.5}$ is composed with numerous elements like carbon-based compound, sulphate, nitrates and metal substances (Kumar et al., 2020). The fine particulate matter 2.5 is considered as fatal element for human health as they are capable to accumulate in respiratory tract and lungs. The excessive existence of metallic ingredients of PM$_{2.5}$ in human body is severely injurious for proteins, lipids and cellular DNA (Huang et al., 2018). The minute suspended particulate matters have the capacity to bring out the casualty load all over the world (Yang et al., 2020). Globally (in 2015), around 27.1% of chronic obstructive pulmonary disease (COPD) related death had been occurred due to the contact with particulate matter of PM$_{2.5}$ (Cohen et al., 2017). It had been estimated that whether the presence of pollutants would be increased by 10 μg m$^{-3}$ in the lower atmosphere, it would notably amplify the daily rate of symptomatic COVID-19 confirmed cases (Mehmood et al., 2020).

World Air Quality Report (2018) has notified that about 22 cities of India were enlisted within the 30 worst polluted urban areas of the world (IQAir AirVisual, 2018). The pollution and meteorological factors take a momentous role in the diffusion and lethality of respiratory disease and air quality index plays an influential role in high COVID-19 deaths (Wong et al., 2009; Gupta et al., 2020). A current study focused that the temperature and humidity largely influence on the several influenza cases and specifically higher relative humidity is responsible for more infections (Bherwani et al., 2020a; Park et al., 2020). The SARS-CoV-2, virus of COVID-19, exposes to diverse atmospheric conditions (such as humidity and air quality index). Another important study accentuated that the SARS-CoV-2 can stay alive for longer time on surfaces at distinctive room temperature with air-conditioning and mean relative humidity (Doremalen et al., 2020). Similarly, the higher relative humidity helps to survive the SARS-CoV-2 for longer on smooth surfaces (Azuma et al., 2020). Various environmental pollution and different environmental ambience crucially regulate the surface survivability of SARS-CoV-2. In this aspect, feral substances, aerosols and specifically, particulate matter are considered as the triggering environmental transmitting pathways of SARS-CoV-2 dispersion (Shao et al., 2021). The aerosol pollution has a positive correlation with the outbreak of COVID-19 disease as the dispersal of SARS-CoV-2 is directly linked with aerosol transmission (Cao et al., 2021). The rapid rate of infection and transmission of SARS-CoV-2 is due to long-lasting life on the surfaces. According to the announcement of the government of United Kingdom, the novel strain of SARS-CoV-2 has the potentiality to transfer more swiftly compared with the other variants (UK Government, 2020). Although, several previous studies have revealed that SARS-CoV-2 have 79% similarities with SARS-CoV-1; but the binding attraction with angiotensin-converting enzyme II (ACE2) is greater in case of SARS-CoV-2 in comparison with SARS-CoV-1 (Chen et al., 2020; Doremalen et al., 2020) and consequently, SARS-CoV-2 have the capability to attack the cells of human lungs more devastatingly (Cao et al., 2021; Shao et al., 2021). Moreover, the transmissibility of SARS-CoV-2 is higher compared with SARS-CoV-1 (Koma et al., 2020; Petersen et al., 2020). A recent study had been conducted in Italy, USA and China on the relationship between air quality index and COVID-19 outbreak and it is highlighted that the low air quality index with increasing trend of CO, SO$_2$ and particular matters is responsible for more deaths (Pansini and Fornacca, 2020). So, it is strongly stated that if the regions have poor air quality, it will be more vulnerable to COVID-19 outbreaks. A study about 72 cities of China reflects that the continuous increase of PM$_{10}$ and PM$_{2.5}$ in the lower atmosphere leads to greater frequency of COVID-19 infections (Wang et al., 2020a). Subsequently, it is stated that the higher pollution levels accelerate maximum number of COVID-19 infection and transmission in India (Bherwani et al., 2020b). The severe air pollution exclusively PM$_{10}$ and PM$_{2.5}$ are connected with the millions of deaths worldwide every year (causing acute respiratory diseases such as lungs inflammation and asthma) (Lelieveld et al., 2015, 2019). A study in the USA reported that the particles PM$_{2.5}$ is found to be notably linked to premature deaths and severe health issues (Fann and Risley, 2013). These studies indicate that the recovery of COVID-19 patients is very difficult due to long term exposure with PM$_{10}$ and PM$_{2.5}$ (Contini and Costabile, 2020).

The short-term improvement of quality of the total environment is due to the result of lockdown system (Gautam et al., 2020a, 2020b; Ambade et al., 2021). The magnitude of air pollution of different metropolitan cities of India (Cities like Mumbai, Kolkata, Bengaluru and Chennai) has been declined during lockdown period (CPCB, 2020; Gautam et al., 2020; Sharma et al., 2020). In West Bengal, 480,813 confirmed cases have been registered till November 29, 2020 and Kolkata (the capital of West Bengal) is considered as the epicentre of COVID-19 in the state of West Bengal. This severe pandemic infects total 105,997 people in Kolkata and 2596 casualties have been reported as of November 29, 2020 (Health and Family Welfare Department, Govt. of West Bengal, 2020). For long term basis the city of Kolkata bears severe air pollution records so the Kolkata is called dusty city (Kumar and Singh, 2003). The Kolkata also stands within 25 most polluted cities in the world and in 10 most badly polluted cities in India (WHO, 2011). It is significant that the number of pulmonary and allergic diseases would be amplified because of the speedy deterioration of air quality in this metropolitan city. Moreover, the great concern is that the day by day COVID-19 infected cases and number of death tolls are recurrently increased in the dusty city Kolkata. In this context, the main objective of this study is to examine the spatiotemporal variation with dispersal of PM$_{10}$ and PM$_{2.5}$ during and pre lockdown years along with rapid transmission of COVID-19 infection. The importance of the study is to estimate the source, causes of spatiotemporal variation and dispersal of PM$_{10}$ and PM$_{2.5}$ over the city. Consequently, the study focuses on role of meteorological factors along with rapid COVID-19 infection and deaths. Similarly, some limitations of the study have been experienced like data availability, limited meteorological stations and restricted laboratory facilities during lockdown period. The researchers and administrators get enough scope to carry out research as well as fight the noxious situation.

2. Methods and materials

2.1. Data sources and data acquisition

The spatiotemporal concentration data of PM$_{10}$ and PM$_{2.5}$ have been obtained from State Pollution Control Board under Govt. of West Bengal. The time span of January 2019 to May 31, 2020 has been considered to assess the spatiotemporal variations of PM$_{10}$ and PM$_{2.5}$. There are five automatic air pollution measurement stations like Fort William (22°33'05.17"N, 88°20'25.26"E), Victoria Memorial (22°32'47.81"N, 88°20'39.92"E), Rabindra Sarobar (22°30'44.33"N, 88°21'15.41"E), IACS Jadavpur (22°29'59.43"N, 88°22'05.81"E) and Rabindrabharati University (22°37'37.94"N, 88°22'43.88"E) which have been located indifferent parts of Kolkata city. Moreover, PM$_{10}$, PM$_{2.5}$ concentration, wind direction and velocity data have been extracted from https://earth.nullschool.net/ (Earth Nullschool, 2020). The daily meteorological data (max. temperature in °C, min. temperature in °C, wind speed in ...
km/h, gust in km/h, relative humidity in %, cloud cover in okta and air pressure in mbar) have been collected from the world weather website (https://www.worldweatheronline.com/). Chord diagrams have been designed to show the variations of PM$_{10}$ and PM$_{2.5}$ during and pre lockdown years over the metropolitan city of Kolkata.

2.2. Forward trajectory study through HYSPLIT model

Forward trajectory study is a very significant tool of atmospheric science that also gives a simulation model of direction and path of the air mass. Here, forward trajectory has been computed for some selected days through HYSPLIT (Hybrid Single Particle Lagrangian Integrated Trajectory) model, recommended by US National Oceanic and Atmospheric Administration Air Resource Laboratory (NOAA ARL). Global data analysis system (GDAS) has been used here to achieve the data set. A single trajectory cannot explain the growth of particle mass due to deviation of the height of wind. The different analytical steps of forward trajectory model are given below.

Position computed from average velocity at the initial position ($P$).

\[ P(t+dt) = P(t) + 0.5 [V(P(t)) + V(P(t+dt))] dt \]

The integration time step variable:

\[ V_{\text{max}} dt < 0.75 \]

Meteorological data interpolation in a sigma coordinate system:

\[ s = (\text{Z}_\text{ep} - \text{Z}_\text{ms})/(\text{Z}_\text{ep} - \text{Z}_\text{gd}) \]

Here, particle concentration has been analysed and volume is defined as the following formulas:

3D particle: \( dC = q (dx dy dz) \)

Hybrid Top - Hat: \( dC = q (\pi r^2 dz) \)

Puff Top Hat: \( dC = q (\pi r^2 dvp) \)

Puff Gaussian: \( dC = q (2 \pi s^2 dvp) \exp (-x^2/2 s^2) \)

Similarly, Parxplot has been used to establish the central position of particles and it also helps us to determine the vertical height of the particles. The vertical heights of these particles have been computed applying the given formulas.

\[ X(t + dt) = X_{\text{mean}}(t + dt) + U'(t + dt) dt \]

\[ U'(t + dt) = R(dt)U(t) + U'(1 - R(dt)^2)^{0.5} \]

\[ R(dt) = \exp(-dt/T_{\text{ax}}) \]

\[ U' = (s_0) \text{ (Gaussian Random Number)} \]

2.3. Statistical analysis

The stations-wise daily and monthly arithmetic mean along with percentage of PM$_{10}$ and PM$_{2.5}$ has been computed for the year 2019 and 2020. The descriptive statistical techniques like standard deviation, standard errors have been done to find out the temporal deviation of these parameters over the city of Kolkata (Table 1). The statistical analysis has been done through IBM SPSS (v25) statistical software. In this study, 't' test has been used to resolve the significance level of change of PM$_{10}$ and PM$_{2.5}$ during 2019 and 2020 (Table 2). The analytic steps of 't' test are given below.

\[ t = \frac{X_1 - X_2}{\sqrt{s_1^2(1 + \frac{1}{n}) + s_2^2}} \]

\[ s_1^2 = \frac{\sum_{i=1}^{n_1} (X_i - X_1)^2 + \sum_{i=2}^{n_2} (X_i - X_2)^2}{n_1 + n_2 - 2} \]

where $X_1$ and $X_2$ are sample average of different groups, $s^2$ = sample variance, where as $n_1$ and $n_2$ = sample sizes of variables.

The multivariate statistical technique like Principal Component Analysis (PCA) has been used by IBM SPSS (v25) statistical software to examine interrelationship among seven different meteorological parameters for pre and during lockdown of Kolkata city (Supplementary Data, Table S5). The Principal Component Analysis is performed through some mathematical algorithms. The following steps have been considered to analyse the relationship among the variables. These are as follows:

\[ x_{\text{new}} = \frac{x - \mu}{\sigma} \quad \text{(For standardization)} \]

For population \( \text{Cov}(x, y) = \frac{\sum(x_i - x)(y_i - y)}{N} \)

(For Covariance matrices)

For sample \( \text{Cov}(x, y) = \frac{\sum(x_i - \bar{x})(y_i - \bar{y})}{N - 1} \)

Subsequently, correlation matrix (applying Pearson’s method) has also been used to show the relationship of PM$_{10}$ and PM$_{2.5}$ with other meteorological parameters (Supplementary Data, Tables S6 and S7). The coefficient of variation (CV) is used to examine the relative difference or degree of dispersion of PM$_{10}$ and PM$_{2.5}$ among the stations within the city during and pre lockdown years (Tables 3 and 4). Higher value represents the greater level of fluctuations of PM$_{10}$ and PM$_{2.5}$ among the stations or months within the city. For each station and month-wise CV has been calculated using the following equation.

\[ CV = \frac{1}{\bar{x}} \sqrt{\frac{1}{n} \sum_{i=1}^{n} (x_i - \bar{x})^2} \]

where $x_i$ is the PM$_{10}$ and PM$_{2.5}$ concentration of the $i$th sites; $\bar{x}$ means the mean PM$_{10}$ and PM$_{2.5}$ concentration of all the sites and months, and $n$ represents the number of sites or days/months.

3. Results

3.1. Spatiotemporal variation of PM$_{10}$ and PM$_{2.5}$ concentration among the sample sites within the city (from January 2019 to May 2020)

The seasonal variation of PM$_{10}$ and PM$_{2.5}$ among five sample sites within the city shows similar trends and the highest figure was recorded in winter and lowest value was registered in summer (Fig. 3). In case of PM$_{10}$ the highest monthly average was 276.43 $\mu g/m^3$ in January 2019 while the lowest monthly average was 36.52 $\mu g/m^3$ in the month August 2019 (Supplementary Data, Table S1). The several studies show that the concentration of PM$_{10}$ and PM$_{2.5}$ is higher in the winter season and followed by spring, autumn and summer (Chen et al., 2019; Bera et al., 2021). The Kolkata metropolitan city is no exception. The lockdown and previous year study showed that there is a downward trend of particulate matters from January to June but the concentration of PM$_{10}$ and PM$_{2.5}$ in three winter months (November, December and Jan-
were significantly higher with respect to other months. In the case of PM$_{2.5}$, monthly average concentration, the significant decrease is recorded in the month of May 2020 at Rabindrabharati site (14.24 μg/m$^3$) followed by IACS, Jadavpur (14.94 μg/m$^3$), Victoria Memorial (15.16 μg/m$^3$), and Rabindra Sarobar site (15.88 μg/m$^3$) respectively (Supplementary Data, Tables S1 and S2). The concentration of particulate matters but the fluctuation level is very high in case of PM$_{10}$ whereas IACS, Jadavpur has maintained the more consistency throughout the year in comparison to other stations for PM$_{2.5}$ whereas IACS, Jadavpur site has very low consistency level. The concentration of PM$_{10}$ and PM$_{2.5}$ is very high throughout the year at the Rabindrabharati site but simultaneously the fluctuations rates are very low whereas at IACS, Jadavpur shows low concentration of particulate matters but the fluctuation level is very high in case of PM$_{10}$. The CV has been calculated based on monthly mean of PM$_{10}$ and PM$_{2.5}$ and the lowest CV (6.01) appeared in April 2020 (for PM$_{10}$) and in January 2019 (for PM$_{2.5}$) both the months are showing more consistency with less fluctuation with respect to other months. In case of PM$_{2.5}$, monthly average concentration, the significant decrease is recorded in the month of May 2020 at Rabindrabharati site (14.24 μg/m$^3$) followed by IACS, Jadavpur (14.94 μg/m$^3$), Victoria Memorial (15.16 μg/m$^3$), and Rabindra Sarobar site (15.88 μg/m$^3$) respectively (Supplementary Data, Table S2). The concentration of particulate matters is gradually declined from the month April to September and it shows below 50 μg/m$^3$ (monthly average) for all the sites in Kolkata metropolitan city while in the lockdown months in 2020, the significant reduction has been recorded (Fig. 3). The month-wise hourly mean of PM$_{10}$ and PM$_{2.5}$ brings a bimodal distribution in winter, spring and autumn in the year 2019. Basically, the winter PM$_{2.5}$ shows two peaks during morning (8:00 to 10:00 IST) and evening (18:00 to 20:00 IST) respectively (Supplementary Data, Fig. S1 and Table S3). The minimal figure has been registered at 16:00 to 18:00 IST throughout the year. Similarly, during summer the value is lowest but there is no uniform trend while daytime the concentration of particulate matters is comparatively lowest (Supplementary Data, Fig. S1 and Table S3). The spatial variation of PM$_{10}$ and PM$_{2.5}$ has also been recorded among five stations within the city and it reveals that the sites IACS, Jadavpur and Rabindra Sarobar have witnessed comparatively low with respect to other three stations because of city peripheral locations and comparatively high ecological resources (Supplementary Data, Tables S1 and S2). In general, the concentration of PM$_{10}$ and PM$_{2.5}$ is higher in the city centre and north-east and north western part and it has been recorded at the stations like Rabindrabharati, Victoria Memorial and Fort William because of high density built-up area with anthropogenic activities, location of industries and high traffic density (Supplementary Data, Tables S1 and S2).

The stations wise monthly CV (for twelve months in 2019 and January to May in 2020) of PM$_{10}$ and PM$_{2.5}$ has been calculated and the lowest CV value (65.43) of PM$_{10}$ reflects at Rabindrabharati site while the highest CV value (78.47) shows at IACS, Jadavpur (Table 3). Similarly, the lowest CV value (60.23) of PM$_{2.5}$ reveals at IACS, Jadavpur whereas the highest CV value (71.47) stands at Victoria Memorial (Table 3). It is clearly stated that the Rabindrabharati site has maintained the more consistency throughout the year in comparison to other stations for PM$_{2.5}$ whereas IACS, Jadavpur site has very low consistency level. Subsequently, IACS, Jadavpur site has maintained very good consistency for PM$_{2.5}$ while Victoria Memorial has very low consistency level. The concentration of PM$_{10}$ and PM$_{2.5}$ is very high throughout the year at the Rabindrabharati site but simultaneously the fluctuations rates are very low whereas at IACS, Jadavpur shows low concentration of particulate matters but the fluctuation level is very high in case of PM$_{10}$. The CV has been calculated based on monthly mean of PM$_{10}$ and PM$_{2.5}$ and the lowest CV (6.01) appeared in April 2020 for PM$_{10}$ (Table 4). Similarly, the lowest CV value (13.29) stands in January 2019 for PM$_{2.5}$. So, it is stated that the April 2020 (for PM$_{10}$) and in January 2019 (for PM$_{2.5}$) both the months are showing more consistency with less fluctuation with respect to other months (Table 4). The meteorological or environmental and anthropogenic factors are controlling the spatiotemporal variation as well as dispersal of particulate matters in different stations within the city.
If the presence of particulate matters is greater than 100 \( \mu g/m^3 \) in atmosphere, it is highly detrimental for human health (WHO, 2006). It is evident that the concentration of PM10 and PM2.5 has been significantly reduced during lockdown period of 2020 in comparison with pre-lockdown phase (in 2019) over Indian sub-continent (Figs. 1 and 2). The study reflects that monthly average accumulation range of PM10 is varied from 33.23% to 46.57% during the lockdown period in 2020 (Supplementary Data, Tables S1 and S2). After initiation of lockdown (25th March 2020) PM10 level is declined to 6.86% in comparison with the past year and the amount of dropping propensity is gradually prominent throughout the lockdown period. In the same way, PM2.5 is diminished up to 42.06% in May 2020 in comparison with the same month of the previous year. The current study shows nearly 14% to 42% dropping of PM2.5 emission in comparison with the year of 2019 (Supplementary Data, Tables S1 and S2).

3.2. Analysis of meteorological data through statistical techniques in terms of the relationship with PM10 and PM2.5 concentration

In case of PM10 in 2019, the values of mean & standard error (SE) are 67.1204 and 2.89303 respectively whereas in the year 2020 the mean and SE are 42.5227 and 1.83640 respectively while \( t \) (68) value is = 7.687 and \( p < 0.05 \) (Tables 1 and 2). So, it is established that the concentration of PM10 is less in lockdown phase that is statistically significant or tested. In the case of PM2.5 in 2019, the value of mean & SE are 37.9243 and 1.57389 respectively whereas in the year 2020 the value of mean and SE are 21.7054 and 1.19123 correspondingly with \( t \) (68) = 8.453 and \( p < 0.05 \) (Tables 1 and 2). So, it has been established that the concentration of PM2.5 is less in lockdown period which is also statistically significant. So, it is statistically verified and established that the lockdown phase plays a significant role to reduce the concentration of PM10 and PM2.5.

The principal component analysis has been performed here on meteorological data during pre (2019) and lockdown phase (2020) in Kolkata metropolitan city. In 2019 total three principal components (PC) have been extracted based on its Eigen value (greater than one) with total 86.930% cumulative explained variance (Supplementary Data, Tables S4 and S5). These important parameters such as wind speed, gust, relative humidity, cloud cover, maximum temperature and minimum temperature have been highly loaded in case of PC1, PC2 and PC3 respectively. In 2020, total two principal components (PC) have been extracted based on the similar Eigen value (greater than one) with around 78.671% total cumulative explained variance (Supplementary Data, Table S5). In 2020, the meteorological parameters like wind speed; gust, cloud cover, relative humidity, maximum temperature and minimum temperature have been positively loaded for PC1 and PC2. In 2019, the maximum temperature and minimum temperature are distantly correlated (insignificant correlation) with other meteorological factors while in case of 2020; the maximum temperature, minimum temperature and air pressure are distantly correlated with other important climatic factors (Fig. 4).

The correlation matrix has been applied (during and pre lockdown periods) to determine the relationship between climatic factors and suspended particulate matters (PM10 & PM2.5). In 2019, maximum temperature and minimum temperature have a positive correlation with the suspended particulate matters; whereas other climatic variables such as wind speed, gust, relative humidity, air pressure and cloud cover have a negative correlation with suspended particulate matters (Fig. 5a and b; Supplementary Data, Table S6). In 2020 (during lockdown phase) maximum tempera-
ture, minimum temperature and air pressure have a positive correlation with suspended particulate matters, whereas other climatic factors such as wind speed, gust, relative humidity and cloud cover have a negative correlation with the suspended particulate matters (Fig. 5c and d; Supplementary Data, Table S7).

3.3. Particle dispersal direction path through HYSPLIT model

Trajectory represents the path of small particles of air through which the particles move in a temporal manner. The past path defines source region of particles which is termed as back trajec-

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**Fig. 2.** Spatiotemporal concentration of PM$_{2.5}$ over Indian sub-continent during lockdown, 2020 and pre-lockdown, 2019.

**Fig. 3.** The changing pattern of PM$_{10}$ and PM$_{2.5}$ through the sampling period (January 2019 to May 31, 2020) during (2020) and pre lockdown (2019) period.
tory and the future path denotes destination areas of particles which is described as forward trajectory. The wind direction and velocity over Indian sub-continent during lockdown (2020) and pre-lockdown (2019) phase has been illustrated in Fig. 6. It has been clearly observed that the forward direction of the trajectories (Fig. 7) follows the north and slightly north east direction except the month of March in lockdown phase. The parxplot has been designed to display the vertical extension of particles through the cross section on the central position of the particles. It is also observed that both years (during and pre lockdown phase), the maximum height of the particles is lengthened up to 1000 m particularly in summer season (Fig. 8).

4. Discussions

The seasonal and diurnal variation of PM$_{2.5}$ and PM$_{10}$ in different sites of Kolkata metropolitan city was influenced by both meteorological and anthropogenic factors. The morning peak of PM$_{10}$ and specially PM$_{2.5}$ is related with the fumigation result in the boundary layer which carries aerosols from the night residual layer quickly after the sunrise (Stull, 1988). The very low average concentration of both PM$_{10}$ and PM$_{2.5}$ during and pre lockdown years is found during the afternoon in winter (16:00–17:00 IST) mainly due to dynamic atmospheric ventilation along with larger boundary layer (Zhang and Cao, 2015). Intense solar heating during the late afternoon intensifies the dispersion of aerosols and the concentration of particulate matters has been diluted due to deeper boundary layer and high turbulent effects. During winter, the concentration of PM$_{10}$ and PM$_{2.5}$ has been slowly augmented and reached a peak in the evening due to surface inversion of temperature after sunset. Thus, the pollutants are subsequently trapped in the lower layer of the atmosphere due to high atmospheric air pressure. The meteorological factors can play significant role to modify the air quality standard of any places on the Earth (Supplementary Data, Table S4). The variation of temperature, moisture, wind speed, clouds fraction and radiation has an effect to bring the boundary layer stability. For example, if the wind speed is higher than the normal, the PM$_{10}$ and PM$_{2.5}$ will be washed out over the city (Supplementary Data). In case of Kolkata metropolis, during lockdown summer the tropical cyclones frequently transport the particulate matters from the city.

The various factors such as morphology of the city (Yuan et al., 2017), landform (Romero et al., 1999; Zheng et al., 2017), traffic scenario (Boarnet et al., 2011; Edussuriya et al., 2011), anthropogenic activities like construction (Lenschow et al., 2001) are responsible for the variations of particulate matters from site to site. From macro perspective, it is stated that the urban land-use plays a vital role for air quality modifications. The previous study showed that the larger industrial zone, fast extension of the city built-up area and loss of ecological lands accelerate the emission of PM$_{10}$ and PM$_{2.5}$ throughout the year in this dusty city Kolkata (Bera et al., 2021). From the micro perspective, the variations of PM$_{10}$ and PM$_{2.5}$ in different location of the city are also caused by the vehicular sources and supply to PM$_{2.5}$ pollution. Meanwhile, the different meteorological or broadly environmental factors are significantly regulating the spatiotemporal variation of PM$_{10}$ and PM$_{2.5}$ in the city of Kolkata. The lower spatial variation of particulate matters during summer, 2020 (in March, April and May 2020) is due to strict imposition of lockdown in the city. But the greater spatial variation in summer enhances the atmospheric convection in the vertical direction and it leads the dispersal of particulate matters due to higher temperature. The high temperature also facilitates the photosynthesis and adsorption of particulate matters by plants (Nowak et al., 2006; Dawson et al., 2007; Liu et al., 2014). Similarly, the lockdown system, high temperature in summer and leaf on period create most significant effects on plants for the reduction of PM$_{10}$ and PM$_{2.5}$ and these factors largely regulate greater seasonal and diurnal variation of particulate matters (Chen et al., 2019). For such factors, Rabindra Sarobar and IACS, Jadavpur sites have experienced comparatively low PM$_{10}$ and PM$_{2.5}$ with respect...
to other sites. The study reflects that the diffusion of particulate matters is not restricted within urban boundary and it is largely controlled by meteorological or environmental factors (wind speed, wind direction, temperature, relative humidity etc.). Applying HYSPLIT model, it is clearly stated that the particles dispersion is found dominantly towards north and north-east from south and south west due to strong meteorological factors like high temperature and strong wind with speed (active atmospheric ventilation) and both the years (during and pre lockdown), particles are restricted within 1000 m height (Fig. 7). Meanwhile, a study already established that during winter in Kolkata metropolitan city, the particles height is restricted within the 100 m because of surface inversion of temperature and calm wind with low speed (Bera et al., 2021).

In the last decade, the annual death tolls are rapidly increasing in different corners of the world due to deterioration of air quality standard. The worldwide human’s death is directly associated with respiratory disorders (26%), continual obstructive pulmonary disease (25%), ischemic heart and stroke (17%) due to the poor air quality standard (WHO, 2020). The World Health Organization (WHO, 2016) has clearly notified that around 8% human deaths are caused due to severe air pollution mostly the inhabitants of Africa, Asia and a smaller part of European continents. A recent study is focussed that the quantity of allergic illness and respiratory diseases has been amplified due to unrestrained modern economic actions of humans (Haque and Singh, 2017). It is estimated that worldwide around 1.1 billion population have been bound to inhale venomous air (UNEP, 2002). The concentration of PM_{2.5} is higher at the lower atmosphere of China during winter as a result of constructional works, industrial activities, and road dust and mainly due to residential burning (Guo et al., 2020). The anthropogenic sources such as industrial sector, coal and petroleum burning are considered as the key sources of PM_{2.5} (Yang et al., 2019).

An important study stated that around 70% people are severely suffering from pulmonary infections because of concentration of high toxic elements in the lower atmosphere of Kolkata (Mukhopadhyay, 2009). Those people who are suffering in cardiovascular diseases, pulmonary disorders and lung cancer, they are extremely vulnerable to the threat of severe COVID-19. The infection rate of coronavirus is relatively greater in those regions where...
Fig. 6. Wind direction and velocity during and pre lockdown phase (2019–2020) over Indian sub-continent.

Fig. 7. Forward trajectory showing particle dispersal direction path through HYSPLIT model for the year 2019 and 2020.
the lower layer of the atmosphere is extremely concentrated with PM2.5 (Mehmood et al., 2020). In Kolkata, the one of the vital reasons of the high growth rate of infection and deaths due to COVID-19 is co-morbidity (around 84% deaths are directly connected with co-morbidity) (Health and Family Welfare Department, Govt. of West Bengal, 2020). The CPCB of India (2012) previously reported that the Eastern economic growth pole (Kolkata) of India is notified as worse polluted city like Delhi in terms of air pollution (Das et al., 2015). The heavy burden of particulate matters (PM10 and PM2.5) is not only degenerated the quality of atmosphere in this city, it also amplifies the morbidity level of the people over the years. In the last two decades, the increasing trend of morbidity as well as mortality due to cardiovascular disease, chronic obstructive pulmonary disease, infections, asthma, bronchitis are regarded as the fatal consequences of tremendous air pollution in Kolkata metropolitan city. This metropolitan city becomes an infection hub of coronavirus (COVID-19) as numerous residents are the victims of respiratory, cardiac and pulmonary diseases because of severe air quality deterioration and people are easily infected by the COVID-19 transmittable disease.

5. Conclusions

From the scientific study it is concluded that both the meteorological and anthropogenic factors regulate the seasonal and diurnal variation of PM10 and PM2.5 in the dusty city Kolkata. The very low mean concentration of PM10 and PM2.5 during and pre lockdown years is registered during the afternoon (16:00–17:00 IST) primarily due to active atmospheric ventilation along with larger boundary layer. Extreme solar heating during the late afternoon amplifies the dispersion of aerosols. During winter, the concentration of PM10 and PM2.5 has been slowly augmented and reached a peak in the evening due to surface inversion of temperature after the sunset. During summer (both pre and lockdown years), the height is expanded up to 1000 m because of active atmospheric ventilation (for high temperature, strong wind, high speed, moderate to high humidity and low air pressure) whereas during winter it is confined within 100 m. The HYSPLIT model clearly indicates that the particles have been dispersed from south, south-west to north and north east direction due to strong wind. A previous study proved that around 70% people are severely suffering from pulmonary infections because of concentration of high toxic rudiments in the lower atmosphere of Kolkata (Mukhopadhyay, 2009). The infection rate of COVID-19 is relatively higher in those regions where the atmosphere is previously oversaturated with PM2.5. In Kolkata, the one of the crucial reasons of high infection and deaths (COVID-19) is co-morbidity of people.

The short-term impact of COVID-19 lockdown gives an important memorandum to all the world leaders, administrators and policymakers to recover the damaged environmental quality along with global human health. The high rate of COVID-19 infection and huge number of deaths is directly connected with severe air pollution in most of the cities of India and at this point Kolkata is no exception. The sustainable environmental management plan is highly required to tackle such harmful air pollution in the city of Kolkata. The extension of greeneries is extremely essential to get back the freshness of air of this extremely polluted city. Several plant species including Ficus Bengalensis, Ficus Religiosa, Mangifera Indica, Azadirachta Indica, Cascabela Thevetia, Neolamarckia Cadamba, Eucalyptus Globus etc. can be recommended to place along the roadways and vacant areas of Kolkata as these species have the high tolerance capacity in terms of air pollution (Lohe et al., 2015; Acharya et al., 2017). The short-term lockdown system is the best remedy for all industrial nations to manage high pollution signature of the total environment. Although, the partial lockdown
is not permanent solution to recover the health of the total environment, so more research and development is required in this specific research gap. Here, applied research is highly essential to combat the terrific situation and scientists should take proper responsibility to minimize the pollution standard for sustainable urban environmental management. It is evident that the fresh and clean atmospheric ambiance is required to alleviate the deadly threat of present COVID-19 pandemic. Thus, despite the brutality of the current unfamiliar scenario, the temporary lockdown system should be treated as the environmental blessings.

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.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.geofr.2021.101291.

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