Ambient Air Quality Monitoring and Modelling In Kanpur City during the Covid-19 Pandemic

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Abstract— **The outbreak of the COVID-19 pandemic in India in mid-March has had a lot of human activity, which has recorded drastic upsurge in the environment around the world, but with the gradual onset of countries the significant impact on the environment will not last long. The bar of economic activity prior to lockdown of COVID-19 and to participate in austerity measures. In this study, the change in air quality during lockdown and unlock in Kanpur Nagar in Uttar Pradesh, is analyzed along with the pre lockdown and post lockdown duration. Air pollution was analyzed in February-July 2020.Air quality is being monitored and modeled using STREET AND CALINE-4, Changes in local temperature and precipitation as well as geological changes in pollution also analyzed. A noticeable downfall in the overall concentration of NO_2, CO and PM_{10}, $PM_{2.5}$, Nitrogen dioxide (NO_2) and Sulphur dioxide SO_2, because there were so many restrictions like there were no construction and demolishing activities as well as restrictions on vehicle movement. The average temp. Decrement was also analyzed. Research shows that as the rainfall started in mid-June there was a sudden decrement in the air pollution load and the NO_2 came below the detection limit in 2 out of three places we have chosen for the study.**

Keywords: Air pollution, Pandemic, Human health, Covid-19, Lockdown, Kanpur

I. INTRODUCTION

Air Quality can be described as the quality of air in our surroundings. With air being one of essentials of life, quality of air affects our breathing and ultimately our existence. Good air quality directly indicates the degree to which the air is clean i.e. pollution free or less polluted. Degradation of air quality damages most resources which combine to form the environment. The air pollution is a result of large number of elements, predominantly by anthropogenic activities and some natural sources. Industrialization and globalization have helped in developing the economy of the countries. However, increasing population along with urbanization has led to an abrupt and unsystematic industrialization and vehicular sources. These factors have become the primary element of concern for developed as well as developing countries. In past, only domestic and industrial activities resulted in release of air pollutants especially SO_2 and TSP. High levels of smoke and SO_2 are outcomes of combustion of Sulphur containing fossil fuels like coal. Moreover, rapid increase in population created the demand for meeting the transportation needs. The consequence was substantial increase in number of motor vehicles, which eventually led to degradation of air quality. Thus, air quality degradation in present state has been consequence of automobiles and industrial activities. Air pollution has been repercussion of the anthropogenic activities like vehicles, industrial gaseous effluents, burning of fossil fuels, firecrackers and wood, construction activities etc. However, studies have shown influence of natural sources like volcanic eruptions, wildfires, and dust emissions from windstorms and bio aerosols such as pollen grains and spores. The majorly concerned pollutants which are produced by these anthropogenic and natural sources are oxides of Sulphur and Nitrogen, particulates, Carbon monoxide, Ozone, heavy metals and other hazardous pollutants.

Prevailing meteorological conditions like wind speed; wind direction, ambient temperature, relative humidity etc. play an important part in improving or weakening the quality of air by affecting transportation and distribution of air pollutants. Winds carry pollutants from their source causing them to disperse and thus, decreasing their concentration. However, stable conditions result in accumulation of pollutants near the source causing localized air pollution. One such episode of latter situation was Great Smog of London of 1952 where, little wind conditions and moist air formed fog. This fog in turn got mixed with the pollutants released from combustion

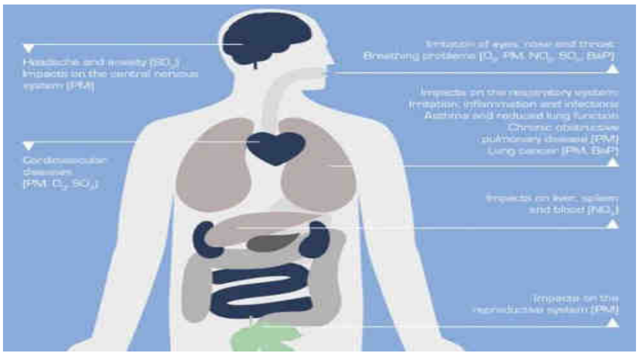

Figure 1.1: Impacts of Different Pollutants on Different Body parts

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II. AIR POLLUTION IN INDIA : CURRENT SCENARIO

Ambient air quality in urban areas of India has deteriorated particularly attributed to rapid urbanization and industrialization as well as rampant increase of vehicles. Several other anthropogenic activities like garbage burning, dearth of public awareness, wood and coal burning for domestic purposes and natural causes such as dust storms have also contributed in deteriorating the air quality Air pollution largely responsible for increased mortality and morbidity in India is yet become an electoral issue. The concerned regulatory bodies in central and state governments have intervened to reduced air pollution, however lack of rational policies and disorganized expansion of several sectors instrumental for economic growth of country like construction, industry etc. has proved to be barriers in the efforts. The absence of stringent air pollution regulations and policies and lack of adequate transportation system for public contribute further to the problem of local air pollution. According to WHO data, there are fourteen cities from India placed among the world's 20 most polluted cities, worst being Uttar Pradesh's one of the largest cities, Kanpur having highest $PM_{2.5}$ levels in the world. Fine particulate matter ($PM_{2.5}$) is one of the critical pollutants produced by intensive fuel burning, which can enter our body while inhaling and get trapped in the lungs, damaging the lungs and other body parts as well.

On average, exposure to $PM_{2.5}$ concentrations of citizens in India is between 15 and 32 times the WHO air quality guidelines. The researchers and scientists have projected that India's $PM_{2.5}$ levels might get doubled by 2050 relative to 2015 levels. The Lancet Commission on Pollution and Health 2015 has reported that pollution caused nine million deaths globally out of which highest deaths (2.51 million) were recorded only in India. Poor air quality has created 1.09 million in our country. Moreover, household pollution has led to .97 million deaths. According to the GBD report, ambient air and household pollution have caused deaths of approximately 2 million preterm infants annually. Thus, contribution of air pollution in aggravating the health conditions in the country is very large. Moreover, it can be placed above other elements like high blood pressure, smoking, child and maternal malnutrition which impact the human health. Air pollution deaths have been a result of many non-communicable diseases such as cardiovascular diseases (heart stroke, lung cancer) and respiratory diseases. The present report of World Bank suggests that deaths due to air pollution account for 7.69 % of India's GDP. Thus, potential impacts of the pollutants on human health and environment have created the urgency for analysis of ambient air quality. Assessment of air quality is generally done in two ways. First technique is large scale monitoring at varied sites. This approach is quite comprehensive and involves measurements of air pollutants and meteorological parameters. However, longer monitoring durations and cost involved are the disadvantages of this method. Second approach is development of an air quality model which is used to assess the present conditions and estimating the future concentrations of air pollutants. This way we can identify the troubled spots and ensure the steps for remediation for ensuring cleanest air possible.

III. SITE DESCRIPTION

Kanpur, also known as Cawnpore, is a metropolitan city in the state of Uttar Pradesh in India. Founded in 1803, Kanpur became one of the most important commercial and military stations of British India. Nestled on the banks of Ganges River, Kanpur stands as the major financial and industrial center of North India and also, the ninth-largest urban economy in India. Today it is famous for its colonial architecture, gardens, parks and fine quality leather products which are exported mainly to the West.

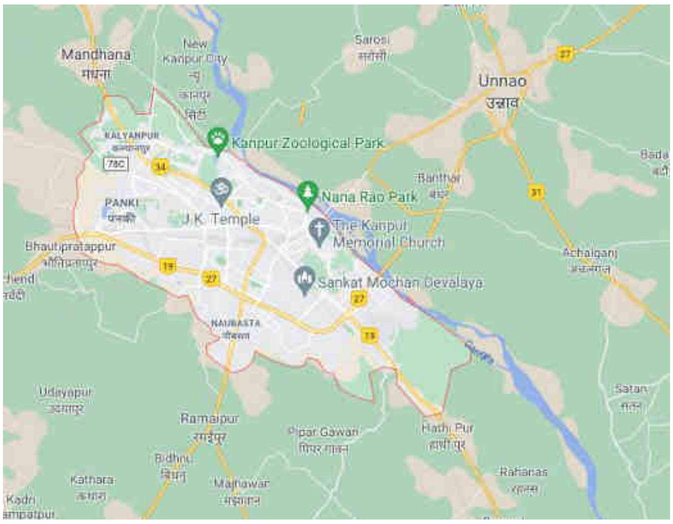

Figure 3.1 Map of Kanpur (source: Google maps)

IV. METHODOLOGY

The monitoring of air pollutants at both the stations is carried out conforming to the guidelines as prescribed by CPCB (Central Pollution Control Board). The Sulphur dioxide concentrations are determined by modified West and Gaeke method. SO_2 is absorbed from a certain controlled volume of air into sodium tetrachloromercurate solution. The absorbed SO_2 then reacts with solution in impinger to form a stable sodium tetrachloromercurate. The SO_2 reacts with sodium tetrachloromercurate to produce dichlorosulphitomercurate which is also a stable compound. This compound then reacts with formaldehyde solution producing a color spectra which is determined using spectrophotometer to determine SO_2 concentrations. The concentrations of oxides of nitrogen are estimated by the modified Jacobs and Hochheiser technique. The sample of ambient Nitrogen Dioxide gas is sucked into the impinger which contain a blended solution of sodium hydroxide and sodium arsenite. NO_2 - ions are generated in the above process, which is then reacted with phosphoric acid, sulphanilamide and NEDA to generate a stable highly coloured dye whose absorbance is measured using spectrophotometer. Measuring of PM_{10} concentrations involve use of a RDS sampler with a cyclonic connector having the air suction rate of 1.1 m^3 /min. The particulate matter is collected on a glass fiber filter paper and the mass of particulate matter retained is determined in laboratory which is divided by sample air volume and is reported in ppm units. Meteorological data like wind speed and its direction, surface air temperature, RH etc. was also obtained.

V. MONITORING METHODS

Annual Exceedance, also called Exceedance Factor is the ratio of annual mean concentration of a pollutant to its standard value. It represented as follows:

$$Exceedance\ Factor = \frac{Observed\ annual\ mean\ concentration\ of\ criteria\ pollutant}{Annual\ Standard\ for\ respective\ pollutant\ and\ area\ class}$$

Air quality has been classified into four categories based on Exceedance Factor:

a) EF > 1.5 – Critical Pollution

b) 1.0<EF<1.5 – High Pollution

c) .5<EF<1.0 – Moderate Pollution

d) EF<.5 – Low Pollution

First two categories (Critical and High Pollution) depicts that present air pollutants does not meet the prescribed pollutant standards. The third category (moderate pollution) signifies that prescribed standards are met however, may exceed in future if concentrations of air pollutants are allowed to increase and remains unabated. The last category (low pollution) suggests that concentrations of air pollutants are well within the prescribed standards either due to lack of anthropogenic activities or strict regulations and policies.

5.1 Air Quality Index

It is a comprehensive tool used for intimation of information regarding the status of air quality of surroundings in which people are residing. It helps in understanding the quality of air by awarding a definite number to express the measured air quality in respect of its repercussions on health of human. Formula used for estimating the AQI (Air Quality Index) is based on the concept of 'liner segmented principle.

$$I_p = \left[\frac{I_{HI} - I_{LO}}{C_{HI} - C_{LO}}\right](C_p - C_{LO}) + I_{LO}$$

Where,

Ip = AQI of pollutant 'p'

Cp = Monitored concentration of pollutant

CHI = Breakpoint concentration (mentioned in Table 1 of Appendix A) ≥ Cp

CLO = Breakpoint concentration (mentioned in Table 1 of Appendix A) ≤ Cp

IHI = Sub index value corresponding to CHI

ILO = Sub index value corresponding to CLO

5.2 Description of air quality models

Gaussian model in its elementary form is used to measure the field concentrations originating from point sources. The point source emissions are presumed to be directly proportional to rate of emissions, and inversely to the wind velocities. Thus, the obtained horizontal and vertical average concentrations of pollutants are described by bell shaped curve as in Gaussian distribution. However, Gaussian models can be modified to forecast the concentrations of pollutants for street canyons and line sources i.e., vehicular pollution. Two Gaussian plume models viz. STREET and CALINE4 have been used for analyzing the ambient air quality of the city. They use modified equations of Gaussian distribution in forecasting the pollutant concentrations.

5.3 STREET

It is one of the earliest and simplistic models which can be used to derive the concentrations of pollutants in street canyons. The prediction of pollutant concentration assumes that, two component exits in a roadside pollutant namely, concentrations generated due to vehicular emissions (Cs) and the background concentrations in the urban locality (Cb)

$C = Cs + C$b

The Cs consists further two components comprising of leeward and windward side components. The former depicts the build-up and intensification of pollutant and latter represents the pollutant concentration developed from recirculation. Pollutant concentration on leeward side of street is given by the following expression:

$$C_S^L = \frac{KQ}{(U + U_s)(\sqrt{x^2 + z^2} + h_o)}$$

Where,

K- Empirical constant parameter (normal values 6,7,8)

Q- Rate of emission discharge in street

U- Roof level wind speed

Us- Constant accounting for additional movement of air induced by movement of traffic (empirical value .5 m/s)

x- Horizontal distance of receptor from center of traffic lane

z- Receptor height

ho- Constant which represents initial pollutant dispersion height (empirical value- 2m)

It has been reported that concentrations on windward side of street decreases due to entrainment of fresh air from the roof top into the street canyon. Thus, original equation has been modified to calculate the windward side concentrations

$$C_S^W = \frac{KQ}{W(U+U_s)}\left(\frac{H-z}{H}\right)$$

Where, H and W represents the height and width of the canyon. Relationship has been derived for calculation the roof level wind speed (U) which uses the airport wind speed

$$U\ (m/s) = .33Ua + 1$$

5.4 CALINE 4

It is latest and final version of the line source emission models drafted by the California transport department. The model uses modified version of Gaussian dispersion equation and concept of 'mixing zone' to forecast the dispersion of line source emissions in proximity of street. Mixing zone is the region which lies directly above the road which is assumed to have turbulence and uniform rate of emissions. This model has the ability perform within the distance 500m of receptor from roadway and predict the concentrations of pollutant with great efficiency. It can be employed to predict the concentrations of particulates and gases like CO and NO_2. CALINE 4 predicts the concentrations of pollutant for a particular receptor by dividing roadway into a series of segments and calculating the individual concentrations of these segments using Gaussian dispersion equation. The following equation is used to estimate the concentrations of any pollutant at any point (x, y, z).

$$C = \frac{q}{2\pi u\sigma_y\sigma_z}\left\{\exp\left[\frac{-(z-H)^2}{2\sigma_z^2}\right]+\exp\left[\frac{-(z+H)^2}{2\sigma_z^2}\right]\right\}\int_{y1}^{y2}\exp\left(\frac{-y^2}{2\sigma_y^2}\right)$$

Where,

q- Line source strength

U-wind speed

σz and σy are vertical and horizontal Gaussian dispersion parameters which are functions of x, not y

H- Height of source

5.5 Performance Evaluations

The working efficiency of models were evaluated by comparative analysis of predicted concentrations with respect to the monitored concentrations using relevant statistical measures. Seven statistical parameters were used for performance evaluation of models. Mean is indicative of the central tendency of a large set of data, while standard deviation signifies the dispersion of any data from the point of central tendency. The index of agreement (IA) indicates the degree of similarity or correctness between predicted and monitored concentrations. NMSE highlights the scattering in data set. Pearson's Coefficient 'R' is measure of degree of dependency between two variables. Fractional bias is a dimensionless number used as a measure of symmetry between mean concentrations indicating the overestimation or underestimation. Factor of two is indicative of degree of prediction of the model.

The formulae of the above said statistical indicators with respect to predicted (Cpred) and monitored (Cobs) concentrations have been described below:

i) The Standard Deviation (SD):

$$S.D. = \sqrt{\frac{1}{n}\sum_{i-1}^{i=n}(C_i - \bar{C})^2}$$

Where,

n- Total number of observations,

Ci - Concentration of ith observation

$\bar{C}$– Mean concentrations of n observations

ii) Index of Agreement (I.A.)

$$I.A. = 1 - \frac{\overline{(C_{pred} - c_{obs})^2}}{\overline{\left(|C_{pred} - \overline{C_{obs}}| + |C_{obs} - \overline{C_{obs}}|\right)^2}}$$

I.A. = 1-perfect agreement between measured and modeled concentration

I.A. = 0- complete disagreement

iii) Normalized Mean Square Error (NMSE):

$$NMSE = \frac{\overline{(C_{obs} - \overline{C_{obs}})^2}}{\overline{C_{obs}}\,\overline{C_{pred}}}$$

iv) Pearson's Coefficient of Regression (R)

$$R = \frac{\overline{(C_{obs} - \overline{C_{obs}})\,(C_{pred} - \overline{C_{pred}})}}{\sigma_{pred}\sigma_{obs}}$$

Where,

$\sigma pred and \sigma obs$ are standard deviations of predicted and monitored data.

Value of R ranges between 0 to 1.

v) Fractional Bias (FB)

$$FB = \frac{2(\overline{C_{pred}} - \overline{C_{obs}})}{\overline{C_{pred}} + \overline{C_{obs}}}$$

Value of FB ranges between -2 to 2. FB equal to -2 implies extreme over prediction while, value of FB equal to 2 indicates extreme under prediction

vi) Factor of two (F2)

$$F_2 = 0.5 < \frac{C_{pred}}{C_{obs}} < 2$$

6. Short Term Analysis:

Variations during lockdown short term air quality degradation episodes can pose long term adversities on humans and environment. Daily average concentrations of criteria pollutants NO_2 and RSPM have been studied for the period of lockdown and one year before the lockdown. Concentrations, a year prior to lockdown can be treated as normal duration which can be used to compare the fluctuations of pollutants during lockdown .A graphical comparison between the 24-hourly concentrations of the atmospheric pollutants over the Kanpur city during lockdown period and a normal duration.

As it shown in Fig 6.1 the average concentration of NO_2 monitored At Monitoring site Pre-Lockdown, during Lockdown and post lockdown. The graph is drawn as per the increment in NO_2 as we approached to lockdown the value showed sudden decrement. . Daily average concentrations of criteria pollutants NO_2 and RSPM have been studied for the period of lockdown and one year before the lockdown.

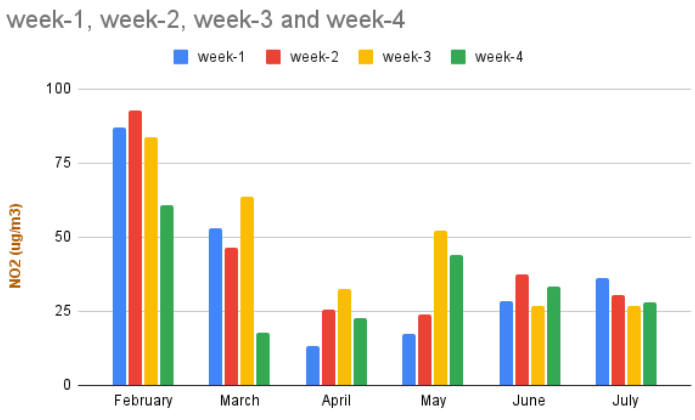

Fig 6.1Average Concentration of NO2 monitored at Monitoring Site Pre-Lockdown, during Lockdown and post Lockdown

As in Fig 6.2 Average concentration of $PM_{2.5}$ Monitored at Monitoring site pre-lockdown, during lockdown and post lockdown .The graph is drawn as per the increment in $PM_{2.5}$ as we approached to lockdown the value showed sudden decrement .A graphical comparison between the 24-hourly concentrations of the atmospheric pollutants over the Kanpur city during lockdown period and a normal duration.

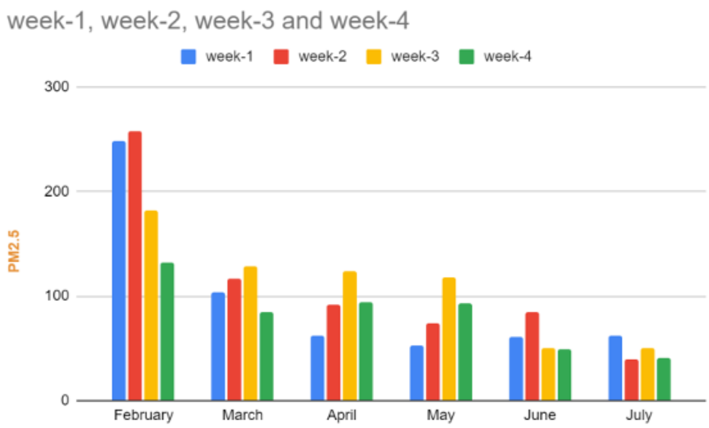

Fig 6.2Average Concentration of PM 2.5 monitored at Monitoring Site Pre-Lockdown, during Lockdown and post Lockdown

The graphs in figure 6.1 and 6.2 shows the respective decrement in the NO_2 and the $PM_{2.5}$ in the atmosphere during the lockdown period, as there is banned to move out of house so no more industries or vehicular pollution . Variations during lockdown short term air quality degradation episodes can pose long term adversities on humans and environment. Daily average concentrations of criteria pollutants NO_2 and RSPM have been studied for the period of lockdown and one year before the lockdown.

6.2 Long Term Analysis

Long term trend analysis involves studying the spatio-temporal variations of air pollutants annually as well as seasonally. This analysis becomes important because of strong association between long term exposures of air pollutants with human health. Short term variations are always dependent on the long-term trends. Long term trends can be validated determining the annual Exceedance factors and percentage increase in concentrations.

4.2.1 Annual variations of pollutants.

Table 4.3 shows the average annual concentrations of NO2 and RSPM at two monitoring sites. The annual average concentrations of NO2 were within prescribed limits as per NAAQS (40µg/m3) for the entire period.

Performance Evaluation of Models

the statistical evaluations of both the models. The mean and NMSE values validates the efficient working of CALINE 4 for the prediction of particulate matter concentration with some degree of accuracy, whereas STREET model resulted under prediction of pollutant concentration. FB values indicate the considerable amount of compliance between the forecasted and measured pollutants. However, IA values are high for STREET model which highlights the relatively error free results indicating the adherence of legitimate modeling approach. Pearson's coefficient of correlation "R" is relatively low for both the models, but in comparison predicted concentrations of STREET model are better correlated than the CALINE 4 results. In overall evaluation of parameters, predictions of CALINE 4 are much superior than the estimates calculated using the STREET model.

SUMMARY AND CONCLUSIONS

1. Ambient air quality of Kanpur city during the lockdown was investigated to evaluate the short term trends. AQI calculations confirmed the adversities of high pollutant concentrations generated due to pyrotechnic activities.

2. pre lockdown, lockdown and post lockdown trend analysis of RSPM and NO_2 was performed to assess the long term exposure of air pollutants and the variations were also validated using Annual Exceedance Factor.

3. Seasonal analysis revealed the elevation of pollutant concentrations during summer season and least effect during rainy season.

4. PM10 concentrations were also correlated with the meteorological parameters like wind speed, wind direction, relative humidity and temperature.

5. Two air quality dispersion models were evaluated for prediction of pollutant concentrations. The performance of CALINE 4 was relatively well in comparison to the other model used for pollutant forecasting for the city.

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