A Study of Impact of Air Pollutants on Human Health during COVID-19 in Delhi

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Abstract: ***The aim of the study is to envisage the dose of deposition of particulate matter mainly PM2.5 and PM10. 35 monitoring stations as installed by Central Pollution Control Board have been considered under the study. International Commission on Radiological Protection method also known as RDD estimation was used in investigating the Station wise value of RDD2.5 and RDD10 during standing and walking during. Apart from the empirical study, GIS and remote sensing techniques also used to see the effect of population density. The results show that the values of RDD10 during standing and walking were found to be relatively more in dense populated areas, however the values of RDD2.5 found to be more in relatively less dense populated areas. Therefore, the deposition of particulate matter which played an important role in the enhancement of mortalities during Novel Corona Virus occurred in dense populated areas. The GIS study also shows that on the basis of pollution data available from CPCB, 250 no. of people per kilo-meter square are under exposure of PM2.5 and PM10.***

Keywords: Particulate Matter, RDD, DF, Precipitation, Buffer, Zonal statistics, Arc GIS etc.

1. Introduction

Air pollution refers to the release of various gases and finely divided solids or dispersed aerosols that disturb the natural state of the air. Air pollution now become a major issue to human and environmental health worldwide [1]. Worldwide every year, 7 million premature deaths are due to particulate matter (PM) [2]. In India 1.67 million deaths were reported to air pollution in 2019, resulting in 17.8% of the total deaths in the country. The main causes of these deaths were outdoor particulate matter and indoor air pollution [3]. PM is a suspended particle composed of liquid and solids in air derived from different sources and is present in different sizes [7-8]. PM can be classified into two categories, pollutants which are directly emitted from the source known as primary pollutants and secondary pollutants which are formed in the chemical reaction of sulfur dioxide and nitrogen oxide which are emitted from industries, power plants, and automobiles[6-7].Concentration of PM depend on population density[6]

Particulate matter is of three types coarse particle PM_{10} (particle having a diameter less than 10μm), fine particle $PM_{2.5}$ (particle having a diameter less than 2.5μm) and ultrafine particle $PM_{0.1}$ (particle having a diameter less than or 0.1μm).

According to past experimental and empirical studies, PM has shown negative impacts on human health [9-10][9] and falls under the category of group 1 carcinogen to humans. According to several studies, it has been confirmed that PM_{10} harm human health and can result in medical conditions such as congenital heart defects [10], ischemic heart disease [11], respiratory and circulatory mortality [12], preterm-birth risk [13], mutagenicity and DNA damage [14], fetal growth characteristics and adverse birth outcomes [15], inflammatory responses [16] and increased cancer risk [17]. Apart from this, PM also reduces visibility and harms air quality [19-20].

In Wuhan, China on December 2019 the first novel coronavirus was reported [18]. World Health Organization declared COVID-19 as a pandemic on 11 March 2020 as it was spreading worldwide. COVID-19 virus belongs to the *coronaviridae* family which causes a variety of respiratory diseases in human beings [18]. It was found that until 5 December 2022, 4.6 million cases and 17 thousand deaths were reported in china. Till December 2022, 4.4 million cases and 5 lakh deaths were reported in India[19]. Various measures were taken by the Indian government to control the situation by imposing a series of lockdowns with concomitant restrictions on commercial, industrial and social activities. The first complete nationwide lockdown was introduced on 24th March 2020 to 14th April 2020 when all the services like institutional, commercial, and industrial were suspended including ban on the movement of citizen except essential services such as medical service police service. The nationwide lockdown was extended from 15 April 2020 – 3 May 2020. The third lockdown was imposed from 4 May 2020 – 17 May 2020 dividing the country into three zones red (area which have high number coronavirus cases and it was remain under lockdown), orange (area which have comparatively less cases than red zone and only private vehicle were allowed with no public transportation) ,and green zones (area which do not have any corona cases in the past 21 days and normal movement was allowed with 50 percent bus capacity). Forth lockdown was imposed from 18 May 2020 -31 May 2020 while further dividing the red zone into contaminated and buffer zone. From 1 June 2020 – 31 June 2020 unlock phase 1 was imposed with the opening up of the shopping malls, religious places, hotels, and restaurants with gathering of up to

50 people were allowed while the night curfew (9:00 PM – 5:00 AM) was still there.

According to a study, there is a strong correlation between the oxidative potential of PM, genotoxicity, ecotoxicity and PM's exposure [20]. Exposure to PM for a longer period has an impact on aggravating emerging diseases because of the presence of Severe Acute Respiratory Syndrome(SARS) and COVID-19 variants in the atmosphere [21]. According to research carried out in Italy, it was found that the major cause of COVID-19 was air pollution to human transmission rather than human-to-human transmission [23-24].

International commission on radiological protection (ICRP) and the National Council on Radiation Protection and Measurement (NCRP) are the two Mathematical models were used for the prediction of the total and regional deposition of particles. For assessment of health risks due to airborne particulate matter, Respiratory lung deposition dose is determined by calculating the amount of particles that are deposited in lungs per unit of time. These values are calculated based on the ICRP model used in different physical activities [24].According to past studies walking/exercising near busy road lead to more PM deposition than working out in parks [25]. Previous studies have shown that particulate matter is deposited more during walking/exercise than rest [26] as breathing rate is found to increase during physical activity which leads to an increase in the concentration of PM as it is directly related to breathing rates. [28-29].

Delhi is one of the most polluted cities in the world [28] It has a higher level of PM in the ambient atmosphere including fine ($PM_{2.5}$) and coarse (PM_{10}). During COVID 19 India went through different lockdown phases which result in variations of pollutants due to a decrease in industrial activity, and lesser/no transportation. Delhi comes in the list of most polluted cities in the world, and the sudden change of PM concentration and its deposition was studied. The present study uses the RDD concentration of both fine and coarse particles at the different sites during, before, and after lockdown phases in Delhi, India. As RDD is directly connected to PM concentration

2. Materials & Methods/ Methodology

Site Description

In the present study, Delhi has been chosen as a study area where the Central Pollution Control Board, India (CPCB) Delhi has installed 40 stations, out of which 35 locations are considered as 5 station's data was unavailable. The whole city is divided into 11 areas as administrative area, institutional area, residential area, institutional-residential area, commercial-administrative area, village area, residential-industrial area, industrial area, commercial area, institutional–commercial area and residential–commercial area describes in Figure 1.

Data Collection

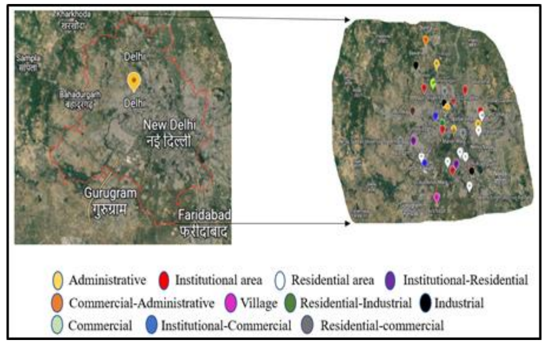


Figure 1: Location of Air Quality Monitoring station and their locations

In the present study real-time data have been collected from the monitoring stations of the central pollution control board (CPCB), and Delhi pollution control board (DPCC) of $PM_{2.5}$ and PM_{10} concentration (µg/m^3). All the raw data used in this study is available at the CPCB portal (https://cpcb.nic.in/automatic-monitoring-data/). Data from 24 January 2020 to 30 June 2020 have been studied to analyses air quality before, during and after the lockdown COVID-19 phase.

The air quality data has been divided into 6 parts, corresponding to the lockdown and unlock phases in the city of Delhi. More details on the differences between these phases and timelines are detailed in Table 1

Data Analysis

In the present study, International Commission on Radiological Protection method also known as RDD estimation is being used [29]. In this study for RDD calculation, three equations are used [30]–[32].

$$\text{RDD of PM} = (V_T * f) * DF * PM \quad (1)$$

Where V_T stands for tidal volume (m^3 per breath), f represents typical breathing frequency (breath per minute), and DF shows deposition fraction of a size fraction i.

PM_i = Mass concentration in different size ranges (in µg/m^3)

$$DF=IF(0.058+\frac{0.911}{1+\exp(4.77+1.485\,In\,dp}+\frac{0.943}{1+\exp(0.508-2.58\,In\,dp)}) \quad (2)$$

$$IF=1-0.5(1-\frac{1}{1+0.00076d_p^{2.8}}) \quad (3)$$

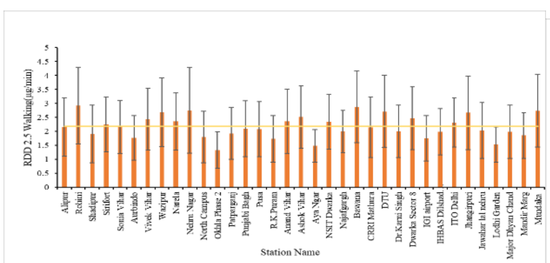
The V_T and f values mainly depend on the physical activity and gender of a person [30], [32].In the present study, to evaluate RDD, all the calculations were done using values available for males to know the general trend of RDD. For walking mode V_T and f values used here are 12.5×10^{-4} m^3 per breath and 20 breaths per minute, respectively and for sitting mode 7.5×10^{-4} m^3 per breath and 12 breaths per minute, respectively for males. For DF_i calculation, particle diameter (represented as d_p) of $PM_{2.5}$ and PM_{10} is used here[33]. RDD2.5 walking and sitting represent the Respiratory lung deposition dose of $PM_{2.5.}$ RDD10 walking and sitting represent the Respiratory lung deposition dose of $PM_{10.}$

Table 1: Major relaxation and restriction during different lockdown phases[35]

Phase Name	Dates	Major Relaxation And Restriction
Before lockdown	24 January-24 March 2020	All activities in the usual mode, with no restrictions at all
Lockdown Phase -1	25 March-14 April 2020	All private and commercial, hospitality services, transport, and industries establishment closed, and schools, colleges, and shopping malls were closed including the ban on the movement of a citizen except for essential services such as medical and police services.
Lockdown Phase -2	15 April-3 May 2020	Farming and some industries were allowed. All restrictions were the same as in lockdown phase 1
Lockdown Phase -3	4 May-17 May 2020	Classification of cities into three zones (Orange, red and green) green and the orange zone was relaxed. Activities during phase 2 and construction, vehicle movement for some activities were permitted.
Lockdown Phase -4	18 May-31 May 2020	Permission is granted for the opening of industries and the movement of vehicles without restriction. The red zone was further divided into contaminated and buffer zone.
Unlock Phase -1	1 June-30 June 2020	All religious places, hotels, shopping malls, and hospitality services were opened. Night curfew was still there and large gatherings were still not allowed.

Table 2: Top three RDD values during different lockdown Phase

	RDD WALKING		RDD SITTING	
	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}
Before lockdown	Rohini(2.914±1.374)	Dwarka Sector 8 (5.842±2.125	Bawana(1.033±0.459)	Dwarka Sector 8(2.103±0.765)
	Bawana(2.87±1.578	Wazipur (5.041±1.577)	NehruNagar(0.988±0.553)	Wazipur(1.815±0.568)
	Nehru Nagar(2.744±1.578)	DTU(5.024±1.290)	Mundaka(0.982±0.466)	DTU(1.809±0.729)
lockdown phase 1	Mandir Marg(2.535±0.238)	Najafgargh(3.04±0.917)	Ashok Vihar(0.755±0.119)	Ashok Vihar(1.236±0.198)
	Ashok Vihar(2.035±0.331)	Bawana(2.594±0.884)	Mundaka(0.487±0.157)	Najafgargh(1.094±0.33)
	Mundaka(1.353±0.437)	Rohini(2.363±0.862)	Bawana(0.447±0.164)	Rohini(0.851±0.310)
lockdown phase 2	ITO(2.305±0.953)	North campus(4.281±1.876)	Punjabi Bagh(0.523±0.306)	North Campus(1.541±0.411)
	Punjabi Bagh(1.538±0.729)	Alipur(3.673±1.2230)	Bawana(0.5±0.173)	Bawana(1.269±0.659)
	Lodhi Garden(1.405±0.334)	Rohini(2.9520.983)	Rohini(0.453±0.162)	Ashok Vihar(1.134±0.285)
lockdown phase 3	Punjabi Bagh(2.003±1.436	Narela(3.683±1.096	Mandir Marg(0.999±0.116)	Rohini(0.509±0.220)
	Aya Nagar(1.796±0.177	Alipur(3.364±1.110	Punjabi Bagh(0.721±0.517)	Mandir Marg(2.281±0.252)
	Bawana(1.389±0.481	Punjabi bagh(3.421±1.909	Rohini(0.509±0.220)	Narela(1.326±0394)
lockdown phase 4	Punjabi Bagh(2.137±1.794)	Narela(4.576±1.873)	Punjabi Bagh(0.769±0.646)	Narela(1.647±0.674)
	Bawana(1.753±0.83)	DTU(4.483±1.876)	Bawana(0.631±0.299)	Alipur(1.627±0.694)
	NSIT(1.726±0.549)	Jahangirpuri(3.118±0.434)	NSIT(0.622±0.198)	Bawana(1.6±0.611)
Unlock phase 1	ITO(1.576±0.522)	Bawana(3.522±1.406)	ITO(0.567±0.188)	Bawana(1.268±0.506)
	NSIT(1.421±0.483)	Narela(3.364±1.267)	NSIT(0.511±0.174)	Dwarka Sector 8(1.161±0.476)
	Anand Vihar(1.414±0.411)	Dwarka Sector 8(3.226±1.322)	Anand Vihar(0.505±0.148)	Narela(1.211±0.459)



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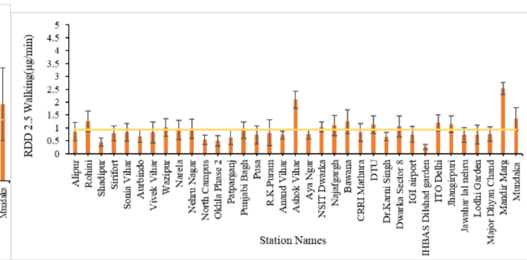

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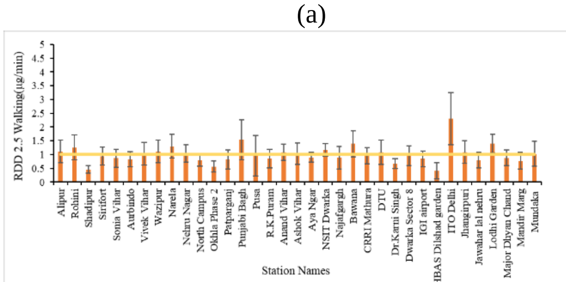

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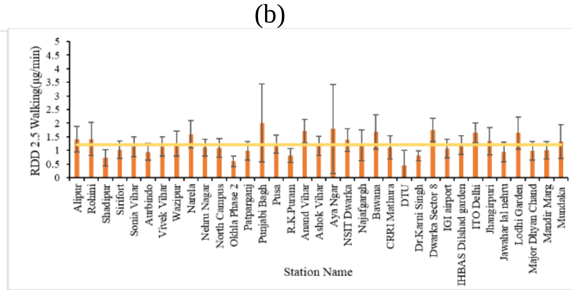

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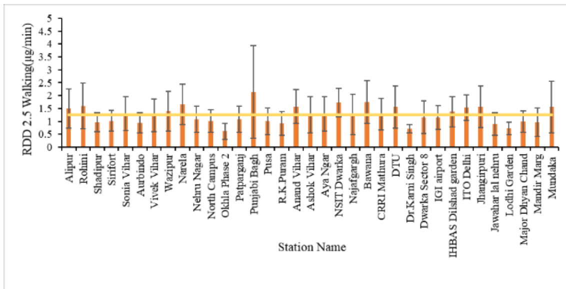

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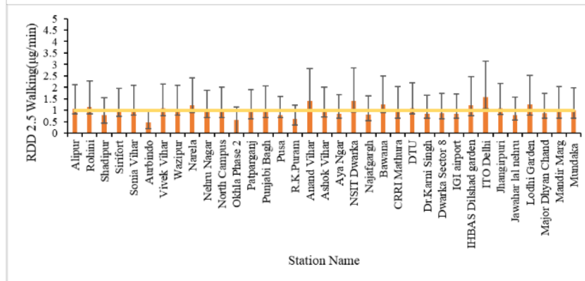
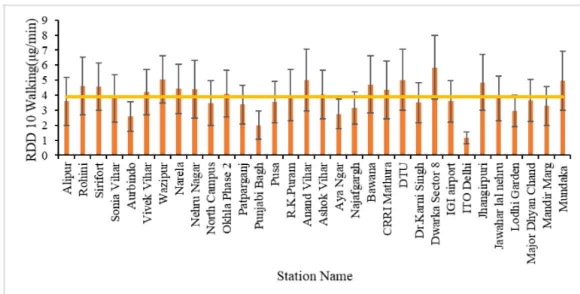


(f)

Figure 2: RDD2.5 Walking values during (a) before lockdown (b) lockdown phase 1 (c) lockdown phase 2 (d) lockdown phase 3 (e) lockdown phase 4 (f) unlock phase 1. The vertical error bars represent the standard deviation



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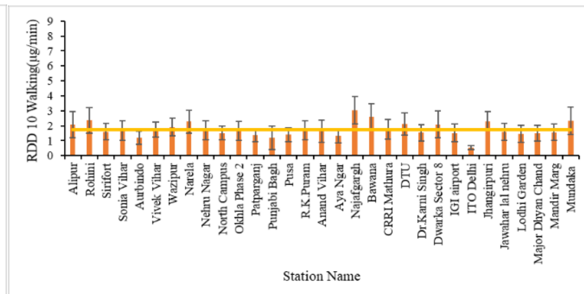

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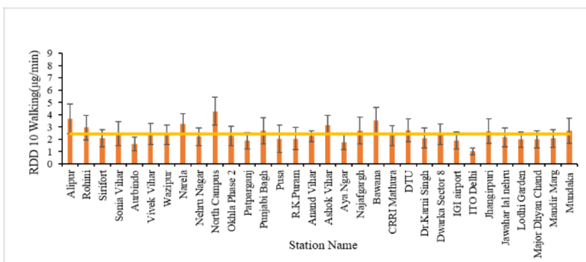

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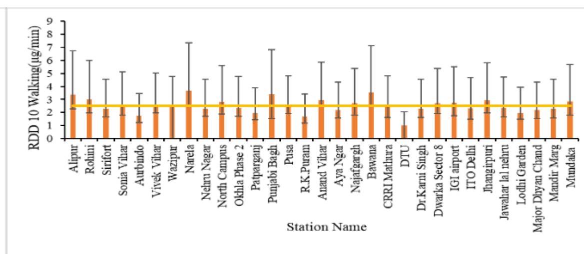

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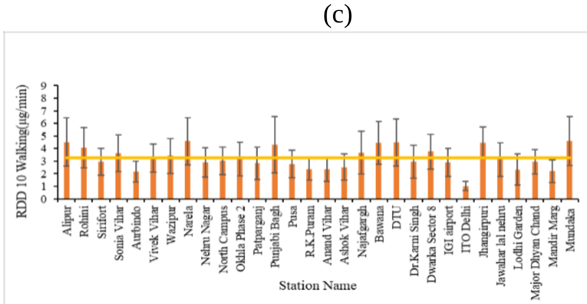

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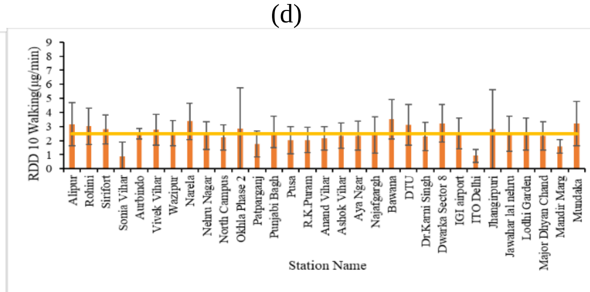
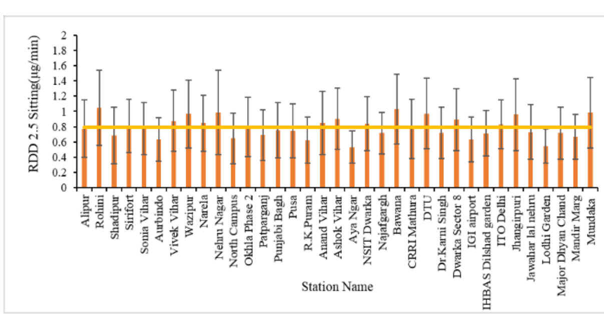


(f)

Figure 3: RDD 10 Walking values during (a) before lockdown (b) lockdown phase 1 (c) lockdown phase 2 (d) lockdown phase 3 (e) lockdown phase 4 (f) unlock phase 1.The vertical error bar represents the standard deviation.



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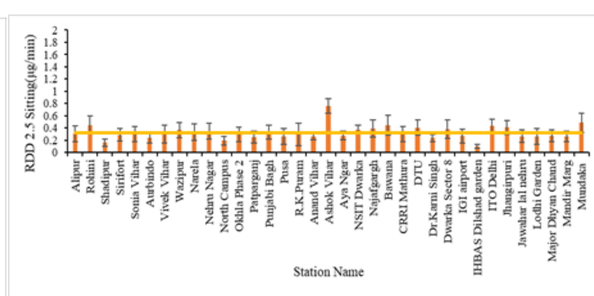

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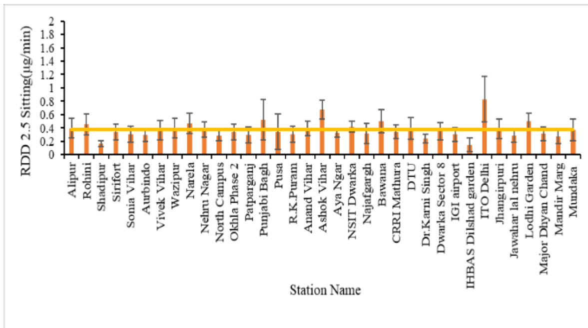

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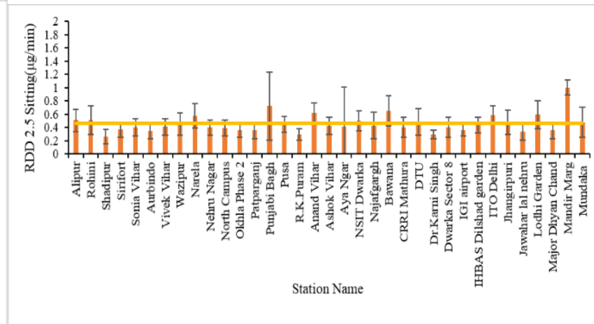

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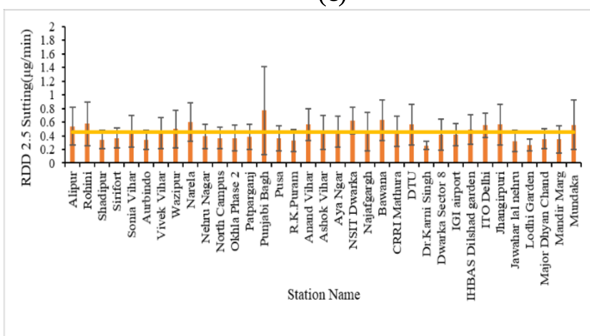

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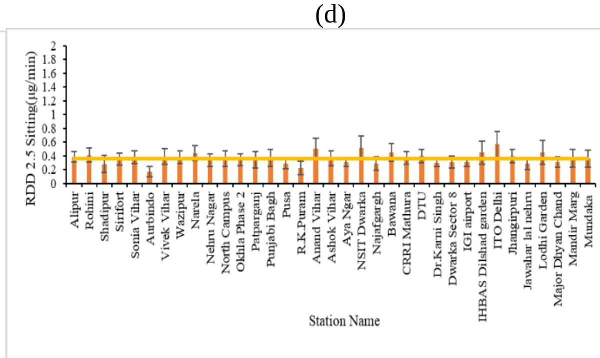
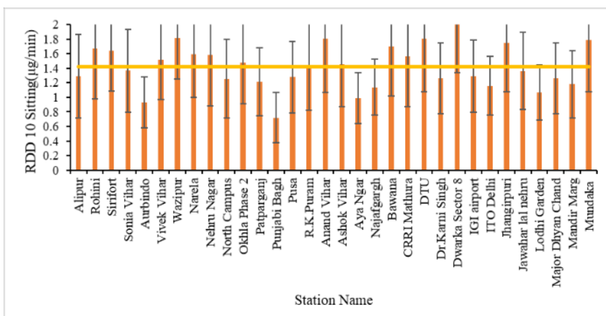


(f)

Figure 4: RDD 2.5 Sitting values during (a) before lockdown (b) lockdown phase 1 (c) lockdown phase 2 (d) lockdown phase 3 (e) lockdown phase 4 (f) unlock phase 1.The vertical error bar represents the standard deviation.



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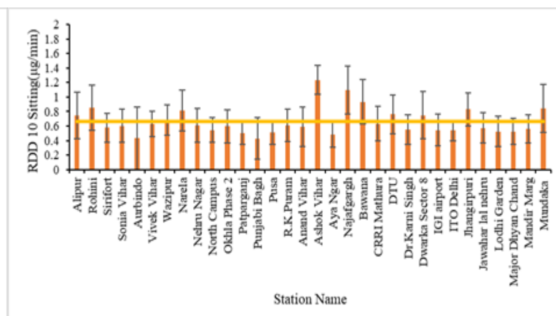

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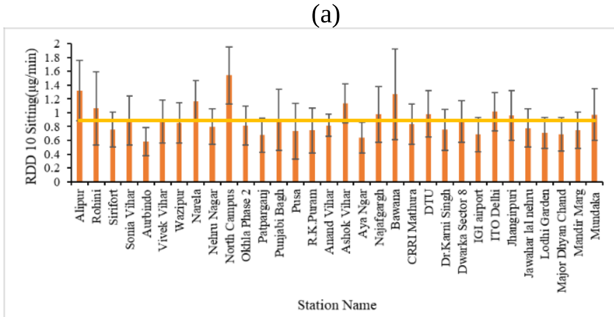

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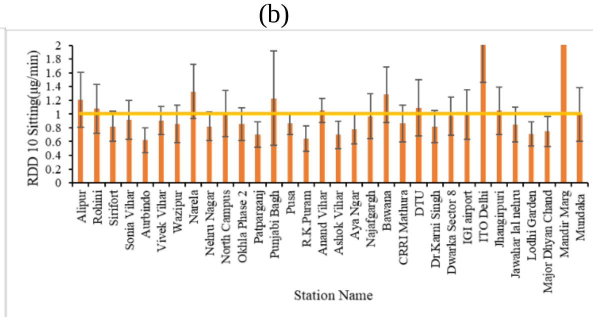

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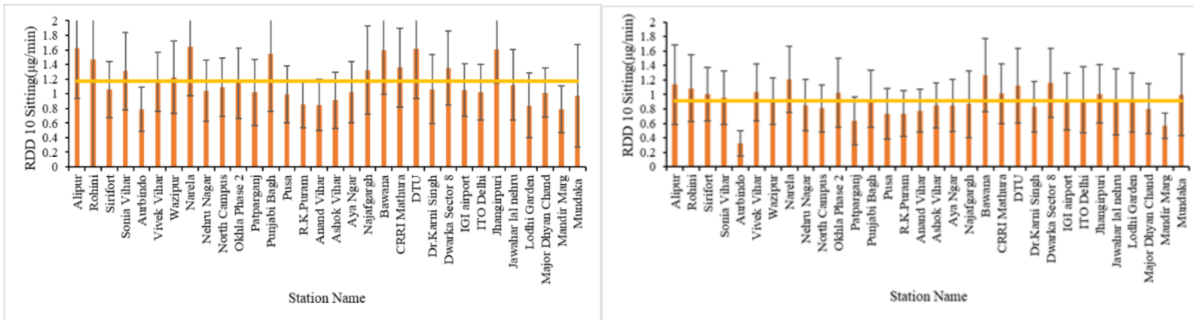


(e) (f)

Figure 5: RDD 10 Sitting values during (a) before lockdown (b) lockdown phase 1 (c) lockdown phase 2 (d) lockdown phase 3 (e) lockdown phase 4 (f) unlock phase 1.The vertical error bar represents the standard deviation.

While conducting the GIS study, the shape file of Delhi ward boundary,2022 has been uploaded from Environmental Systems Research Institution(ESRI). The pollution data of 35 stations have been mapped in GIS environment under under Geographic co-ordinate system, GCS_WGS_1984.

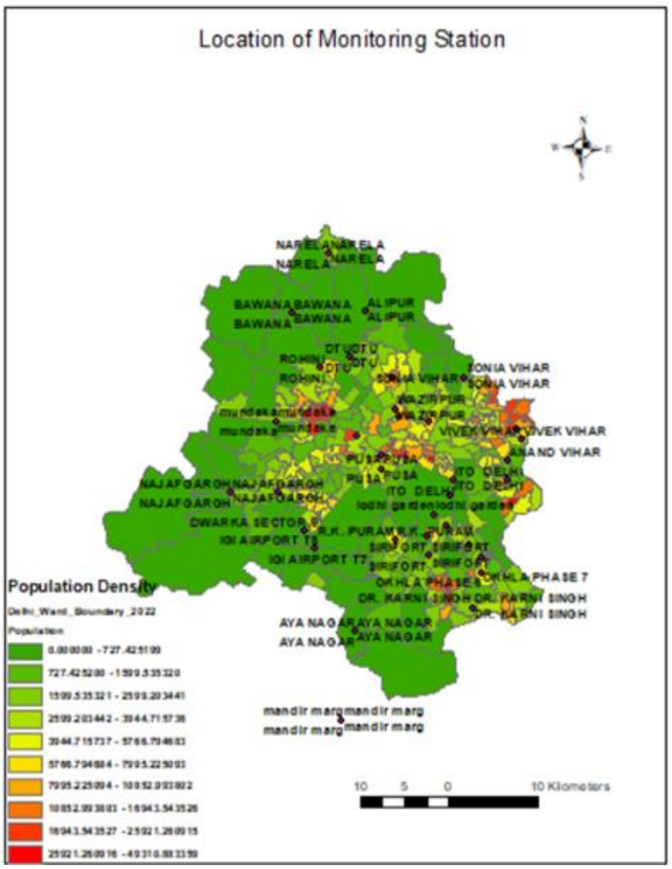


Figure 6: Location of Pollution Monitoring Station

In the above map, legends show the population density, which has been reclassified in 10 sections.

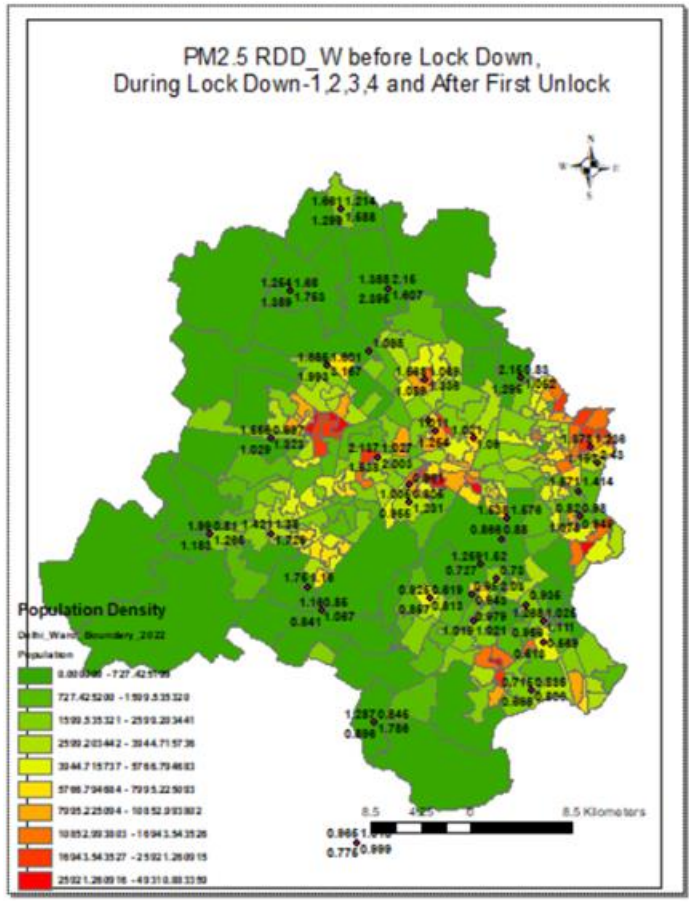


Figure 7: PM2.5 RDD_W before lock down and during lock down ph-1,2,3,4 and after first unlock

The above map shows that RDD load was higher in dense populated area except Bawana as it is industrial area, hence RDD load is more despite being non-dense populated area.

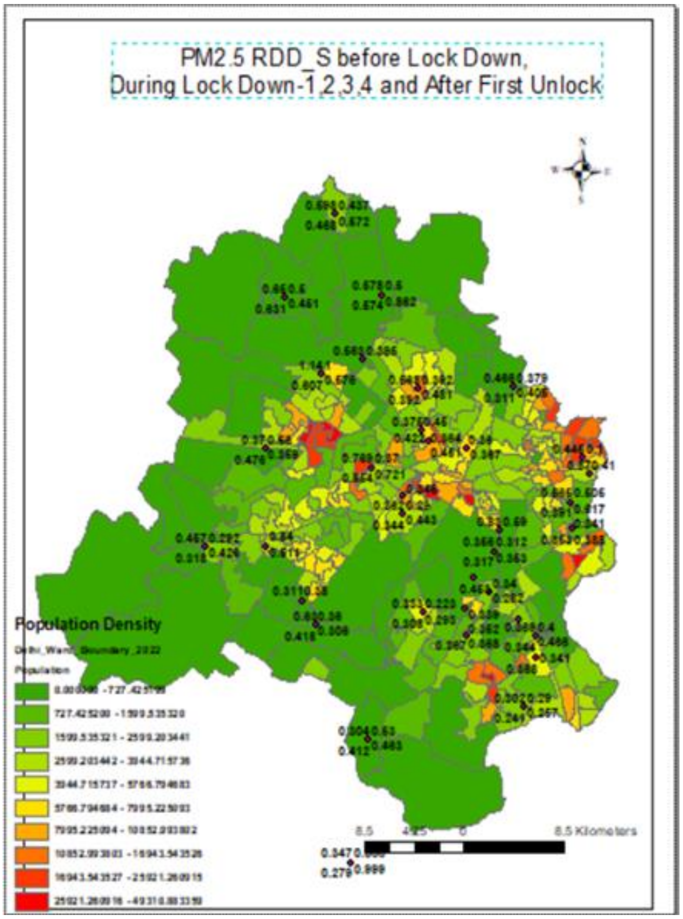


Figure 8: PM2.5 RDD_S before lock down and during lock down ph-1,2,3,4 and after first unlock

The above map shows that RDD load was again higher in dense populated area even in sitting condition except Bawana as it is industrial area, hence RDD load is more despite being non-dense populated area.

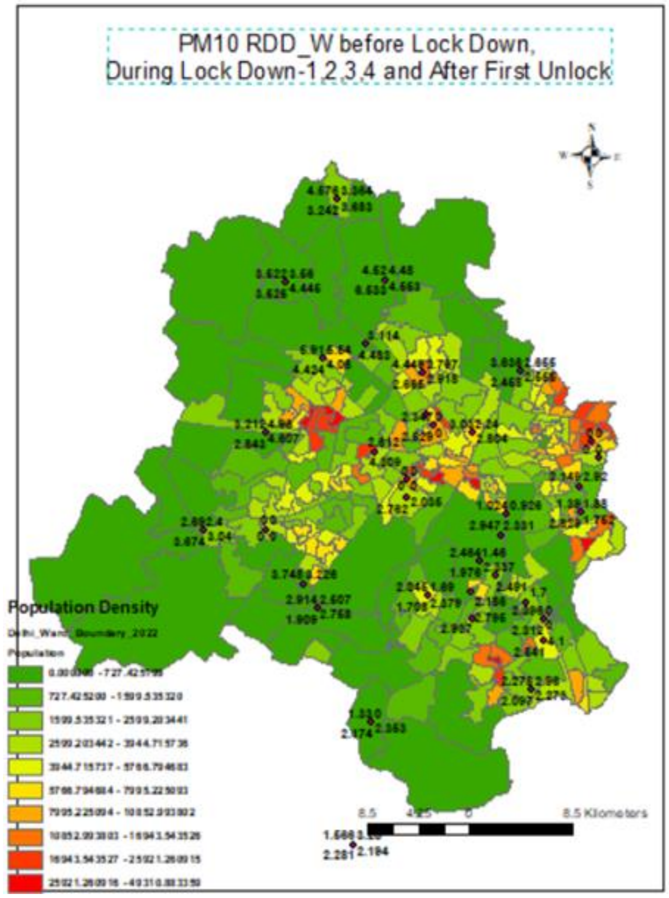


Figure 9: PM10 RDD_W before lock down and during lock down ph-1,2,3,4 and after first unlock

The above map shows that RDD load is higher in dense populated area except Bawana as it is industrial area, hence RDD load is more despite being non-dense populated area.

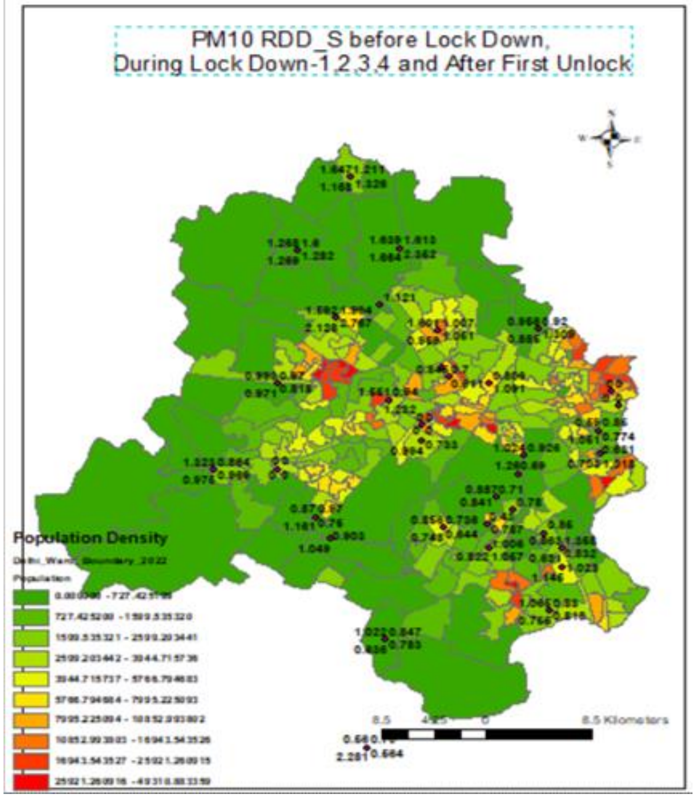
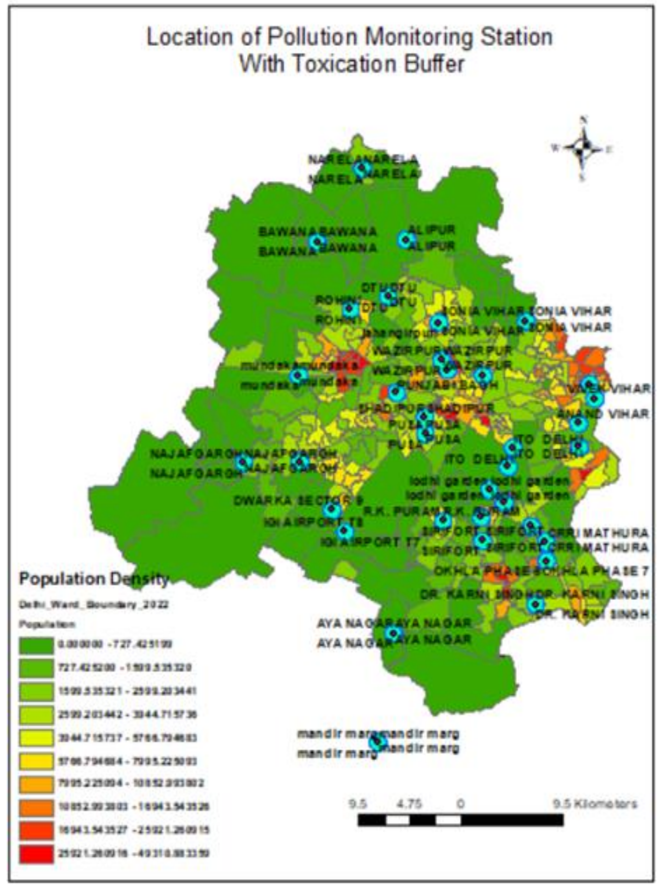


Figure 10: PM10 RDD_S before lock down and during lock down ph-1,2,3,4 and after first unlock

The above map shows that RDD load is higher in dense populated area even in sitting condition except Bawana as it is industrial area, hence RDD load is more despite being non-dense populated area.



The Buffer tool used in ArcGIS to create a new coverage of buffer polygons around specified input coverage features. In our case the feature is PM2.5, PM10 concentration around monitoring station.

Buffer tool has been used to identify or define an area within a specified distance around a feature i.e. ½ miles (802 meter) as recommended by United States Environmental Protection Agency and the effect of pollutant is observed on people, who are present after a buffer distance of 802 meter.

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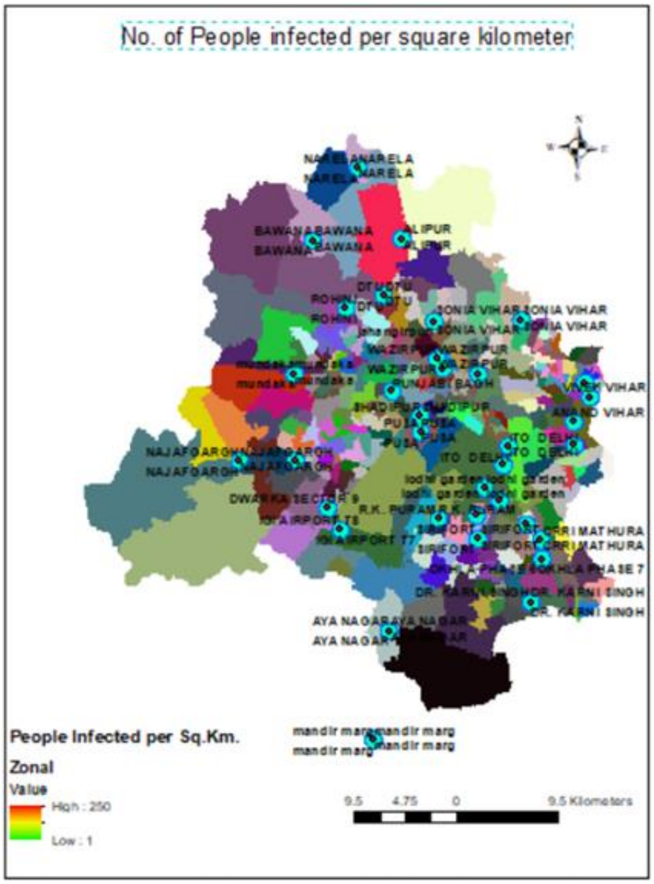

With the Zonal Statistics tool, a statistic is calculated for each zone defined by a zone dataset, based on values from another dataset (a value raster). A single output value is computed for every zone in the input zone dataset.

A zone is all the cells in a raster that have the same value, whether or not they are contiguous. The input zone layer defines the shape, values, and locations of the zones. An integer field in the zone input is specified to define the zones. A string field can also be used. Both raster and feature datasets can be used as the zone dataset.

The input value raster contains the input values used in calculating the output statistic for each zone.

Accordingly, above map shows that 250 no. of people per kilo meter square are would be affected by toxic release inventory as per the data of CPCB in this study.

3. Results and Discussion

RDD values are calculated for both fine and coarse particles using the data collected from the CPCB portal. Station wise RDD2.5 and RDD10 during standing and walking during all phases is shown in Figure 3 to Figure 5. In between 35 stations, it was found that most of the time Bawana has higher RDD2.5 and RDD10 values during different phases as it's an industrial area. Sri Aurobindo Marg and ITO, Delhi have low RDD10 values most of the time particularly during lock down as its dense populated institutional areas and commercial and residential areas respectively. Both the values of RDD2.5 and RDD10 decreased during lockdown phase 1, there was a decrease of 58.08% as there was a complete lockdown. After the removal of restriction during different lockdown phases there was an increase in RDD (10 or 2.5) values for about 24.24% in lockdown phase 2 then about 15.12% lockdown phase 3, 11.8% during lockdown phase 4. On the contrary, during unlock phase 1 there decrease in values of RDD(10 or 2.5)) of about 21.76% because of the precipitation which suppresses the concentration of ambient particulate matter in the environment [27]. One study was conducted in small city of Portugal in two different phases emergency phase (lockdown phase) and calamity phase (less restricted phase) and its was found a low concentration of PM in the emergency phase ($PM_{2.5}$ = 5.15 ± 2.77 μg m^{-3}; PM_{10} = 23.30 ± 21.53 μg m^{-3}) then in calamity phase ($PM_{2.5}$ = 30.92 ± 31.93 μg m^{-3}; PM_{10} = 111.27 ± 104.53 μg m^{-3})[34]. Another study was conducted in four cities in Europe and one in China and it found a reduction in PM_{10} concentration of 6% in Nice, 32% in Valencia, 49% in Wuhan, 9 % in Turin and an increase of 2% in Rome while for $PM_{2.5}$ reduction in concentration was 2.9% in Nice,12.6% in Turin 12.6% in Valencia 36.6% in Wuhan and increase of 10.6% in Rome[36]. For Delhi, before lockdown $PM_{2.5}/PM_{10}$ is 0.555 during lockdown phases its value decreased in lockdown phase 1 $PM_{2.5}/PM_{10}$ ratio was reduce to 0.517 in lockdown phase 2 it reduces to 0.455 but as the restriction remove its value increase up to 0.488 in lockdown phase 3 and 0.504 in lockdown phase 4 again its value decreases in unlock phase 1 0.429 because of the precipitation. The top three RDD values during different lockdown Phases is shown in Table 2

4. Conclusions

The study shows higher Respiratory deposition dose for both $PM_{2.5}$ and PM_{10} in walking and sitting mode before COVID-19 lockdown than during lockdown and unlock conditions. It shows that Delhi is exposed to higher particulate matter during normal days before lockdown and in lockdown phase once RDD values decrease and again by removing the restriction in different lockdown phases RDD value increase due to an increase in construction activity and vehicular traffic. Though after lockdown phase 4 RDD value decreased in unlocking phase 1 due to precipitation which reduce the particulate matter concentration and hence reduce the RDD value.RDD values were higher for 2019 as compared to 2020 because of the restriction during lockdown phases for both pre-monsoon and post-monsoon. Also, RDD walking values were always found to be greater than RDD in the sitting mode which shows that particle deposition is more during physical activity like walking than sitting. Hence RDD is directly related to the concentration of PM and physical activity. This study shows the importance of RDD in determining the health effect due to PM exposure during physical activity like walking and sitting in dense and less dense populated areas and the importance of continued efforts to reduce pollution and implement sustainable transportation and develop policies to maintain lower PM concentration seen during the lockdown. It is also concluded that results of the empirical study are corroborated perfectly by the GIS study. The population density favours the PM2.5 and PM10 RDD_W and RDD_S loads. The study also reveals that 250 nos. of people per square km of area would be 100% affected, however those who are away from buffer distance would be less affected relatively.

References

[1] R. Fuller *et al.*, "Pollution and health: a progress update," *Lancet Planet. Heal.*, vol. 6, no. 6, pp. e535–e547, 2022, doi: 10.1016/S2542-5196(22)00090-0.

[2] WHO, *Managing epidemics*. 2018. [Online]. Available: https://www.who.int/emergencies/diseases/managing-epidemics/en/

[3] A. Pandey *et al.*, "Health and economic impact of air pollution in the states of India: the Global Burden of Disease Study 2019," *Lancet Planet. Heal.*, vol. 5, no. 1, pp. e25–e38, 2021, doi: 10.1016/S2542-5196(20)30298-9.

[4] A. Fiordelisi, P. Piscitelli, B. Trimarco, E. Coscioni, G. Iaccarino, and D. Sorriento, "The mechanisms of air pollution and particulate matter in cardiovascular diseases," *Heart Fail. Rev.*, vol. 22, no. 3, pp. 337–347, 2017, doi: 10.1007/s10741-017-9606-7.

[5] M. R. Miller, C. A. Shaw, and J. P. Langrish, "From particles to patients: Oxidative stress and the cardiovascular effects of air pollution," *Future Cardiol.*, vol. 8, no. 4, pp. 577–602, 2012, doi: 10.2217/fca.12.43.

[6] P. Fantke *et al.*, "Global Effect Factors for Exposure to Fine Particulate Matter," *Environ. Sci. Technol.*, vol. 53, no. 12, pp. 6855–6868, 2019, doi: 10.1021/acs.est.9b01800.

[7] J. Guo *et al.*, "The climatology of planetary boundary layer height in China derived from radiosonde and reanalysis data," *Atmos. Chem. Phys.*, vol. 16, no. 20, pp. 13309–13319, 2016, doi: 10.5194/acp-16-13309-2016.

[8] C. F. Wu *et al.*, "Association of short-term exposure to fine particulate matter and nitrogen dioxide with acute cardiovascular effects," *Sci. Total Environ.*, vol. 569–570, no. 17, pp. 300–305, 2016, doi: 10.1016/j.scitotenv.2016.06.084.

[9] P. J. Landrigan, "Air pollution and health," *Lancet Public Heal.*, vol. 2, no. 1, pp. e4–e5, 2017, doi: 10.1016/S2468-2667(16)30023-8.

[10] K. Agay-Shay, M. Friger, S. Linn, A. Peled, Y. Amitai, and C. Peretz, "Air pollution and congenital heart defects," *Environ. Res.*, vol. 124, no. 2, pp. 28–34, 2013, doi: 10.1016/j.envres.2013.03.005.

[11] L. wen Zhang *et al.*, "Long-term exposure to high particulate matter pollution and cardiovascular mortality: A 12-year cohort study in four cities in northern China," *Environ. Int.*, vol. 62, pp. 41–47, 2014, doi: 10.1016/j.envint.2013.09.012.

[12] P. Li *et al.*, "Time-series analysis of mortality effects from airborne particulate matter size fractions in Beijing," *Atmos. Environ.*, vol. 81, pp. 253–262, 2013, doi: 10.1016/j.atmosenv.2013.09.004.

[13] P. Schifano, A. Lallo, F. Asta, M. De Sario, M. Davoli, and P. Michelozzi, "Effect of ambient temperature and air pollutants on the risk of preterm birth, Rome 2001-2010," *Environ. Int.*, vol. 61, pp. 77–87, 2013, doi: 10.1016/j.envint.2013.09.005.

[14] M. V. Coronas *et al.*, "Genetic biomonitoring of an urban population exposed to mutagenic airborne pollutants," *Environ. Int.*, vol. 35, no. 7, pp. 1023–1029, 2009, doi: 10.1016/j.envint.2009.05.001.

[15] A. Pollution, E. During, and U. Measures, "Research | Children ' s Health Air Pollution Exposure During Pregnancy , Ultrasound Measures of Fetal Growth , and Adverse Birth Outcomes : A Prospective Cohort Study," vol. 150, no. 1, pp. 150–157, 2012.

[16] A. Nf- *et al.*, "Ambient Particulate Matter Induces Interleukin - 8 Expression through an," vol. 119, no. 10, pp. 1379–1383, 2011.

[17] S.-H. Park *et al.*, "Particulate matter promotes cancer metastasis through increased HBEGF expression in macrophages," *Exp. Mol. Med.*, no. August, 2022, doi: 10.1038/s12276-022-00886-x.

[18] S. R. Weiss and S. Navas-Martin, "Coronavirus Pathogenesis and the Emerging Pathogen Severe Acute Respiratory Syndrome Coronavirus," *Microbiol. Mol. Biol. Rev.*, vol. 69, no. 4, pp. 635–664, 2005, doi: 10.1128/mmbr.69.4.635-664.2005.

[19] S. Kumar, "Effect of meteorological parameters on spread of COVID-19 in India and air quality during lockdown," *Sci. Total Environ.*, vol. 745, p. 141021, 2020, doi: 10.1016/j.scitotenv.2020.141021.

[20] S. Romano *et al.*, "Ecotoxicity, genotoxicity, and oxidative potential tests of atmospheric PM10 particles," *Atmos. Environ.*, vol. 221, no. June 2019, p. 117085, 2020, doi: 10.1016/j.atmosenv.2019.117085.

[21] Y. Cui *et al.*, "Air pollution and case fatality of SARS in the People's Republic of China: An ecologic study," *Environ. Heal. A Glob. Access Sci. Source*, vol. 2, pp. 1–5, 2003, doi: 10.1186/1476-069X-2-1.

[22] M. Coccia, "Factors determining the diffusion of COVID-19 and suggested strategy to prevent future accelerated viral infectivity similar to COVID," *Sci. Total Environ.*, vol. 729, p. 138474, 2020, doi: 10.1016/j.scitotenv.2020.138474.

[23] WHO, "No Title," 2019. [Online]. Available: https://www.who.int/emergencies/diseases/novel-coronavirus-2019

[24] A. Goel and P. Kumar, "A review of fundamental drivers governing the emissions, dispersion and exposure to vehicle-emitted nanoparticles at signalised traffic intersections," *Atmos. Environ.*, vol. 97, pp. 316–331, 2014, doi: 10.1016/j.atmosenv.2014.08.037.

[25] K. V. Abhijith and P. Kumar, "Evaluation of respiratory deposition doses in the presence of green infrastructure," *Air Qual. Atmos. Heal.*, vol. 14, no. 6, pp. 911–924, 2021, doi: 10.1007/s11869-021-00989-w.

[26] K. Slezakova, M. C. Pereira, and S. Morais, "Ultrafine particles: Levels in ambient air during outdoor sport activities," *Environ. Pollut.*, vol. 258, p. 113648, 2020, doi: 10.1016/j.envpol.2019.113648.

[27] S. Fatima, A. Ahlawat, S. K. Mishra, V. K. Soni, and R.

Guleria, "Respiratory Deposition Dose of PM2.5 and PM10 Before, During and After COVID-19 Lockdown Phases in Megacity-Delhi, India," *Mapan - J. Metrol. Soc. India*, 2022, doi: 10.1007/s12647-022-00548-3.
[28] N. Schneider, M. Mele, C. Magazzino, and N. Khan, "An Exploratory Study of Impact of Lockdown on the Air Quality of Delhi," *Appl. Ecol. Environ. Sci.*, vol. 8, no. 5, pp. 261–268, 2020, doi: 10.12691/aees-8-5-11.
[29] ICRP publication 66, "Human Respiratory Tract Model For Radiological Protection." pp. 1–482. [Online]. Available: https://www.icrp.org/publication.asp?id=icrp publication 66
[30] P. Kumar, I. Rivas, A. P. Singh, V. J. Ganesh, M. Ananya, and H. C. Frey, "Dynamics of coarse and fine particle exposure in transport microenvironments," *npj Clim. Atmos. Sci.*, vol. 1, no. 1, 2018, doi: 10.1038/s41612-018-0023-y.
[31] F. Azarmi and P. Kumar, "Ambient exposure to coarse and fine particle emissions from building demolition," *Atmos. Environ.*, vol. 137, pp. 62–79, 2016, doi: 10.1016/j.atmosenv.2016.04.029.
[32] S. K. Gupta and S. P. Elumalai, "Size-segregated particulate matter and its association with respiratory deposition doses among outdoor exercisers in Dhanbad City, India," *J. Air Waste Manag. Assoc.*, vol. 67, no. 10, pp. 1137–1145, 2017, doi: 10.1080/10962247.2017.1344159.
[33] W. C. Hinds, "Aerosol Technology Properties, Behavior, and Measurement ofAirborne Particles Second Edition," *J. Aerosol Sci.*, vol. 14, no. 2, p. 175, 1999.
[34] Y. Alonso, A. Cr, P. Krecl, L. Campestrini, A. Alves, and M. Feliciano, "Ambient concentrations and dosimetry of inhaled size-segregated particulate matter during periods of low urban mobility in," vol. 13, no. August, 2022, doi: 10.1016/j.apr.2022.101512.
[35] Sicard, P., De Marco, A., Agathokleous, E., Feng, Z., Xu, X., Paoletti, E., Rodriguez, J.J.D., Calatayud, V., 2020. Amplified ozone pollution in cities during the COVID-19 lockdown. Sci. Total Environ. 735, 139542 https://doi.org/10.1016/J. SCITOTENV.2020.139542.