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Review Article

Impact of Particulate Matter (RSPM) on First and Second Wave of COVID-19

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ABSTRACT

Particulate pollution poses a great threat to the health quality of humans and has been found to have caused many respiratory problems and may also influence diabetes mellitus. This study is aimed to establish a connection between the mortality statistics and the $PM_{2.5}$ concentration and discuss the variation trend during the first and the second wave of COVID-19 pandemic in India. The air quality index related to $PM_{2.5}$ was recorded from September 1, 2020, to September 30, 2020, and April 1, 2021, to May 31, 2021. Mortality trend during this duration was plotted with respect to the $PM_{2.5}$ concentration for three heavily polluted Indian cities, namely, Delhi, Lucknow, and Mumbai. The correlation (R^2 value) in Delhi during the second wave of COVID-19 was only 8.21%. During the first and second waves, the correlation in Lucknow was 0.18% and 5.49%, respectively. During the first wave of COVID-19 in Mumbai, a 1.94% correlation was seen. Because of the poor correlation values, no well-defined link between mortality and $PM_{2.5}$ concentration could be established. The R^2 values of 26.91% and 25.59% for Delhi during the first wave and Mumbai during the second wave, respectively, exhibit a clear link between mortality and $PM_{2.5}$ concentrations. This paper attempts at establishing a relationship between $PM_{2.5}$ concentration and mortality with regard to the first and second wave of the pandemic.

Key words: Correlation, COVID-19, Mortality, Particulate matter.

1. INTRODUCTION

Air pollution is one of the leading causes of premature mortality throughout the globe, killing about 7 million people each year (the World Health Organization, 2014). Long-term air pollution exposure has been linked with an increased risk of respiratory illness and mortality. $PM_{2.5}$, or fine particulate matter with a diameter of 2.5 µm, is one of the most significant environmental health risks. $PM_{2.5}$ and PM_{10} are both linked to an increased risk of respiratory illness, when present at higher quantities in the environment. Nitrogen dioxide (NO_2) is another significant air pollutant that is harmful to human respiratory systems [1]. Sulfur dioxide (SO_2) is a pollutant that exists in the form of a gas in the atmosphere. Long-term high-level exposure worsens respiratory symptoms and impairs lung function [2].

As defined by the Environmental Protection Agency (EPA), particulate matter or PM is a mixture of microscopic particles and liquid droplets [3]. In general, particle pollution incorporates a various number of components, which includes acids (e.g., nitrates and sulfates), organic chemicals, metals, and soil or dust particles. Most particulate matter is the result of complex reactions of SO_2 and nitrogen oxides which are mostly emitted from power plants, industries, and automobiles.

EPA categorizes particle pollution [4] into two categories:

1. "Inhalable coarse particles" (2.5–10 µm in diameter, found near roadways and dusty industries)
2. Fine particles (<2.5 µm in diameter, found in smoke and haze).

The particle size is directly related to their ability to cause health problems. Some of the short- and long-term health impacts of $PM_{2.5}$ and PM_{10} are been summarized in Table 1.

India suffers from severe air pollution. Over the last many years, the air quality in most Indian cities has deteriorated. Anthropogenic sources of air pollution, such as transportation, industry, power production, construction, residential, and commercial activities, have been steadily growing in recent years. Open burning of municipal garbage and agricultural residues adds to the region's air pollution problems (Figure 1), worsening them substantially, especially during the winter, when sluggish weather encourages the build-up of pollutants in the atmosphere [5]. According to the WHO estimate, 1.4 billion people living in cities in developing nations breathe air with PM concentrations that exceed WHO permissible limits (Table 2). PM pollution has risen to worrisome levels in cities across the Indian subcontinent, including New Delhi, Mumbai, and Lucknow, during the previous decade. Allergies, skin disorders, and respiratory problems might be caused by PM deposited on the skin and in the nasal passage. Fine particles, which can enter the lungs and get accumulated, offer the most significant health concerns. PM build-up in the lungs can lead to lung tissue fibrosis [6]. Individuals with reduced lung functioning are more prone to suffer severe breathing and blood O_2 saturation-related problems, which commonly necessitate hospitalization and ventilator care, and therefore air pollution has indirectly contributed to the

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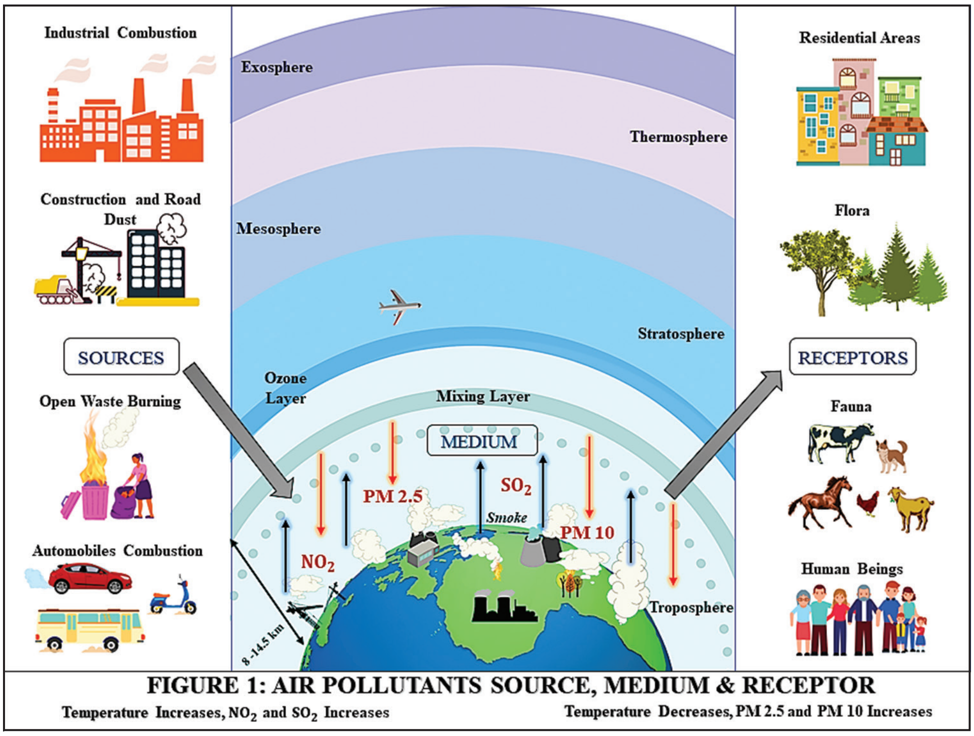

Figure 1: Air pollutants source, medium and receptor.

Table 1: Short-term/long-term effects for $PM_{2.5}$ and PM_{10}.

Pollutants	Indoor air pollutant		Outdoor air pollutant	
	Short-Term Effects	Long-Term Effects	Short-Term Effects	Long-Term Effects
$PM_{2.5}$	• Eyes, nose, throat, and lung irritation • Coughing • Sneezing • Shortness of breath	• Chronic bronchitis • Reduced lung function • Increased mortality from lung cancer and heart disease	• Premature mortality, • Chronic bronchitis • Asthma attacks	• Chronic heart or lung diseases • Reduced lung function
PM_{10}	• Coughing • Runny nose • Eyes Sting	• Respiratory mortality	• Worsening of respiratory diseases, • Asthma and chronic obstructive pulmonary disease	• Respiratory mortality

Table 2: Permissible limit values for $PM_{2.5}$ and PM_{10}

Pollutants	Permissible limit	
	24 h	Annual
$PM_{2.5}$	35 $\mu g\ m^{-3}$ or 0.035 ppm	15 $\mu g\ m^{-3}$ or 0.015 ppm
PM_{10}	150 $\mu g\ m^{-3}$ or 0.150 ppm	-

(1 $\mu g\ m^{-3}$=0.001 ppm)

mortality toll of COVID-19 [7]. Environmental exposures, particularly fine particulate matter ($PM_{2.5}$), have been linked to the development of diabetes in recent research. The previous research has explored a probable linkage between $PM_{2.5}$ exposure and diabetes, but the results have been contradictory [8]. The transportation of air pollutants is affected by metrological parameters such as temperature, wind speed, and relative humidity [9].

The seasonal changes are also responsible for influencing the concentration of PM pollutants. The cities' topography and other geographical details also affect the concentration of PM, directly or indirectly. The meteorological data are tabulated in Table 3.

2. METHODOLOGY

The topmost polluted cities in India, namely, Delhi, Lucknow, and Mumbai were chosen for the present study to see the overall impact of $PM_{2.5}$ on the mortality rate during the first and second wave of COVID 19. The data were collected from September 1, 2020, to September 30, 2020, and April 1, 2021 to May 31, 2021. This data are given in Tables 4 and 5. The source of the meteorological data was taken from www.timeanddate.

Table 3: Meteorological data of Delhi, Lucknow, and Mumbai during first and second wave of COVID-19

Duration	Delhi			Lucknow			Mumbai		
	Average temperature (˚C)	Average humidity (%)	Average wind speed (Km/h)	Average temperature (˚C)	Average humidity (%)	Average wind speed (Km/h)	Average temperature (˚C)	Average humidity (%)	Average wind speed (Km/h)
September 2020	34.41	39.44	8.78	31.26	58.10	10.21	31.49	74.41	7.31
April 2021	34.72	39.05	8.55	31.23	58.22	10.18	31.48	74.27	7.31
May 2021	35.20	33.38	10.15	32.73	42.87	10.51	31.40	73.77	5.45

Table 4: $PM_{2.5}$ concentration and mortality rate recorded during first wave of COVID-19 in India

First wave of COVID-19						
Date (2020)	Delhi		Lucknow		Mumbai	
	PM 2.5 μg/m^3	Mortality rate	PM 2.5 μg/m^3	Mortality rate	PM 2.5 μg/m^3	Mortality rate
September 1	46	18	135	7	29	35
September 2	59	19	134	11	40	34
September 3	67	19	130	13	50	37
September 4	96	13	150	10	47	35
September 5	113	25	126	18	67	33
September 6	84	29	162	17	70	37
September 7	91	32	139	15	94	31
September 8	122	19	144	9	36	42
September 9	87	20	149	8	43	43
September 10	144	28	156	11	50	38
September 11	129	21	160	16	43	44
September 12	125	28	170	10	61	42
September 13	145	29	107	10	37	41
September 14	153	26	120	8	28	31
September 15	149	36	146	15	40	49
September 16	149	33	180	15	33	50
September 17	145	38	162	6	35	43
September 18	121	30	167	16	38	52
September 19	119	38	174	9	46	50
September 20	136	37	163	6	47	44
September 21	152	32	142	13	46	36
September 22	143	37	148	14	58	50
September 23	108	36	80	12	51	49
September 24	74	36	58	14	20	54
September 25	108	24	35	9	47	48
September 26	137	46	99	11	151	44
September 27	129	42	160	11	33	44
September 28	91	37	193	9	42	40
September 29	145	48	194	16	59	49
September 30	153	41	191	3	59	46

com. The PM values were recorded from www.aqicn.org. The mortality rate was collected from the open access website covid19india.org.

The data recorded were freely accessible on the internet and did not require any permissions or copyright. The geographical details of the cities under study are shown in Figure 2.

3. RESULTS AND DISCUSSION

3.1. Statistical Analysis

The average concentrations of $PM_{2.5}$ were obtained with the help of an online air quality index to concentration convertor. The scatter plot

Table 5: $PM_{2.5}$ concentration and mortality rate recorded during second wave of COVID-19 in India

Second wave of COVID-19						
Date (2021)	Delhi		Lucknow		Mumbai	
	PM 2.5 µg/m^3	Mortality rate	PM 2.5 µg/m^3	Mortality rate	PM 2.5 µg/m^3	Mortality rate
April 01	90	9	169	2	146	18
April 02	115	14	149	9	122	19
April 03	134	10	165	6	128	27
April 04	128	21	133	8	123	25
April 05	156	15	159	5	87	21
April 06	160	17	164	7	111	32
April 07	183	20	166	6	87	24
April 08	151	24	186	11	115	25
April 09	125	39	183	13	120	35
April 10	129	39	157	23	158	28
April 11	149	48	143	31	104	79
April 12	156	72	157	21	107	43
April 13	181	81	161	18	107	27
April 14	181	104	161	13	107	54
April 15	149	112	138	26	107	50
April 16	169	141	172	35	118	53
April 17	148	167	176	36	105	51
April 18	107	161	169	22	80	53
April 19	151	240	159	22	80	58
April 20	152	277	169	19	80	34
April 21	134	249	176	21	80	62
April 22	116	306	183	19	85	72
April 23	122	348	115	14	83	71
April 24	118	357	152	42	83	64
April 25	116	350	147	14	83	71
April 26	154	380	141	21	83	59
April 27	248	381	161	38	83	34
April 28	279	368	169	13	83	82
April 29	282	395	178	36	83	89
April 30	244	375	187	37	83	90
May 01	200	412	171	35	83	79
May 02	159	407	163	24	83	78
May 03	149	448	153	25	83	62
May 04	168	338	135	22	84	77
May 05	139	311	145	38	107	64
May 06	160	335	137	60	107	71
May 07	141	341	138	25	107	62
May 08	138	332	105	38	107	68
May 09	142	273	131	22	107	74
May 10	138	319	149	26	107	51
May 11	132	347	117	23	107	66
May 12	128	300	140	23	107	68
May 13	119	308	152	34	107	62
May 14	104	289	62	22	107	62

(Contd...)

Table 5: *(Continued)*

Second wave of COVID-19						
Date (2021)	Delhi		Lucknow		Mumbai	
	PM 2.5 μg/m^3	Mortality rate	PM 2.5 μg/m^3	Mortality rate	PM 2.5 μg/m^3	Mortality rate
May 15	123	337	100	12	107	60
May 16	114	262	128	18	107	48
May 17	138	340	144	22	107	44
May 18	167	265	164	19	107	57
May 19	79	235	118	29	107	37
May 20	97	233	96	21	107	54
May 21	83	252	58	4	107	52
May 22	99	182	60	20	107	49
May 23	89	189	83	18	107	48
May 24	222	207	123	5	107	37
May 25	137	156	183	5	107	34
May 26	121	130	144	11	121	36
May 27	133	117	94	15	90	30
May 28	138	139	91	8	107	25
May 29	106	122	30	11	107	22
May 30	67	78	27	0	107	29
May 31	79	86	85	5	107	23

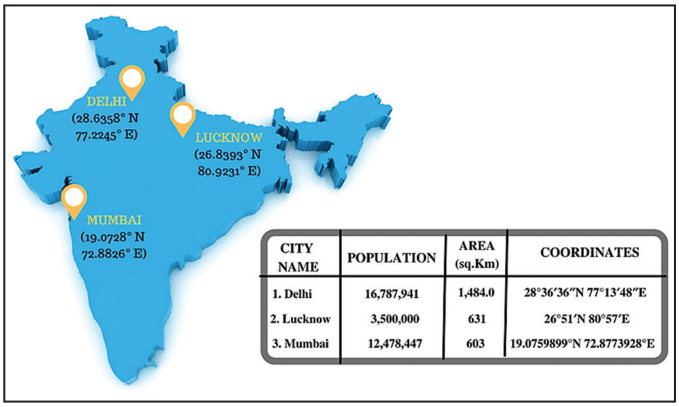

Figure 2: Cities under study and their geographical data

of mortality versus $PM_{2.5}$ concentration was constructed using this data and was analyzed for the trend. This enabled us to determine the connection between mortality and $PM_{2.5}$ concentration and its trend during first and second wave of COVID-19 pandemic.

The vertical and the horizontal axes represent the mortality and the $PM_{2.5}$ concentration, respectively (Figure 3). For the sake of interpretation of the scatter plots, a few points need to be recalled: (1) The equation $y = mx + c$ represents a straight-line equation where m represents the slope of the line and c represents the y-intercept. The value of m may be negative, positive, or even zero representing negative trend, positive trend, or no trend respectively. (2) R represents the correlation between the predicted values and the observed values of y. Meanwhile, R^2 represents the percentage of variation explained by the regression line out of the total variation and is always a positive value.

To read the scatter plots, we utilized this information and predict the trend of mortality with reference to the concentration of $PM_{2.5}$ during first and second wave of COVID-19.

3.1.1. Delhi

The trend line equation of the scatter plot of data taken during the first wave in Delhi showed a positive trend with a slope of 0.15. This implies that for every 1 μg/m^3 increment in $PM_{2.5}$ concentration, a rise of 0.15 was noticed in mortality. Whereas, the trend noticed during the second wave in Delhi displayed an increase of 0.86 for every 1 μg/m^3 rise in $PM_{2.5}$ concentration. While there might be an increase as related to $PM_{2.5}$ concentration, there is another factor at play. The R-squared values were 0.2691 (or 26.91%) and 0.0821 (or 8.21%) for first wave and second wave, respectively. This means that $PM_{2.5}$ concentration may be accountable for 26.91% of mortality during the first wave in Delhi. This falls to a small value of 8.21% during the second wave. Therefore, it can be summarized that about 73.09% and 91.79% mortality during the first and second wave of COVID-19 might have been due to other reasons and not dominantly because of the $PM_{2.5}$ concentration.

3.2. Lucknow

The plot of data recorded during first wave in Lucknow showed a negative trend with a negative slope of 0.0042. The R-squared value recorded was 0.0018 (or 0.18%). Thus, it can be concluded that only 0.18% mortality was attributed to the $PM_{2.5}$ concentration. This case can be deemed as a case of no trend at all since the values are so low and can be ignored. The trend line recorded during the second wave shows a positive slope. However, with the R-squared value of 0.0549 (or 5.49%), it can be inferred that only 5.49% of mortality occurred due to $PM_{2.5}$ concentration while the rest 94.51% of mortality might have been due to some other causes.

3.2.1. Mumbai

Mumbai registered negative slope values of –0.0379 and –0.6176, respectively, for 1^{st} and 2^{nd} wave of the COVID-19 pandemic. This implies a negative trend of mortality with $PM_{2.5}$ values. Furthermore,

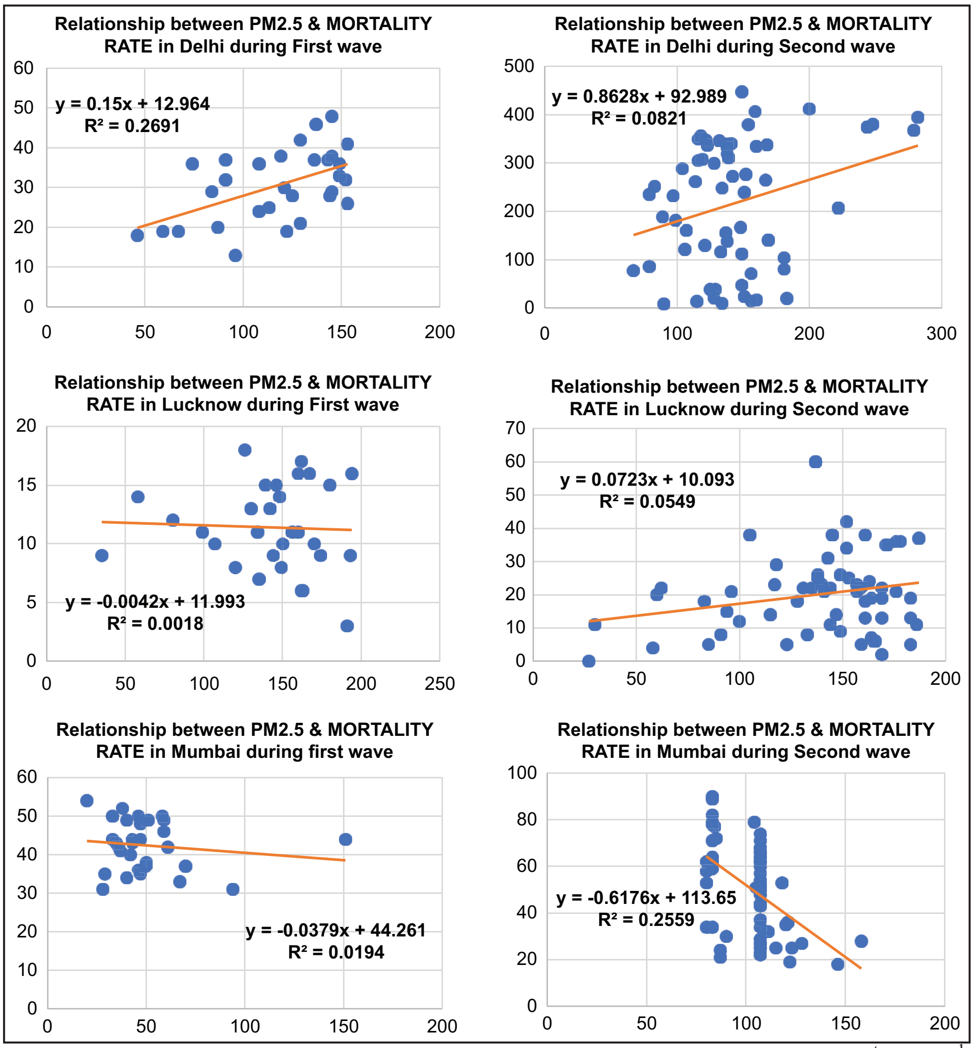

Figure 3: Relationship between air quality index with respect to $PM_{2.5}$ and mortality cases during 1st and 2nd wave of COVID-19 for Indian cities Delhi, Lucknow, and Mumbai. (The vertical axis and the horizontal axis represent mortality and concentration of $PM_{2.5}$ respectively)

the R-squared value during the first wave was found to be 0.0194. This implies that only about 1.94% of mortality can be attributed to the concentration level of $PM_{2.5}$. The plot for the second wave shows the R-squared value to be 0.2559. This is good data; this implies that as many as 25.59% of mortality was due to the $PM_{2.5}$ level while the rest 74.41% may be attributed to some other cause.

India also witnessed the outbreak of mucormycosis during the second wave of COVID-19. This new co-morbidity was COVID-19 triggered and led to an increase in 50% mortality rate in India. The recent studies (Table 6) show that the air pollutants are directly accountable for generating symptoms of diabetes mellitus in humans. These symptoms include abnormalities in glucose homeostasis, increased inflammation in insulin responsive organs, and some other effects summarized in Table 6.

The rise in cases of diabetes mellitus and mucormycosis was observed in COVID-19 patients as a during- or post-COVID-19 symptom. It would be fair enough to mention that these two factors might relate to the non- $PM_{2.5}$ mortality (91.79% mortality in Delhi 2nd wave, 94.51% of mortality in Lucknow 2nd wave, and 74.41% of mortality in Mumbai 2nd wave) as the other factors responsible for high mortality rate. It is to be remembered that this is all a predictive study and might be antithetical.

Table 6: Air pollutants and health impacts

Author	Pollutant	Effect
Liu *et al.*[10]	$PM_{2.5}$	• Impairs energy metabolism • Abnormalities in glucose homeostasis •Increased inflammation in insulin responsive organs • Brown adipose tissue inflammation • Imbalance in circulating leptin/ adiponectin levels
Balti *et al.* [11]	NO_2, $PM_{2.5}$	Overall effect on diabetes mellitus (DM)
Eze *et al.*[12]	PM_{10}	Diabetes Mellitus
Pope *et al.*[13]	$PM_{2.5}$	Risk of development or exacerbation of cardiometabolic disorders, increasing risk of coronary artery disease and cardiometabolic disease mortality

4. CONCLUSION

Particulate matter constitutes miniscule inhalable particles of diameter size 10 µm or less. These particles are responsible for causing respiratory issues and diabetes mellitus. The respiratory issues caused included asthma, breathing problems, chronic bronchitis, and reduced lung function. Particulate pollution is a significant concern for human health, having been linked to a variety of respiratory issues as well as diabetes mellitus.

The data recorded from September 1, 2020, to September 30, 2020, (first wave of COVID-19) and April 1, 2021, to May 31, 2021, (second wave of COVID-19) showed the following: Delhi recorded a $PM_{2.5}$ maxima of 282 µg/m^3 corresponding to mortality 395 on April 29, 2021. On April 1, 2021, it recorded the least value of mortality equal to 9, the $PM_{2.5}$ concentration being 90 µg/m^3. Lucknow recorded a $PM_{2.5}$ maxima of 194 µg/m^3 on September 29, 2021, which corresponded to mortality equal to 16. On May 30, 2021, the minimum concentration of $PM_{2.5}$ was recorded to be 27 µg/m^3 and zero mortality which was the least recorded mortality data for Lucknow. Mumbai registered a $PM_{2.5}$ maxima of 158 µg/m^3 with mortality rate of 28 on April 10, 2021. While the minimum $PM_{2.5}$ concentration (equal to 20 µg/m^3) was recorded on September 24, 2020, registering a mortality of 54.

Delhi during the second wave of COVID 19 registered a correlation (R^2 value) of only 8.21%. With regard to Lucknow the correlation came out to be 0.18% and 5.49% during the first wave and second wave, respectively. About 1.94% correlation was noted during the first wave of COVID-19 in Mumbai. Due to such low values of correlations, no well-defined relationship of mortality with reference to $PM_{2.5}$ concentration could be established. However, the R^2 values 26.91% and 25.59% for Delhi during first wave and Mumbai during second wave show much correlation between mortality and $PM_{2.5}$ concentration. In conclusion, the result remains uneven and unclear. The meteorological conditions might also be involved in the deciding factors for mortality or $PM_{2.5}$ concentration. Furthermore, as discussed in the results, several other COVID-19 triggered infections such as mucormycosis or diabetes mellitus might be one of the deciding factors. But this still remains uncertain and holds much scope for further research.

5. ACKNOWLEDGMENT

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6. CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this article.

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***Bibliographical Sketch**

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