International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 3, 2025
https://www.theaspd.com/ijes.phpa

Influence Of Particulate Matter Pollutants On COVID-19 In The Greater Chennai Region Using In-Situ Data And AERMOD Modelling

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ABSTRACT
Particulate matter (PM) is a major air pollutant that has been associated with negative effects on respiratory health. This study investigates the relationship between particulate matter pollutants and their influence on COVID-19 transmission, positivity, and mortality in selected zones of the Greater Chennai region. Utilizing real-time in-situ data, we analyzed PM2.5 and PM10 pollution levels and employed AERMOD modeling to simulate the dispersion of pollutant concentrations across six distinct zones over four time periods. Our findings identified Annanagar, Ambattur, Valasaravakkam, and Kodambakkam as pollution hotspots, with levels surpassing the Central Pollution Control Board (CPCB) norm of 60μg/m³. The predicted PM10 and PM2.5 concentrations impacted 349 streets and 32 wards, covering approximately 7.41 km² and 21.2 km², respectively, with PM10 levels being widely distributed throughout the study area. This study emphasizes the vital importance of air quality modeling in comprehending the dynamics of disease transmission, especially in the densely populated regions of Chennai, and its potential to combat infectious diseases like COVID-19. Our findings revealed that PM10 concentrations were consistently double those of PM2.5 both prior to and following the lockdown. Furthermore, higher levels of particulate matter were linked to a rise in COVID-19 deaths, with a 54% increase tied to PM2.5 and a 60% rise associated with PM10 pollution in the designated areas.
Keywords: *Particulate matter, Pollution Dispersion, COVID-19 Mortality, COVID-19 Positivity, AERMOD modeling.*

1.0 INTRODUCTION

Air pollution is a critical concern worldwide due to its adverse effects on the environment and human health. In the United States, six criteria air pollutants are regulated, including PM10 and PM2.5, with primary sources being vehicular exhaust and road dust(Ndar & Kosankar 2014). India, specifically Chennai, has witnessed a significant rise in motorized vehicles, making vehicular emissions a major contributor to pollution(M. Nadeem et al. 2020). Chennai, a major Indian city with a booming municipal economy, faces substantial air pollution challenges, particularly concerning Particulate Matter (PM), exceeding the National Ambient Air Quality Standards (NAAQS) at high-traffic urban sites (Sivaramasundaram & Muthusubramanian 2010). To comprehensively assess air quality, health impacts, and environmental consequences, air dispersion modelling tools, such as AERMOD, have been employed at city scales to predict emissions from various pollution sources(Tenforde et al. 2022). However, recent events, including the COVID-19 pandemic, have led to significant

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reductions in pollution levels due to lockdown measures, offering a unique opportunity to study air quality dynamics in Chennai(Puttaswamy et al. 2022). Air pollution remains a global challenge, particularly in Asian countries with higher population densities, including India, where many major cities exceed WHO standards for ambient air pollution(Nirmala, Mallika & Gomathi 2021). Megacities like Chennai are epicentres of intensive human activities, economic growth, and energy consumption, leading to concentrated emissions of air pollutants that adversely affect ecosystems, air quality, and climate(Jacob & Winner 2009). In Chennai, PM_{10} and $PM_{2.5}$ levels have consistently exceeded prescribed standards up to 2019, however, the onset of the COVID-19 pandemic and subsequent lockdowns led to a drastic reduction in particulate matter concentrations. The Greenpeace report revealed that Chennai's annual average $PM_{2.5}$ concentration remained five times higher than the WHO limit(Singh 2024). Hence the study has been attempted to bridge the gaps by evaluating air pollution levels, modelling dispersion, identifying hotspots, and correlating pollution with COVID-19 positivity rates and mortality rates across all four-time frames. Ultimately, this research will aid in prioritizing zones for targeted vaccination efforts to mitigate the spread of COVID-19.

2.0 STUDY AREA

The study area is part of Greater Chennai, India which covers 44 wards and six zones with 10 sampling stations as indicated in the Fig 1.

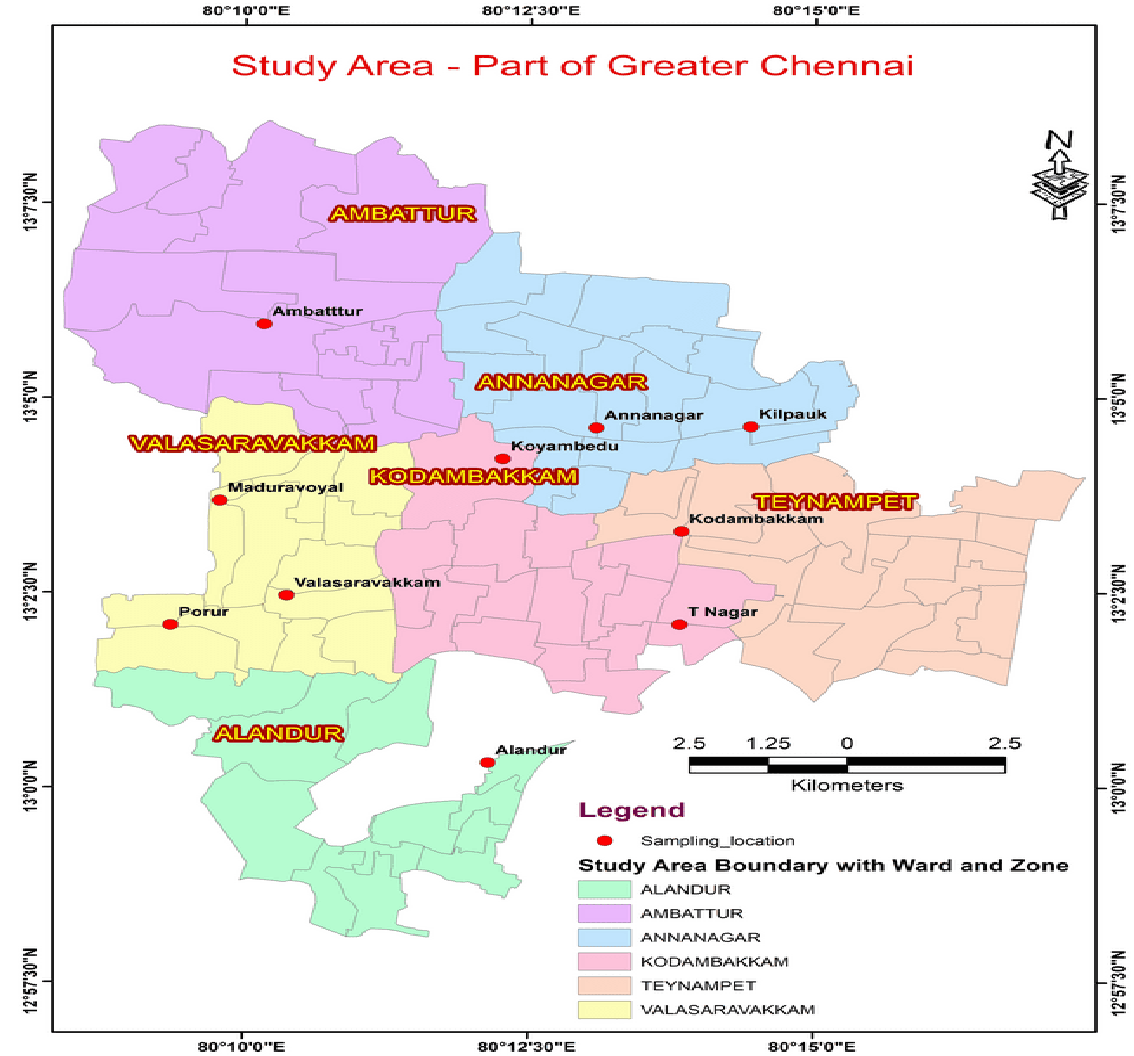

Fig. 1 Sampling Location and Study area

3.0 DATA COLLECTION

3.1 Primary Data Collection

Pollutant ($PM_{2.5}$ and PM_{10}) concentration was primarily collected using fine particulate sampler Envirotech Model APM 550M and indigenous portable MGR air pollution monitoring device Fig. 2 during the pre-lockdown period from 2019 (Oct-Dec) & 2020 (Jan-March-19th).

Fig. 2 Field measurements of particulate matter pollutants using high volume APM550 air sampler and indigenous device with our team

3.2Secondary Data Collection

Meteorological data for the study area were collected in order to run the AERMOD model. Because the model assumes a consistent set of hourly meteorological inputs which influences PM concentrations at all distances throughout the simulated hour. The input data's such as wind speed, wind direction, dry bulb temperature, cloud cover, ceiling height, relative humidity, atmospheric pressure, radiation and dewpoint temperature and other data were obtained from CPCB and Iowa Environmental Mesonet (IEM). Further the COVID-19 positivity and mortality data are collected from Greater Chennai Corporation and ICMR.

4.0 METHODOLOGY

Well-calibrated ambient air quality observing instrument Envirotech APM 550 and indigenous portable MGR Air pollution mobile monitoring device is used to estimate and quantify the particulate matter pollution. The sampling stations and measurements are planned and used with built-in ADC in microcontroller@mega328 and solid-state gas sensors. IOT, GIS, and GPS technologies are used to decode sensor voltage values compared to gas convergence during measurements.

Stepwise procedures

Step1: The existing travel and transport characteristics of the study area were assessed through primary surveys to understand the traffic pattern and mode choice. The survey has been conducted during peak hours (8:00 am to 11:00 am) morning and (4:00 pm to 7:00 pm) evening. From these traffic counts, the quantum of traffic volume during peak hours of the day was obtained and the data was further analysed to understand the composition of traffic by vehicle type.

Step 2: The preliminary literatures suggest that expected COVID-19 cases increase by nearly 100 percent when pollution concentrations increase by 20 percent. Hence the sample size is calculated using the formula for cross sectional or descriptive studies as mentioned below

Sample size $(n) = \frac{\left(z_{1-\frac{\alpha}{2}}\right)^{2*} \times (p) \times (q)}{d^2}$

n = Desired sample size

$z_{1-\frac{\alpha}{2}}$= Critical value and a standard value for the corresponding level of confidence.
(At 95% CI or 5% level of significance (type-I error) it is 1.96 and at 99% CI it is 2.58)
P = Expected prevalence or based on previous research

For conducting a new cross-sectional study to identify the prevalence or proportion of PM influence on Covid-19 patients, minimum 246 subjects will be required.

Step 3: To find out the dispersion plumes and to predict the concentrations of pollutant from surface and elevated sources of simple and complex terrain. The proposed model uses digital elevation data, receptors for terrain pre-processor using AERMAP module, surface observations, upper air data, site meteorological data using AERMET module for calculating boundary layer parameters to use in AERMOD. The emission rates are estimated based on the location, vehicular mode, number of vehicles, number of km travelled by the vehicle in a year and its correlation with ambient air quality data. The AERMOD outputs are used to predict the concentrations and determine compliance with air quality standards.
Step 4: Compare RTPCR test results with the CT value of the infected people and correlate the same with the Particulate Matter size distribution.
Step 5: The correlation of COVID-19 positive cases and mortality rate with $PM_{2.5}$ distribution and PM_{10} distribution has been carried out.
The data used for modelling in AERMOD includes sensible heat flux, convective velocity vertical potential temperature gradient above Planetary Boundary Layer (PBL), height of convectively generated boundary layer - PBL, height of mechanically generated boundary layer - Stable Boundary Layer (SBL), surface roughness length, Bowens ratio, albedo, windspeed, wind direction, reference height for wind speed and wind direction, Monin Obukov length, temperature, reference height for temperature, precipitation rate, relative humidity, surface pressure and cloud cover.
Location, vehicular mode, number of vehicles, annual km travelled, and ambient air pollution data are used to estimate emission rates. The study used digital elevation data, receptors for terrain pre-processor using AERMAP module, surface observations, upper air data, site meteorological data using AERMET module for calculating boundary layer parameters to use in AERMOD.
AERMOD outputs are generated to predict the concentrations and to determine the compliance with air quality standards for all the 10 sampling stations during pre-lockdown, lockdown, semi-lockdown, and post-lockdown periods in 2019, 2020, and 2021. GIS map overlay techniques are used to analyse urban conditions and virus incidence in the study area to determine the relationship between PM pollution and COVID-19. The overall methodology adopted for the study is abridged in Fig. 3.

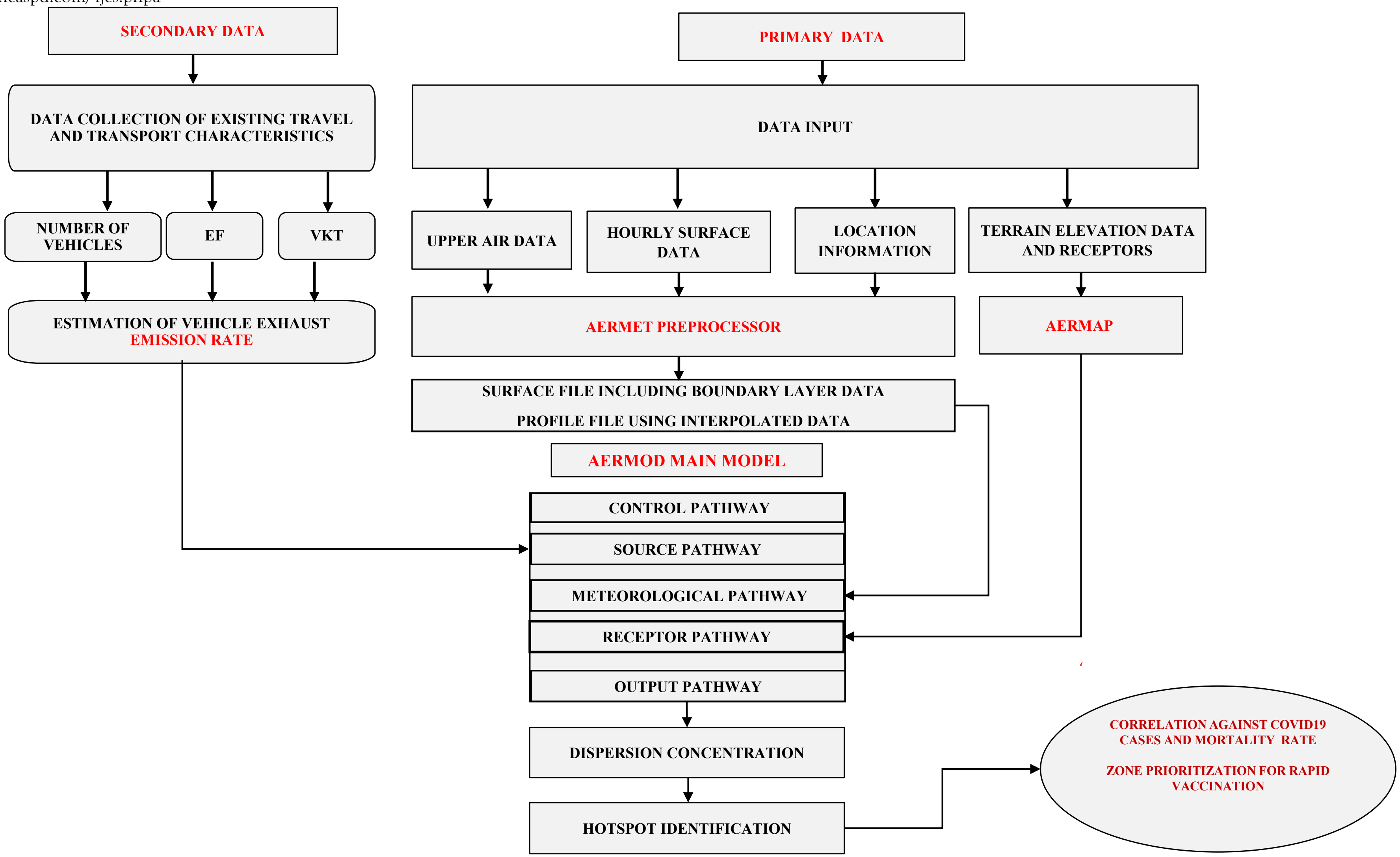

Fig. 3 Methodology developed for the study

5.0 RESULTS

5.1 AERMOD Modelling and Outputs for $PM_{2.5}$ and PM_{10} Pollutants

A baseline study for the atmospheric pollutant $PM_{2.5}$ and PM_{10} has been analysed for ten sampling stations covering part of Chennai during November 2019 and May 2020. During the baseline period the concentrations varied from 299 µg/m^3 to 38 µg/m^3 for $PM_{2.5}$ and 68 µg/m^3 to 3 µg/m^3 for PM_{10}. $PM_{2.5}$ and PM_{10} predictions for hourly, 8 hrs, 24 hrs and period concentrations were carried out and a sample output of AERMOD model is presented in Fig.4. The maximum concentration of the pollutant was taken considering the first three high-ranked values of the output options. Table 1 shows the maximum concentration obtained from the model during pre-lockdown period 2019 (Oct-Dec) & 2020 (Jan-March-19th), lockdown period 2020 (March-May) & 2021 (May), semi-lockdown period 2020 (June-Aug), post lockdown period 2020 (Sep-Dec) & 2021 (June -July).

Table 1 Predicted pollutant concentration using USEPA AERMOD Modelling

Sl.No	Period of Study	Area	$PM_{2.5}$ µg/m^3	PM_{10} µg/m^3	Peak Period (Month)
	2019 Prelockdown	Anna Nagar	141	292	Dec 2019
2	2020 Prelockdown	Ambattur	130	270	March 2020
3	2020 Lockdown	Maduravoyal	46	117	March 2020
4	2020 Semilockdown	Maduravayol	125	264	July 2020
5	2020 Postlockdown	Anna Nagar	173	360	Oct 2020
6	2021Prelockdown	Anna Nagar	116	241	Jan 2021
7.	2021 Lockdown	Maduravayol	38	51	May 2021
8	2021 Postlockdown	Koyembedu	206	428	June 2021

The highest emission concentration was observed in Koyambedu region due with values of 0.000158 g/s-m^2 which is well correlated with the vehicular inventory for the region. By considering the Line source(Gibson, Kundu & Satish 2013), the study utilized AERMOD modelling to predict the dispersion of particulate matters and their influence in the study area. According to model results, $PM_{2.5}$ concentration ranged from 38µg/m^3 to 206µg/m^3 and PM_{10} ranged from 51µg/m^3 to 428µg/m^3, respectively (Table 1).

5.2 HOTSPOT IDENTIFICATION

The $PM_{2.5}$ and PM_{10} hotspots for the study periods (2019-2021) are derived from the GIS map overlay from the outputs of AERMOD dispersion modelling and illustrated in the Fig. 5. The findings reveal that the Valasaravakkam zone, encompassing 107 streets and 12 wards, experienced significant $PM_{2.5}$ pollution with 77.6% of the total area (20.42 km^2) and PM_{10} with 45% of the total area (20.42 km^2).

Anna Nagar zone, comprising 7 wards and 122 streets, has been identified as one of the hotspots with highest pollutant concentrations, accounting for 13.1% of the total area (25.2 km^2) for $PM_{2.5}$ and 20% of the total area (25.2 km^2) for PM_{10} concentration.

The excess pollution loads affect 6.5 % of the total area (22.3 km^2) for $PM_{2.5}$ and 12.1 percent of the total area comprising 40 streets in the Kodambakkam zone, which consists of 5 wards.

About 3% of the total area i.e. 38.3 km^2 of Ambattur zone (S et al. 2022) is highly polluted for $PM_{2.5}$ and 10.4% for PM_{10} consisting 6 wards and 80 streets. However, $PM_{2.5}$ and PM_{10} concentrations in Alandur and Teynampet zones do not exceed the permitted limits and show no evidence of $PM_{2.5}$ concentration dispersion (0.44%), while PM_{10} concentrations have a negligible influence with 4.1% of the total area.

The findings resulted with pollutant levels in Annanagar, Ambattur, Valasaravakkam and Kodambakkam zones are higher and exceeds the prescribed norms of CPCB for the analysed period and hence identified as hotspots and indicated in the Fig. 5. to Fig. 9.

5.3 CORRELATION OF HOTSPOTS WITH COVID-19 POSITIVITY and MORTALITY

The average COVID-19-positive cases were obtained from Greater Chennai Corporation and ICMR for all four-study periods in Table 2. The correlation graphs between covid-19 positivity and mortality for $PM_{2.5}$, PM_{10} pollutants for four different zones i.e., along the hotspots identified for the part of greater Chennai has been presented in the below Fig. 10.1(a) to 10.1(h) & 10.2(a) to 10.2(h).

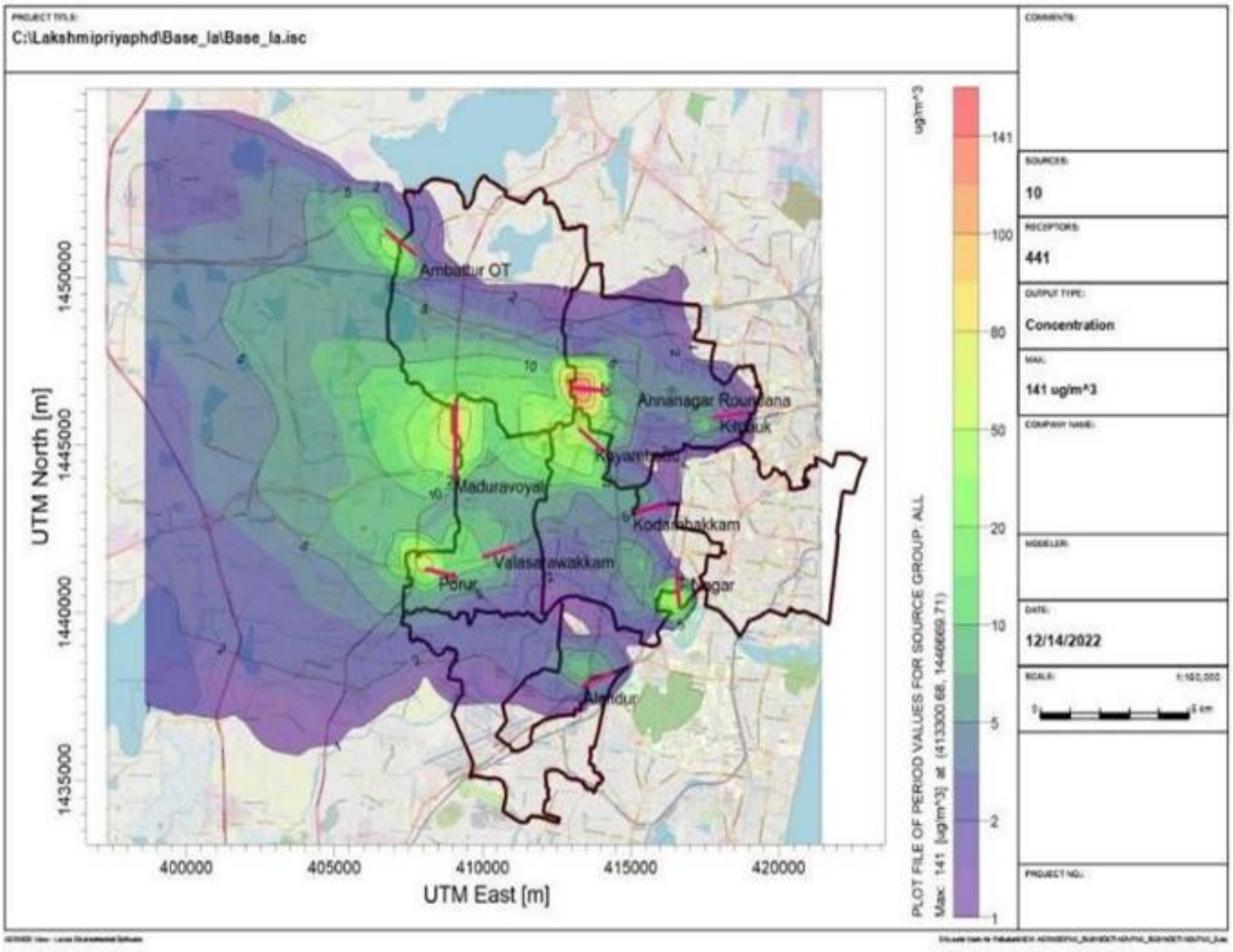

Fig. 4 Dispersion Plume of PM2.5 pollution using AERMOD Modelling

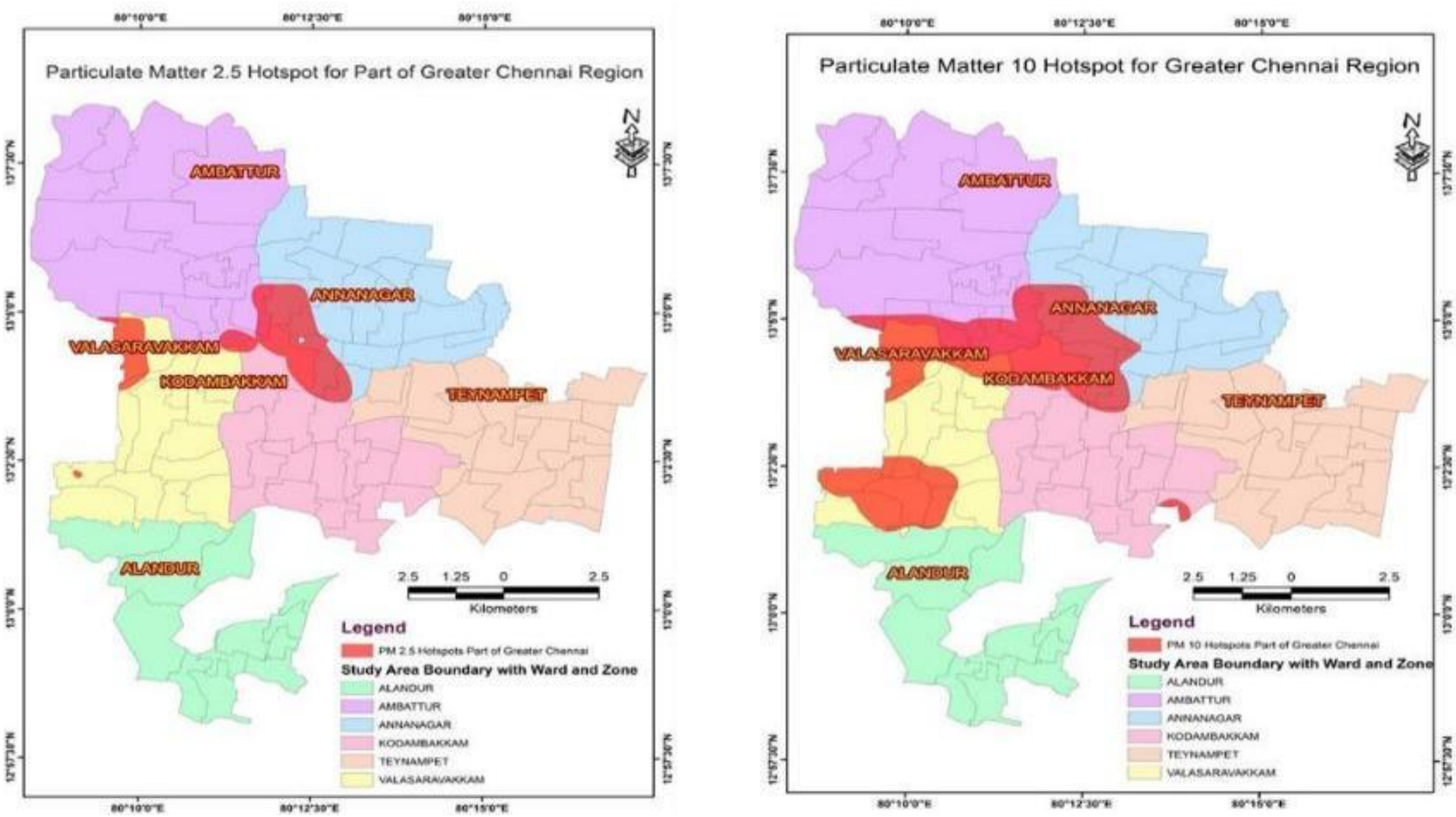

Figure 5 Particulate Matter 2.5 and 10 Hotspot for Greater

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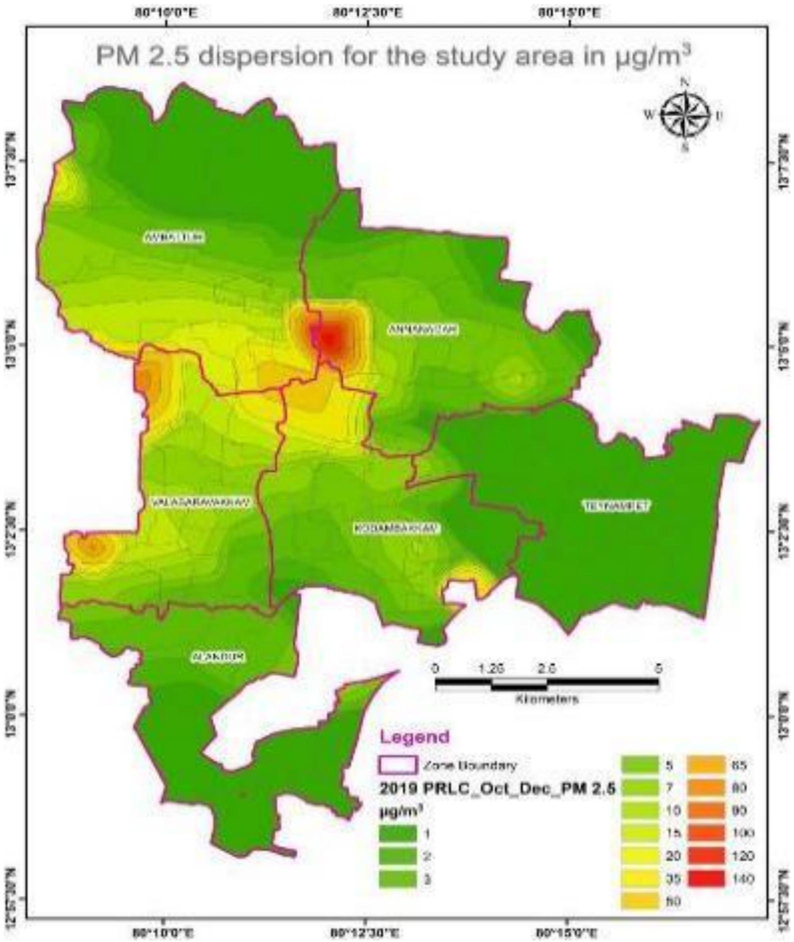

Figure.6. Sample outputs of predicted pollutant concentration using USEPA AERMOD Modelling for Pre Lockdown

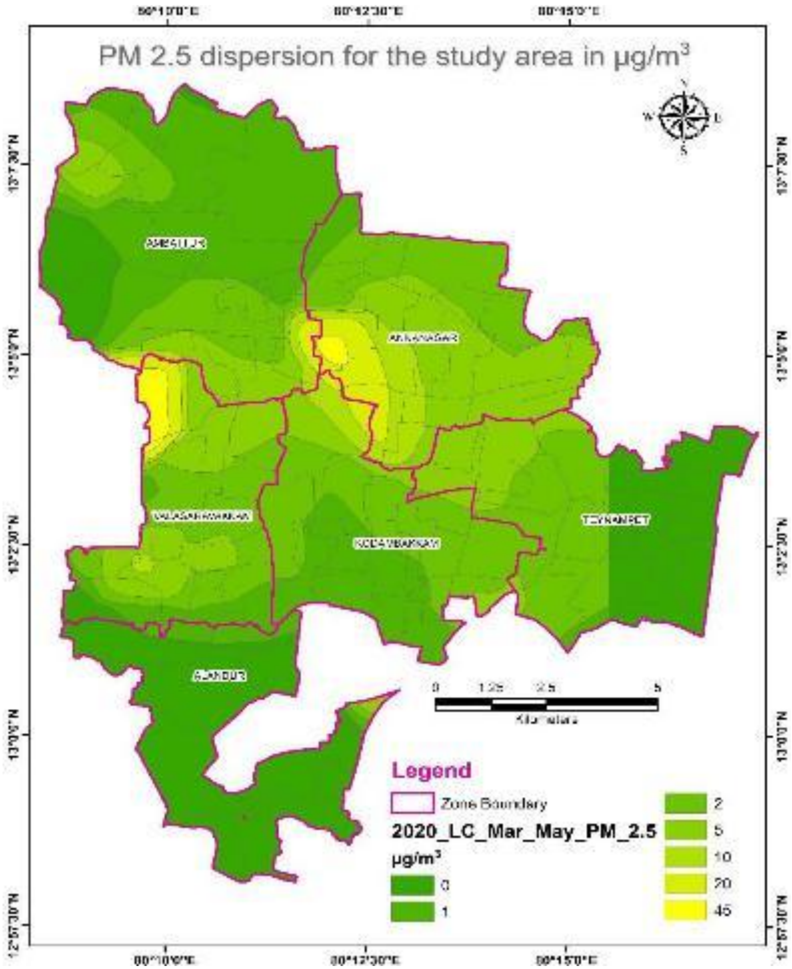

Figure.7. Sample outputs of predicted pollutant concentration using USEPA AERMOD Modelling for Lockdown

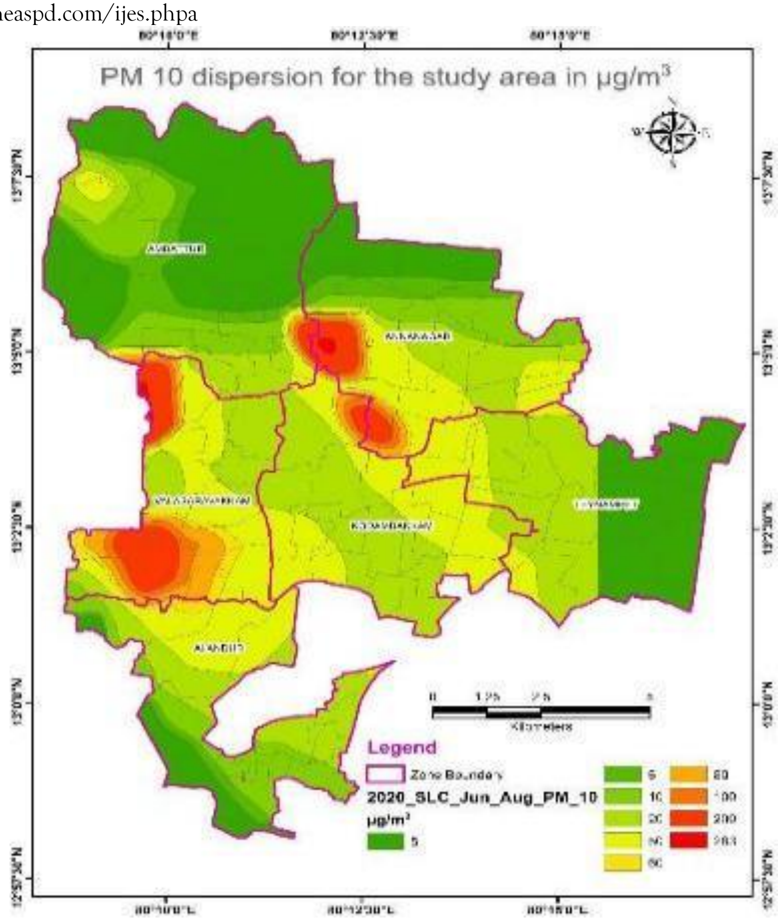

Figure.8. Sample outputs of predicted pollutant concentration using USEPA AERMOD Modelling for Semi Lockdown

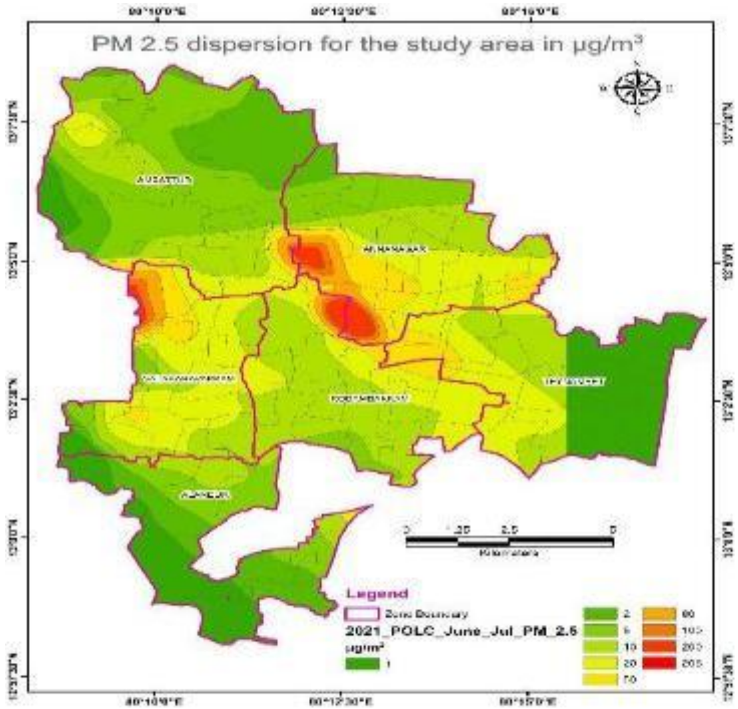

Figure.9. Sample outputs of predicted pollutant concentration using USEPA AERMOD Modelling for Post Lockdown

6.0 DISCUSSION:

The PM_{10} concentration is higher than the prescribed limits in most of the sampling stations. RSPM/PM_{10} is not only the main contributor to the pollution, but also exceeds the limit as prescribed by NAAQS across all regions of Chennai(R & S 2018). The research revealed that the average annual RSPM/PM_{10} concentration at five stations exceeded the 60μg/m^3 threshold by at least 1.5 times, as compared to the study conducted between January 2004 and December 2018(I. Nadeem, Ilyas & Sheik Uduman 2020). Similarly, the current investigation yielded exceedingly high levels of particulate pollutants in the Ambattur zone, which have a substantial detrimental effect on the state of air quality. The main reason for the increase in particulate matter pollution is vehicular emission as Ambattur is a busy industrial area with high traffic density. The field inventory indicates that the volume of vehicles moving to the Koyambedu study region is 2.5 to 5 times greater than that of other areas, resulting in elevated concentrations of PM2.5 and PM10(Velmurugan et al. 2005). Further PM_{10} concentrations were widely distributed across the study area i.e part of Greater Chennai(Koutrakis et al. 2005). Based on observations obtained from all other stations, the PM_{10} concentration has been found to have increased by a factor of two or three times in comparison to the $PM_{2.5}$ concentration.

The concentration of particulate matter pollution during pre and post lockdown period drastically reduced during semi and lockdown periods. The findings indicate that there is no significant correlation between $PM_{2.5}$ and PM_{10} with Covid-19 positive cases resulted with following R^2 values, Anna Nagar (0.24 and 0.29), Valasaravakkam (0.16 and 0.20), Ambattur (0.45 and 0.15) and Kodambakkam (0.08 and 0.12). However comparable correlations of $PM_{2.5}$ and PM_{10} with the Covid-19 mortality(Bossak & Andritsch 2022) resulted with following R^2 values in Anna Nagar with 0.54 for $PM_{2.5}$ and 0.60 for PM_{10}, R^2 values in Valasaravakkam with 0.45 for $PM_{2.5}$ and 0.25 for PM_{10}, R^2 values in Ambattur with 0.07 for $PM_{2.5}$ and 0.45 for PM_{10} , R^2 values in Kodambakkam with 0.20 for $PM_{2.5}$ and 0.29 for PM_{10}.

Among the four hotspots Anna Nagar (Zone8) shows maximum correlation with 54% for $PM_{2.5}$ and 60% for PM_{10} with Covid-19 mortality rate indicating that continuous exposure to high pollution concentrations(Southerland et al. 2022) in this zone may have weakened human immune systems and hence this zone should be prioritized for rapid vaccination.

Table 2 **CORRELATION OF HOTSPOTS WITH COVID-19 POSITIVITY AND MORTALITY**

	ANNA NAGAR					VALASARAVAKKAM					AMBATTUR					KODAMBAKKAM				
PERIOD	$PM_{2.5}$ µg/m³	PM_{10} µg/m³	AVERAGE COVID-19 POSITIVE CASES	MORTALITY IN NUMBERS AND (%)	DEATH RATE	$PM_{2.5}$ µg/m³	PM_{10} µg/m³	AVERAGE COVID-19 POSITIVE CASES	MORTALITY IN NUMBERS AND (%)	DEATH RATE	$PM_{2.5}$ µg/m³	PM_{10} µg/m³	AVERAGE COVID-19 POSITIVE CASES	MORTALITY IN NUMBERS AND (%)	DEATH RATE	$PM_{2.5}$ µg/m³	PM_{10} µg/m³	AVERAGE COVID-19 POSITIVE CASES	MORTALITY IN NUMBERS AND (%)	DEATH RATE
PRELOCKDOWN	180	352	No Data	No Data	No Data	170	240	No Data	No Data	No Data	130	270	No Data	No Data	No Data	90	260	No Data	No Data	No Data
LOCKDOWN' (MAR'20-MAY'20)	78	110	350	No Data	No Data	66	145	215	No Data	0	60	40	140	No Data	No Data	29	47	120	No Data	No Data
SEMILOCKDOWN (JUNE'20-AUG'20)	186	280	2250	36(1.60%)	0.016	183	370	1520	20(1.30%)	0.013	76	118	2269	27(1.20%)	0.0119	105	205	1185	17(1.40%)	0.014
POSTLOCKDOWN (SEP'20-DEC'20)	206	460	825	15(1.85%)	0.018	150	224	980	15(1.50%)	0.015	102	155	580	9(1.60%)	0.01552	140	270	650	12(1.85%)	0.018
PRELOCKDOWN (JAN'21-APRIL'21)	156	330	150	2(1.60%)	0.016	160	260	148	2(1.27%)	0.013	80	130	135	2(1.39%)	0.01481	80	187	172	3(1.62%)	0.017
LOCKDOWN (MAY'21)	38	46	4693	68(1.45%)	0.014	48	71	3245	52(1.60%)	0.010	23	41	4250	52(1.23%)	0.01224	28	46	4500	68(1.52%)	0.015
POSTLOCKDOWN (JUNE'21-JULY'21)	127	334	700	12(1.71%)	0.017	130	340	500	6(1.27%)	0.012	60	94	450	7(1.54%)	0.01556	413	585	630	11(1.76%)	0.017

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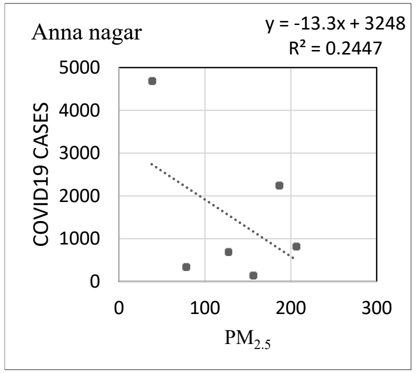

Fig. 10.1(a) $PM_{2.5}$ Vs Covid-19 cases Anna Nagar

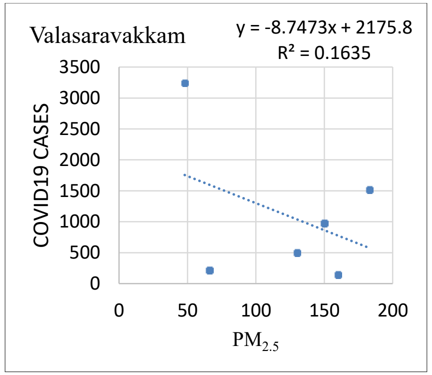

Fig. 10.1(b) $PM_{2.5}$ Vs Covid-19 cases Valasaravakkam

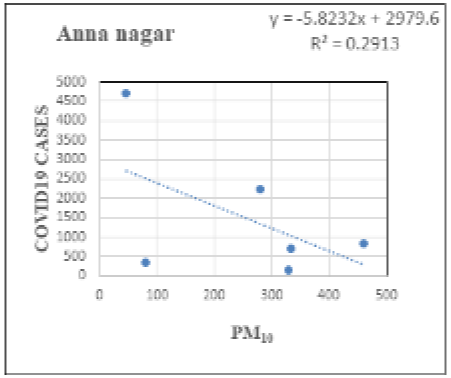

Fig. :

Fig. 10.1(c) PM_{10} Vs Covid-19 cases Anna Nagar

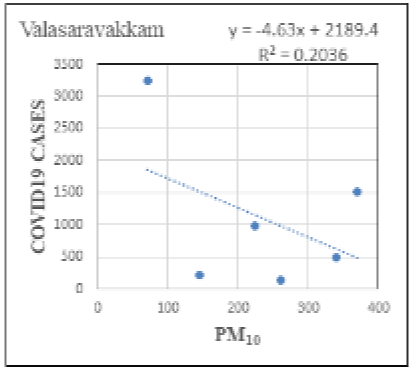

Fig. 10.1(d) PM_{10} Vs Covid-19 cases Valasaravakkam

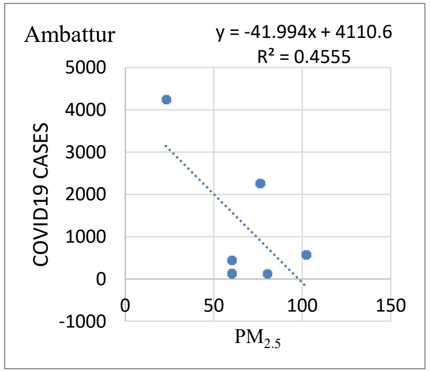

Fig. 10.1(e) $PM_{2.5}$ Vs Covid-19 cases Ambattur

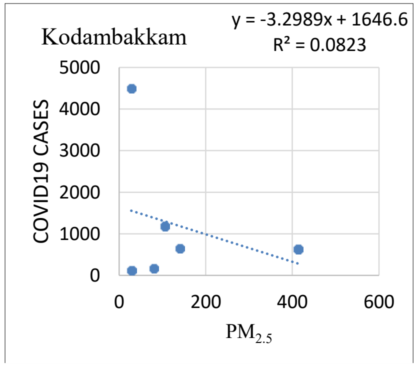

Fig. 10.1(f) $PM_{2.5}$ Vs Covid-19 cases Kodambakkam

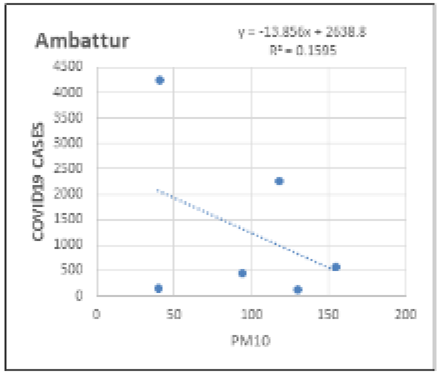

Fig. 10.1(g) PM_{10} Vs Covid-19 cases Ambattur

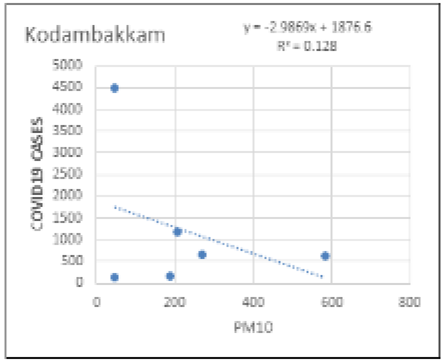

Fig. 10.1(h) PM_{10} Vs Covid-19 cases Kodambakkam

Fig. 10.1(a-h) shows the output obtained for Covid-19 positivity vs PM2.5 and PM10

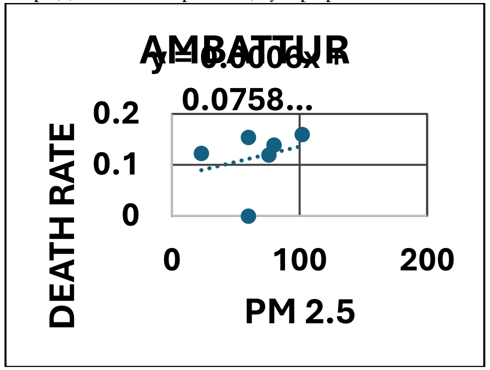

Fig 10.2(a) PM2.5 Vs Death rate Ambattur

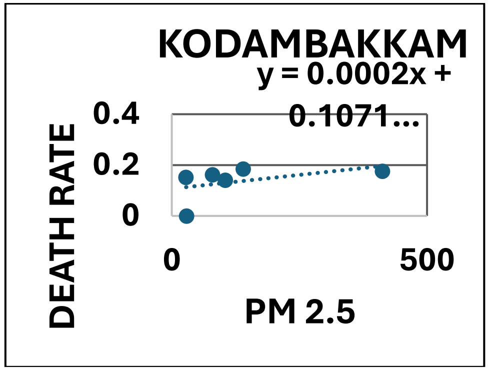

Fig 10.2(b) PM2.5 Vs Death rate Kodambakkam

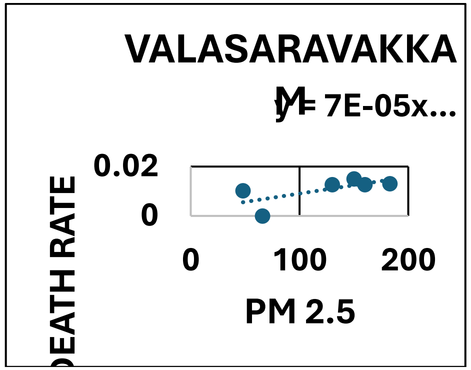

Fig 10.2(c) PM2.5 Vs Death rate Valasaravakkam

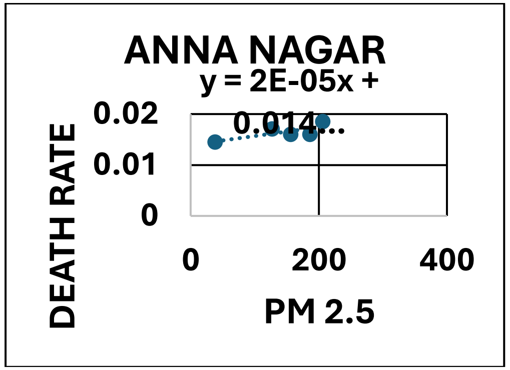

Fig 10.2(d) PM2.5 Vs Death rate Anna Nagar

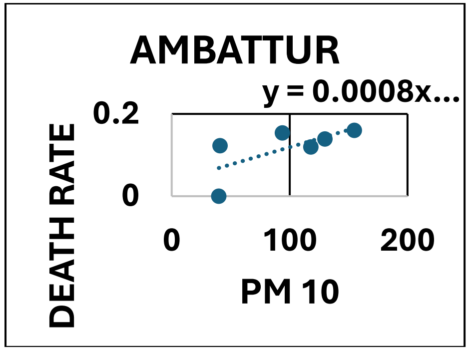

Fig. 10.2(e) PM10 Vs Death rate Ambattur

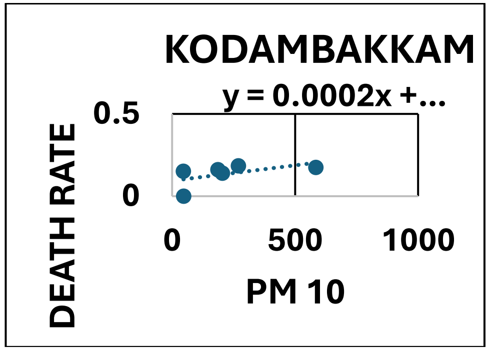

Fig. 10.2(f) PM10 Vs Death rate Kodambakkam

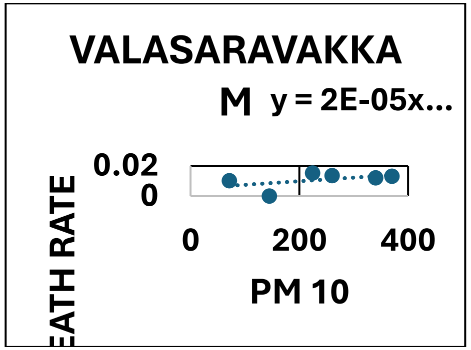

Fig. 10.2(g) PM10 Vs Death rate Valasaravakkam

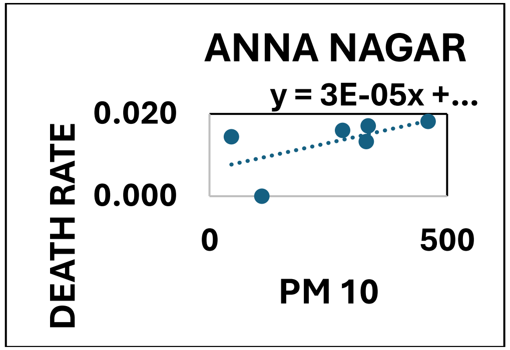

Fig. 10.2(h) PM10 Vs Death rate Anna Nagar

Fig. 10.2 (a-h) shows the output obtained for Covid-19 mortality rate vs PM2.5 and PM10

7.0 CONCLUSION

The findings led to the identification of Annanagar, Ambattur, Valasaravakkam and Kodambakkam zones as hotspots since their pollution levels exceeded the prescribed CPCB norms of 60μg/m^3 for the analysed period. However, $PM_{2.5}$ and PM_{10} concentrations in Alandur and Teynampet zones do not exceed the permitted limits and there is no indication of excessive $PM_{2.5}$ and PM_{10} dispersion. On the basis of the $PM_{2.5}$ and PM_{10} model output, zone-specific pollution statistics were compared. All six zones, which include 32 wards and 349 streets, are affected by PM_{10} and $PM_{2.5}$ concentrations over an area of approximately 21.2 km^2 and 7.41 km^2, respectively. In addition, PM_{10} concentrations are widely distributed throughout the study area.Anna Nagar (Zone8) exhibits the highest correlation among the four hotspots, with a correlation of 54% for $PM_{2.5}$ and 60% for PM_{10}, with a higher Covid-19 mortality rate. This suggests that prolonged exposure to elevated pollution concentrations in this zone may have compromised human immune systems; therefore, prompt vaccination efforts should be concentrated in this zone.

8.0 ACKNOWLEDGEMENTS:

This research work was supported by Indian Council of Medical Research, Government of India through funding Ref: BMI/12(93)/2021 and ID no. 2021-6479 dated 28-03-2022 and we are thankful to ICMR for providing the necessary data. We are grateful to Er. A.C.S. Arunkumar, President, Dr. M. G. R Educational and Research Institute, for his consistent encouragement towards carrying out the research work.

9.0 CONFLICTS OF INTERESTS: Nil

10.0 FUNDING SOURCES: Indian Council of Medical Research, New Delhi – Ref no – BMI/12(93)/2021 and ID no. 2021-6479

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