

# Transport of Particulate Matter Due to Meteorological Changes Analyzed by HYSPLIT

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**Abstract.** *The air quality in the urban region varies based on the sources of air pollution from regions near and far. Any pollution produced in the urban region affects the locality near the pollution source and also adjacent distant regions. The study of the interaction between the local weather patterns of a region and the pollutants in the air is needed for air quality management. It is explicit that Chennai city has a high level of air pollution. But the unavailability of the relevant data on the air pollution sources makes the management difficult. If the data on air pollution in the region of Chennai is known, it will be helpful to provide control measures. Between January 2017 and December 2017, the particulate matter below the size of 2.5 micron ( $PM_{2.5}$ ) was assessed. It was quite concentrated in the metropolitan city of Chennai situated at the shores of the Bay of Bengal. This assessment is to study the transport phenomenon and expansion of the pollutant particles initially emanating from Chennai. This occurs mainly due to the westerly winds originating in the Bay of Bengal. The time duration of the analysis showed an average  $PM_{2.5}$  concentration of  $63.524 \pm 18.942 \mu\text{g}/\text{m}^3$ . This far exceeds the regulations of the World Health Organization (WHO). Various regions of the country as affected by different distant sources of pollution in and around Chennai were evaluated by the trajectory modeling. The pollution in the regions of the vicinity is assessed using the Hybrid Single-Particle Lagrangian Integrated Approach (HYSPLIT) software. The method and results are fruitful for similar estimates elsewhere.*

**Keywords:** *hysplit,  $PM_{2.5}$ , forward trajectory, receptor function*

## 1. Introduction

Particulate matters not only create an imbalance in the weather patterns, flora and fauna but also it has degenerative effects on the human health too [1]. These particulates increase the air quality degradation in urban areas [2]. The air flow patterns, the climatic conditions in the path of air flow from the region of source and the presence of other industrial emissions in the path also affect the pollution levels in a distant region [3]. A study on the air pollutants in Chennai city is useful. Since the city spreads pollutants over the southern part of India leading to water and land pollution. Despite the regulations and the pollution norms have been made strict, the pollution is still on the rise, not only in the vicinity, but also at distant places [4]. This is due to the anthropogenic emission, vehicular and industrial emissions and the flow of the particulate matter through to the air caused by the winds from the Bay of Bengal [2]. Thus a wide region of the southern India is affected by the pollution source of Chennai.

Not only particulate matter are emitted from the industries, but also the gaseous pollutants emitted have to be considered as they could be deposited easily or sometimes they could travel a very long distance without deposition and could cause pollution there. The source can be a single source. But the paths that it travels may be different. Similarly, the receiving sites which receive the pollution can also be different. So, this kind of multiple path multiple receptor models are to be studied using forward trajectory models. This analysis is done because the  $PM_{2.5}$  is more hazardous than  $PM_{10}$ .  $PM_{2.5}$  are even

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smaller and they are found abundant than  $PM_{10}$ . Data on the pollution due to particulate matter of size 2.5 microns ( $PM_{2.5}$ ) in the chosen region monitoring of pollution for one year has been conducted. This is helpful to assess if the pollution levels are under acceptable ranges or exceeding the limit.

The previous results of air pollution over Chennai are shown in Table 1. Previously reported studies gave information on the  $PM_{2.5}$ ,  $PM_{10}$  and  $PM_{1}$  in several major cities. But such studies were just measurements; the reasons of the sources have not been discussed.

This novelty of this study is that this study uses Forward Trajectory modelling over the Backward Trajectory modelling which has been in use for the analysis for spread up of pollution. This study turns out to be the first of its kind analysis over Chennai as this study uses Forward Trajectory modelling to understand pollution outcome patterns better, identifies the potential receptors of the pollution for different seasons and deposition of particles within an elevation of 500m.

## 2. Materials and methods

### 2.1. Study site

Chennai, residence to over 10 million, is a metropolitan city. The site of study in the city, Manali, is located at latitude of  $13.1636^{\circ}N$  and a longitude of  $80.2586^{\circ}E$ . The region has petroleum refineries, tyre manufacturers and several automobile industries. Thus, the place is a mix of industries and transportations. The landmass is situated at an altitude of 3 m from mean sea level.

**Table 1.** List of study of Air pollution over Chennai

S. No	Time period of study	Author name	Component of study
1	March, 2001	Indranigupta et al, 2005[5]	$PM_{10}$
2	February- March, 2001	S. Ramachandran et al, 2003 [6]	Aerosol
3	January- December, 2005	M. Pulikesi et al, 2006 [7]	Ozone, $NO_x$ , RSPM, TSPM
4	January- December, 2005	M. Pulikesi et al, 2006 [8]	Surface Ozone
5	November, 2010	V.S. Chithra et al, 2014 [9]	$PM_{10}$ , $PM_{2.5}$
6	January 2009-December 2012	Hairongcheng et al, 2013 [10]	PAH
7	January 2007 – December 2012	V.S. Chithra et al, 2013 [11]	Particulate elements and ionic composition
8	January, 2009	ShuchitaSrivastava et al, 2012 [12]	Ozone, CO, Methane, NMHC
9	February - August 2017	M.A. Krishnan et al, 2019 [13]	$PM_{2.5}$
10	January 2012- December 2015	Srikanthmadala et al, 2016 [14]	$NO_x$

### 2.2. Data collection and analysis

The data collection in the region was from the CPCB at Manali website from Jan 2017 to Dec 2017. The analysis was made only for the year 2017. Various metrological parameters (24 h mean values) which describe about the characteristics of wind such as wind speed, wind direction and precipitation for the period of January 2017 to December 2017 were downloaded from Central Pollution control board (CPCB). Table 2 shows Chennai  $PM_{2.5}$  concentration level from various places.

**Table 2.** Chennai  $PM_{2.5}$  levels

Type of locality	Place	$PM_{2.5}$ ( $\mu g/m^3$ )
Area 1 (Urban)	Alandur	78
Area 2 (Suburban)	Kodungaiyur	56
Area 3 (Traffic)	Mount road	81
Area 4 (Back ground)	Perungalathur	44

## 2.3. Source apportionment

### 2.3.1. Trajectory modelling

Trajectory modelling of the particles is done by Trajectory plot package of HYSPLIT modelling tool [15]. 120 h runtime is chosen as typical. HYSPLIT is used to run 120 h forward trajectory to track the path of the particles originating from the source location. Lagrangian approach is the approach where the particles are allowed to move while the observer is kept stationary. The trajectories are assessed at a height of 500 m from the mean ground level. The direction of maximum wind flow in wind rose diagrams is the direction in which most of the number of trajectories moves, during the four seasons. This HYSPLIT data was based on the National Centre for Atmospheric Prediction (NCEP)/National Centre for Atmospheric Research (NCAR) and Global Data Assimilation System (GDAS) 1° data set.

### 2.3.2. Dispersion modelling

Hysplit is software by NOAA, a Governmental agency. This model is used for finding air motion causes as to how pollutant particles will travel. It uses wind data and weather prediction.

### 2.3.3. Deposition modelling

This method is used for the apportionment of the pollution in the local region. This is also done by using the Dispersion model in HYSPLIT. The deposition of the particles can be seen by the coloured lines indicating the transport. One could assess the regions of local hotspots of high pollution. Similarly the Spatial - Temporal dispersion of the particles in a particular day can also be plotted. This provides informative details on the time duration that it takes to reach the receptors, both plants and animals, from the time that it leaves the source in the region of vicinity.

### 2.3.4. Potential receptor function

Forward trajectory analysis was done over the city of Chennai. This analysis on flow of the particulates was carried over using HYSPLIT. Now the region of reception of these particulates are assessed and verified by using the Potential Receptor Function. This function is essentially an inverse of Potential Source Contribution Function as the method provides the probability of the trajectory end points of either starting or ending in a particular grid [3]. Since Forward trajectory analysis has been done in our study, the methodology of using PSFC describes the spread of the aerosol over the region of study originating from the site of source generation. The PRF of a cell is defined as

$$\text{PRF}(i,j) = a_{ij}/b_{ij}$$

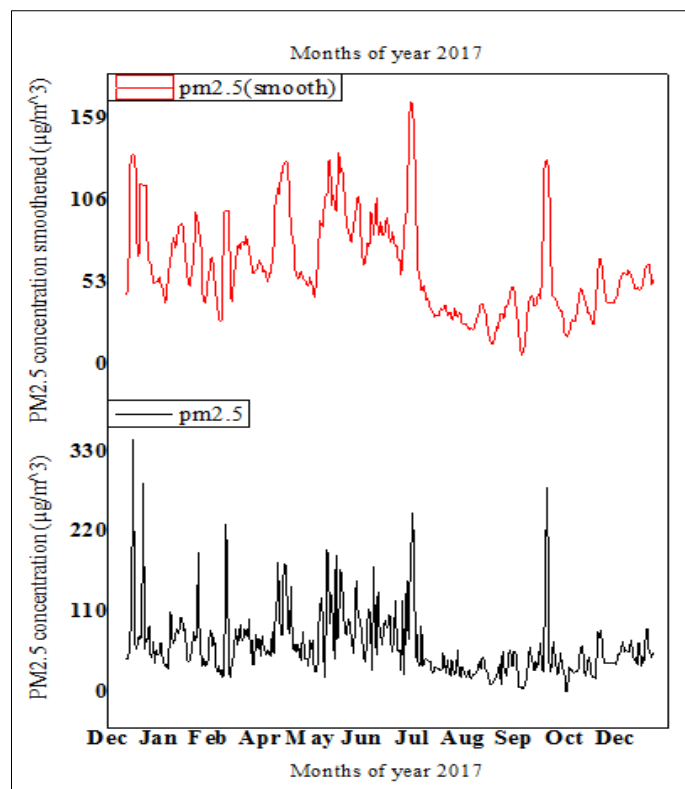
where,  $a_{ij}$  and  $b_{ij}$  are the total number of trajectory end points falling on the particular grid cell on days where the concentration is normal and the days when the concentration exceed the limits prescribed by the standards. As per CPCB norms the concentration of  $\text{PM}_{2.5}$  should be less than  $60\mu\text{g}/\text{m}^3$ .

## 3. Results and discussions

The  $\text{PM}_{2.5}$  concentration in Manali, Chennai is  $63.524 \pm 18.942 \mu\text{g}/\text{m}^3$  which is actually higher than the guidelines provided by the World Health Organization (WHO) by 6.3524 times on yearly basis. On an average,  $\text{PM}_{2.5}$  has an average lifetime of 72 h ([www.webpms.bima.gov](http://www.webpms.bima.gov)). The monsoon of India is mainly two types namely the Northeast and Southwest monsoons. These two monsoon patterns affect the flow of particles from the source location. The trajectory model reveals the path of the particles towards different locations of India. The following sections shows the plot of the particle movement, its concentration, deposition at that particular time in the local region and the spatial - temporal diagram of the particles in that particular time. The sample models are taken from the period of January 2017 to December 2017. The plots are based on the regions where they flow in.

### 3.1. Annual variation

Figure 1 describes the variation in the concentration of PM<sub>2.5</sub> of the year 2017. The diagram has two plots for yearly generation of concentration. The unsmoothed curve represents the raw data of the PM<sub>2.5</sub> generation. The July seasons is dry and retain particles better while the dewy January season condenses particles. So that the values are lower.



**Figure 1.** Yearly concentration of PM<sub>2.5</sub> for the year 2017

### 3.2. Wind rose diagram

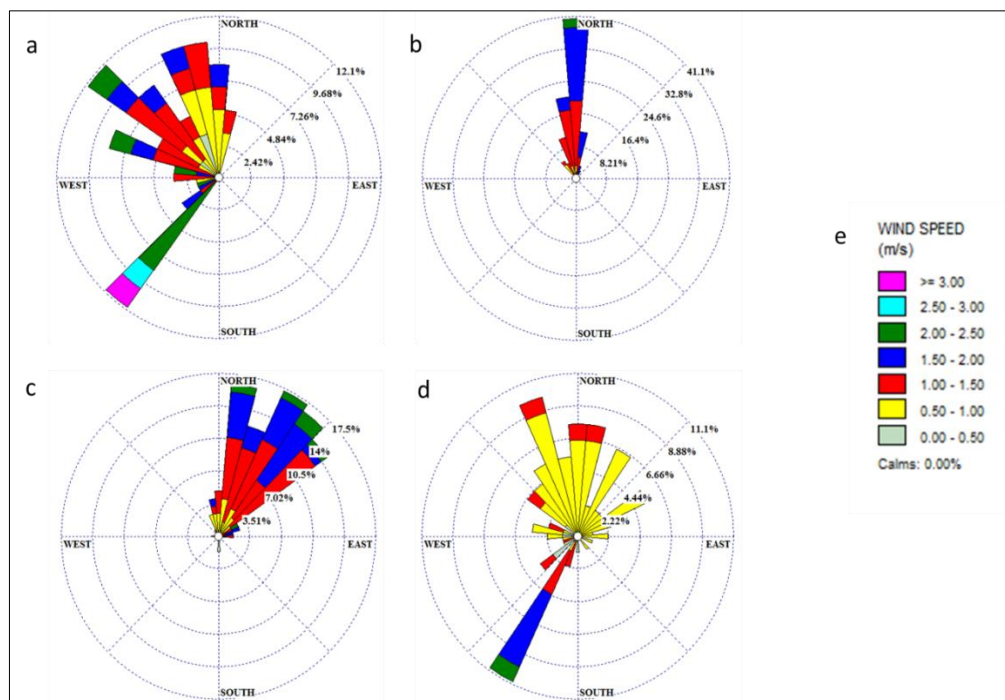
The Figure 2 shows the corresponding wind rose diagram for the four seasons plotted by WRPLOT. The diagram describes the wind velocity in each of the direction. The major wind direction was westward. The spread in the several seasons are given as:

**Table 3.** Variation in wind direction and velocity in all seasons

Title	Summer	Winter	Monsoon	Post monsoon
Direction	North	North West	North East	North and North West
Percentage	32%	9.6%	17%	6.6%

The plot has been divided into 36 directions of wind flow. Chennai generally has four seasons: Winter (January - February), summer (March - May), Monsoon (June - September) and Post-Monsoon (October - December). The wind rose plots for different seasons show the variation in direction and velocity of the wind for different seasons.

The calm conditions as seen in the graphs are extremely minimal (color grey).



**Figure 2.** Wind rose diagram for (a) Winter. (b) Summer. (c) Monsoon. (d) Post monsoon. (e) Scale

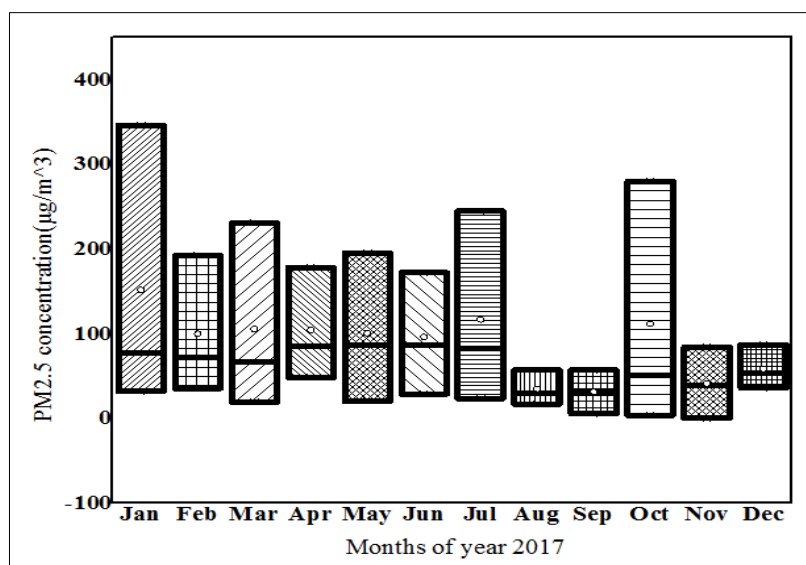
### 3.3. Monthly variation

Figure 3 describes the monthly variation of the PM<sub>2.5</sub> concentration in which the top and bottom edges of the box plot shows the maximum and minimum concentration of PM<sub>2.5</sub>. The central dots represent the average of that particular month. This box plot can tell us the time of the year when the pollution level is higher and also it helps us to backtrack the events that could have caused the higher pollution levels.

From the plot, the following mean values in the four seasons are given below

**Table 4.** Details of PM<sub>2.5</sub> during the seasons

Title	Summer	Winter	Autumn	Spring
PM <sub>2.5</sub> (µg/m <sup>3</sup> )	150	200	40	100
Days above mean (µg/m <sup>3</sup> )	60	30	50	40



**Figure 3.** Monthly concentration of PM<sub>2.5</sub>

### Correlation of PM<sub>2.5</sub> concentration with wind direction and wind speed

Figure 4 describes the plot between wind speed and the PM<sub>2.5</sub> concentration. From this plot, it could be interpreted that calmer the wind, low concentration of PM<sub>2.5</sub> is found to occur. When the wind blows mildly, the concentration is recorded maximum as there is more time for the collectors to collect more particles as they travel slow. This collection decreases as the particle speed increases and it occurs gradually. So higher the speed, lesser will be the PM<sub>2.5</sub> concentration.

The Figure 5 is used to represent the direction in which the concentration levels are higher. As per the plot it could be seen that the larger portion of particle flow occurs in the direction between 120° and 190° considering south as 0°. This covers the states of Andhra Pradesh (AP) area 160205 skm. The highest wind speed occurred towards Kerala (area is 38863 skm). Distance between AP and Kerala is 350km.

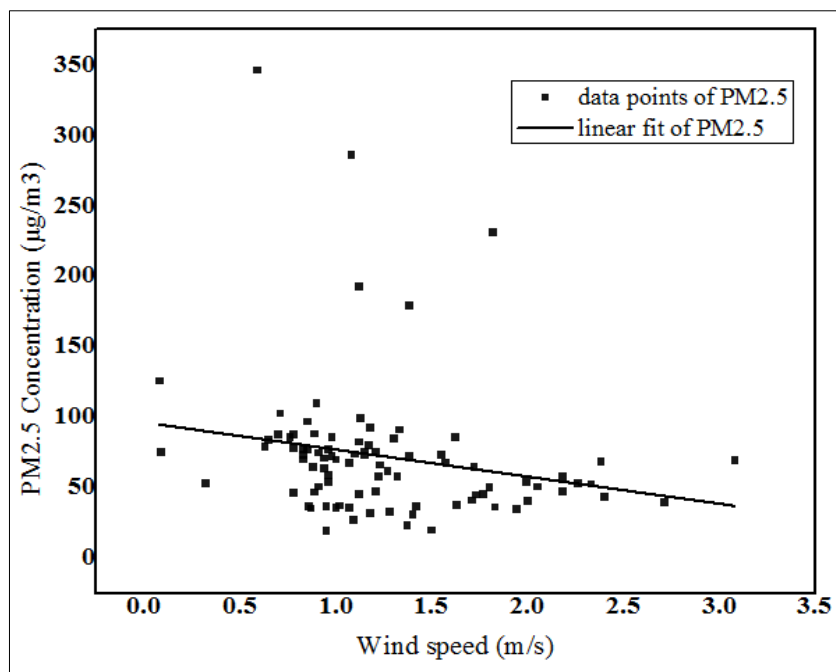


Figure 4. Wind speed vs PM<sub>2.5</sub> concentration

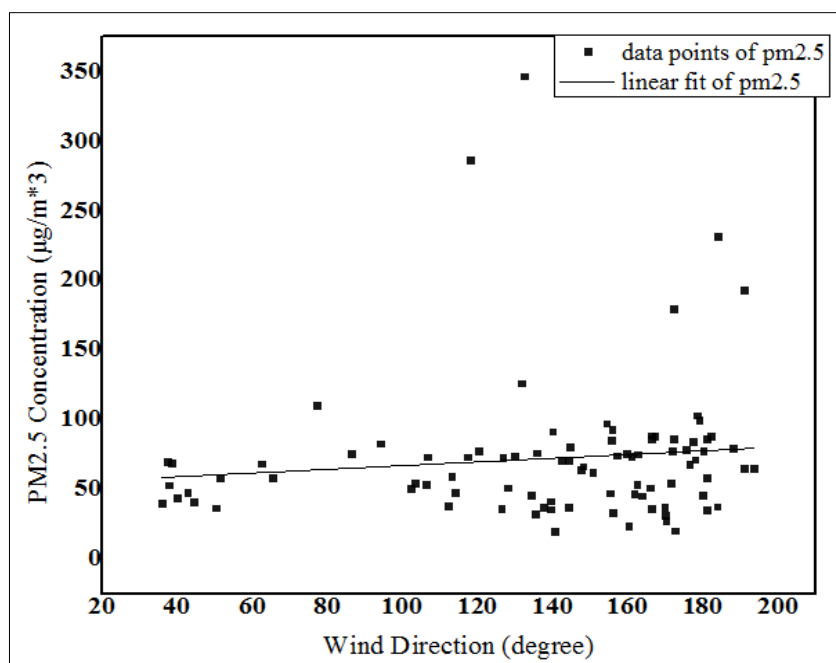
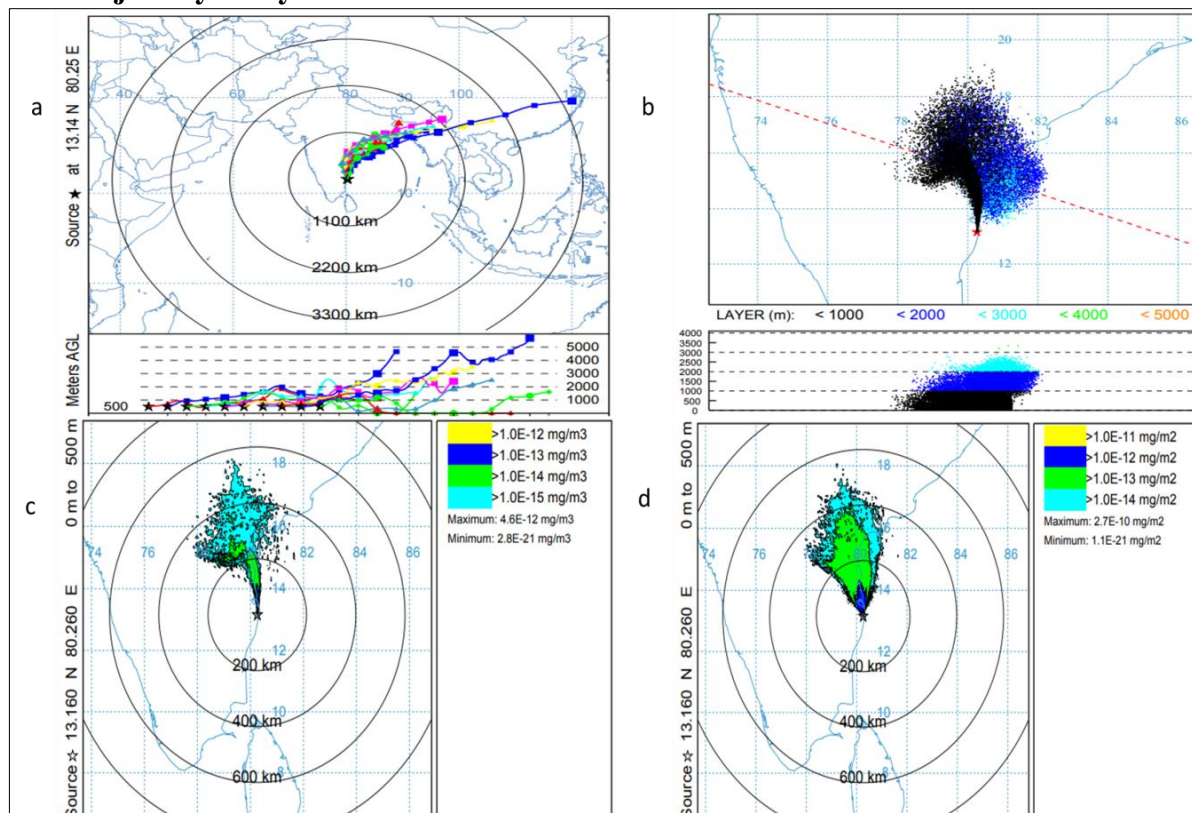


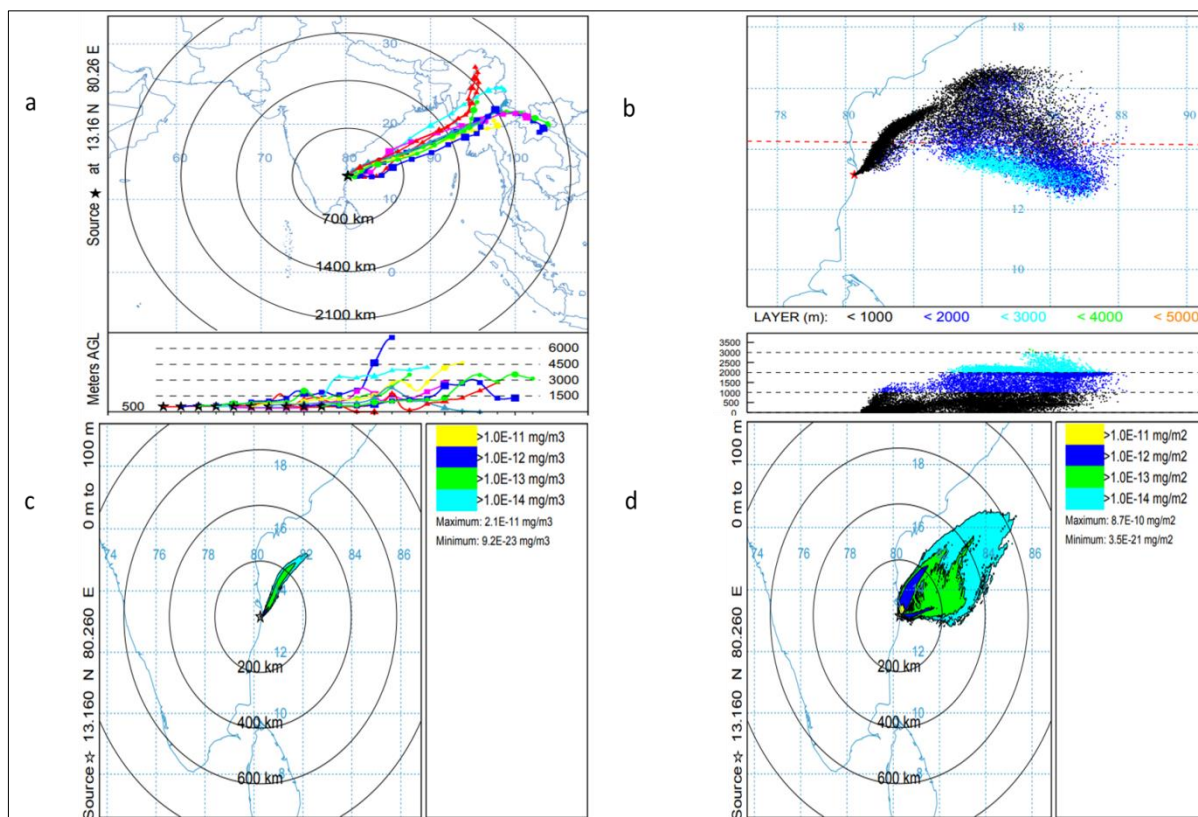
Figure 5. Wind direction vs. PM<sub>2.5</sub> concentration

## Forward trajectory analysis



**Figure 6.** a) The trajectory model of the particles that are flowing towards Andhra Pradesh region from Chennai, b) The particle dispersion of all the possible particles that flow form Chennai, c) The concentration spread up of the PM<sub>2.5</sub> particles in the region of Andhra Pradesh, d) The deposition model of the particles of PM<sub>2.5</sub> which has deposited within a range of 500 m elevation

The particles of PM<sub>2.5</sub> have an average lifetime of 72 h. This is evident by the fact that the trajectories as pictured in Figure 6a before crossing the state of Andhra Pradesh, they are under the elevation of an average of 1500 m from the ground level. So the particles die down due to the reduction in the velocity and energy of the moving particles. And in the Figure 6b and Figure 6c where the particle dispersion and the concentration of particles spread are explained respectively. From Figure 6b and 6c, we could infer that the path of the trajectories, which being a single line denoted in different colours, also affects the region surrounding the path that it follows. Further, the deposition of the particles in the local region is shown in the Figure 6d. This can be validated by the fact that at the time of October the wind force at lower elevation is comparatively lower than the wind force during other months of the annum and the increase in the precipitation also resulted in the deposition of the particles in the northern parts of Chennai. This is also affected by the retreating Southwest monsoon. The time diagram as mentioned depicts the path of the particles for 24 h duration. From the dispersion models it can be seen that the time for the dispersion is 24 h. But the PM<sub>2.5</sub> still would have been active to move in the atmosphere. So there is high potential for these particulates to travel even more region than depicted in the Figure 6b.



**Figure 7.** a) Trajectory of the particles moving over the water body of the bay of Bengal extending up to Myanmar, b) Dispersion of the particles over the sea at the East coast, c) Concentration of particles over East coast, d) Deposition of particles over water

Figure 7 a, b, c and d represents the trajectory of the particle, dispersion of particles, the concentration of particles present and the local deposition of the particulate matter respectively along the water body of the Bay of Bengal. The maximum values of AQI of  $PM_{2.5}$  in the states of Orissa and West Bengal are 162 and 364 (based on US EPA) respectively. The Country of Bangladesh experiences maximum AQI level of 330 (based on US EPA). The trajectories explain that the particles has travelled both onshore and offshore of the Coramandal coast. The trajectories within the average elevation below 1500 m occurs within the average lifespan of the  $PM_{2.5}$  particles. This symbolizes the fact that the air flow with these particles at this time of the year has high probability of settling them in the industrial city of Vizag along the coast of Andhra Pradesh, and the coast of Orissa. The Figure 7 b shows that the onshore region water bodies has also the risk of depositing down the pollutants in water. This is further supported by the Figure 7c and Figure 7d which shows the deposition of the particles which flow at an elevation ranging between 1000 m to 2000 m. This particular study of the Eastern coast helps us understand the effect of  $PM_{2.5}$  particles on marine bodies as well as costal regions.

In the following section, a brief description of the degenerative impacts of the  $PM_{2.5}$  particles has been explained.

### Effects of $PM_{2.5}$

Every person is affected by the  $PM_{2.5}$ . It causes the respiratory problem and cardiovascular illness. The stress is created in heart and lungs which must work hard to supply blood with oxygen, Cells in the respiratory systems are damaged, capacity of lungs are reduced due to which lung function is decreased. It has been found that respiratory syncytial virus causes mortality and morbidity among infants. Disease such as asthma, bronchitis, emphysema, Chronic Obstructive Pulmonary Disease (COPD) and possibility of cancer can be developed. Long term exposure of  $PM_{2.5}$  results in irregular heartbeat, non-fatal heart attack [16]. It causes premature death with people who are having heart disease or lung





disease. Short term exposures of PM<sub>2.5</sub> can cause eye irritation and irritation in nose and throat, chest tightness, shortness of breath, and coughing.

The environmental damages are caused by PM<sub>2.5</sub> are likely to reduce the visibility. When PM<sub>2.5</sub> settles on water, it increases the acidity in the lakes and streams and affects the nutrition balance in lakes and water basin. PM<sub>2.5</sub> [17] when deposited affects the nutrition level of agriculture land, sensitive forest and farm crops, affecting the diversity of ecosystem. PM<sub>2.5</sub> particles contribute to acid rain due to which cultural monuments and statues are being affected.

Generally PM<sub>2.5</sub> has an adverse effect on humans, plant life and built structures too. It is estimated that almost 660 million people of India live in regions that exceed NAAQS for fine particulate emission. Similarly, the water bodies also face severe problems as the particles deposit into land water and fresh water bodies. The water bodies also act as a heat sink to the particles whose energy is dropped as heat into those water bodies. When deposited by rain, they also get mixed with ground water and get deposited in the land affecting the agriculture. It could lead to diarrheal death mainly for children below five years. It is estimated that 60987 children under age 5 are directly, by air pollution, or indirectly, by water pollution caused by air pollution, are dying each year (*cf*; The Weather Channel). And from the modelling techniques we can infer that the pollution levels in the regions of study have increased considerably in the particular periods in which the PM<sub>2.5</sub> particles dispersed into that region from Chennai. The particles dispersed from Chennai could be a significant reason for the increase of pollution in that distant region.

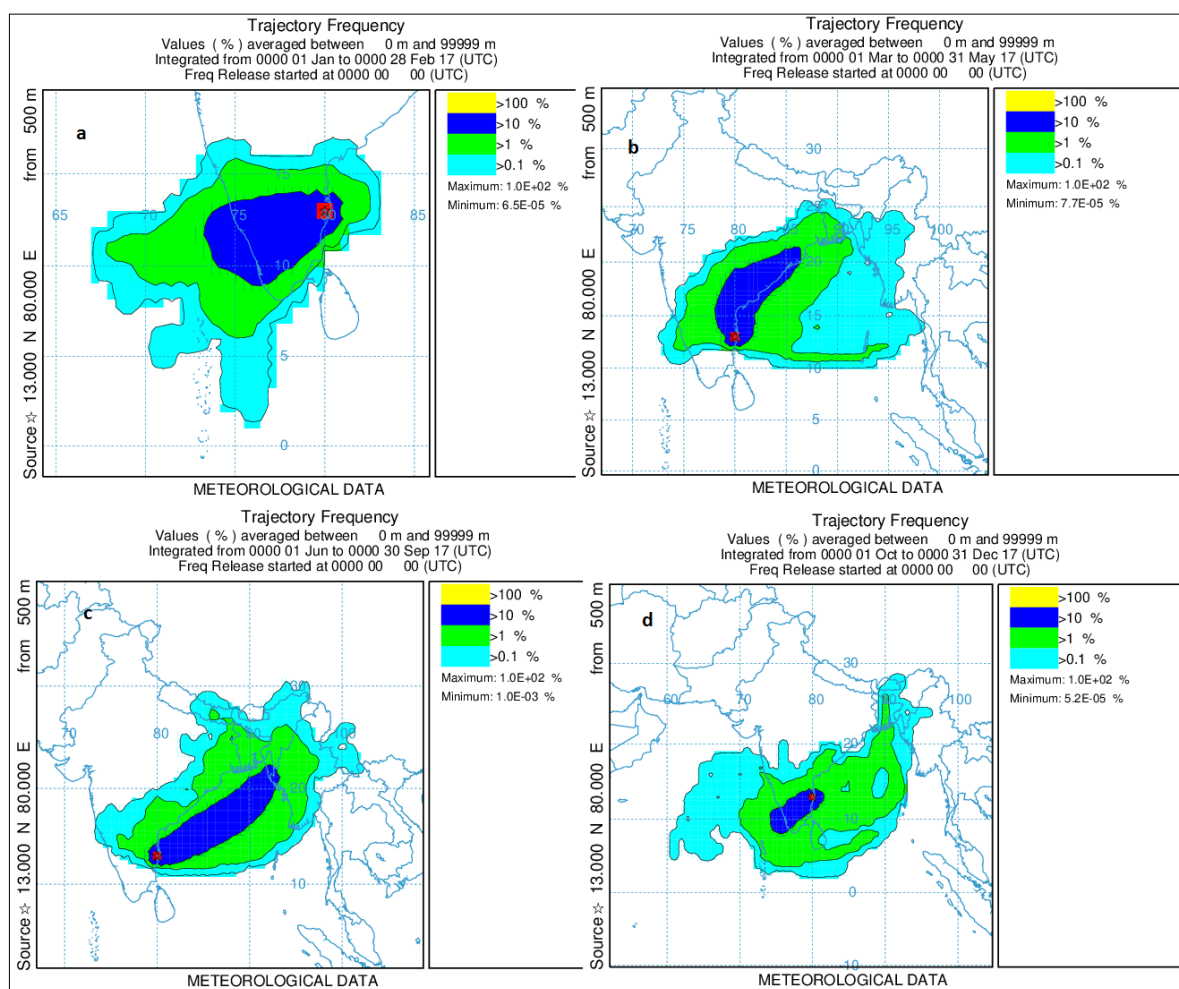
**Table 5.** Average concentration generated from three highly polluted regions of Chennai

Locality	Year	Winter	Summer	Monsoon	Post Monsoon
Alandur	2016	121.19 ± 188.53	81.11 ± 144.03	52.54 ± 32.09	66.24 ± 22.09
	2017	59.83 ± 16.56	51.66 ± 18.57	44.38 ± 14.01	43.23 ± 18.72
	2018	65.20 ± 21.43	36.72 ± 35.14	71.91 ± 110.04	63.73 ± 50.53
	<b>Average</b>	<b>92.44 ± 134.72</b>	<b>59.16 ± 107.39</b>	<b>62.63 ± 82.86</b>	<b>64.84 ± 40.34</b>
Manali	2016	51.31 ± 21.54	95.06 ± 29.73	43.70 ± 47.98	81.26 ± 37.72
	2017	66.31 ± 25.49	65.61 ± 23.76	51.78 ± 29.48	44.80 ± 19.46
	2018	84.29 ± 32.74	48.66 ± 24.59	54.10 ± 19.49	62.39 ± 24.40
	<b>Average</b>	<b>67.29 ± 30.05</b>	<b>73.54 ± 34.18</b>	<b>58.03 ± 43.95</b>	<b>60.50 ± 32.09</b>
Velachery	2016	60.84 ± 58.56	34.12 ± 14.64	28.37 ± 12.40	45.99 ± 24.16
	2017	36.99 ± 14.81	34.88 ± 13.64	27.93 ± 9.85	39.61 ± 18.42
	2018	46.13 ± 13.86	36.41 ± 15.85	40.78 ± 18.46	39.96 ± 22.97
	<b>Average</b>	<b>47.54 ± 38.03</b>	<b>38.21 ± 46.42</b>	<b>30.30 ± 15.30</b>	<b>37.82 ± 25.65</b>

Also, the meteorological data of the three stations over the years 2016, 2017 and 2018 are assessed. It showed that, Kerala, where the wind flows from Chennai mostly during winter and summer seasons, has received most of the PM<sub>2.5</sub> concentration during this particular time period. This is shown in table 3. The three stations showed higher average and standard deviation during the first two seasons of a year. Thus it is evident that Chennai continuously acts as a potential source of concentration for Kerala during the winter and summer seasons over the years.

Kolkata is another spot of significantly increased pollution level. During the periods of 2010 to 2011, the pollution levels of Respirable Particulate Matter (RPM), Suspended Particulate Matter (SPM) and NO<sub>2</sub> at Kolkata increased, causing a variety of diseases which were analyzed [18]. The increased pollution due to vehicular emission at Chennai and the emission from industries of the region under study have also a potential effect to affect the pollution at Kolkata. The period of increased pollution at Kolkata was analyzed by HYSPLIT trajectory. That showed the motion of particles from Chennai at that point of time. From the Figure 8 which describes the particle trajectory from Chennai to Kolkata at various time scales within November 2010 to February 2011; it can be understood that the high pressure

winds that originate at the Eastern coast scavenges the generated pollutants towards the state of West Bengal, especially the capital city of Kolkata. It can be evident that at the time of increased pollution, Chennai was a potential source of contribution.



**Figure 9.** Plot of Potential Receptor Function (PRF) values of PM<sub>2.5</sub> for (a) Winter (b) Summer (c) Monsoon (d) Post Monsoon seasons over a period of year at 500m from ground level for 120 h forward trajectories

Figure 9 shows the plot of Potential Receptor Function for various seasons for the regions of potential reception. Post monsoon and winter seasons show potential reception regions in the direction of west and south west respectively. Post monsoon brings the higher reception within the state of Tamil Nadu and during winter season; it also shows the particles are trying to escape to Kerala in southwest direction. Both of these occur sequentially. As the season goes on as a cycle, it can be inferred that the winds which blow the particles to Tamil Nadu during October - December (Post Monsoon) of the year shift to Kerala during January - February (Winter). During summer, there is a clear indication of the reversal of the wind due to the monsoon changes.

#### 4. Conclusions

The potential regions of reception occur in Northwest direction of Chennai. The wind pollutes the common region of the states of Karnataka, Andhra Pradesh and Telengana. The hot air stream during summer and absence of a potential barrier to the pathway of the particles causes the concentrations of PM<sub>2.5</sub> found to be high at summer. During the Monsoon, the wind direction shifts towards Northeast. Thus, during Monsoon, Northeast direction acts as potential region of reception. This deposits particles



over the land and water bodies of the Eastern coast. Then due to the monsoon reversal, the wind starts blowing the particles over Tamil Nadu towards west and southwest and the cycle goes on. Also during Monsoon (June - September), the concentration of PM<sub>2.5</sub> is on the lower side due to the rainfall. Moderate Concentration levels are found during the Post monsoon and winter periods (October – February), when majority of Kerala and Tamil Nadu are affected.

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