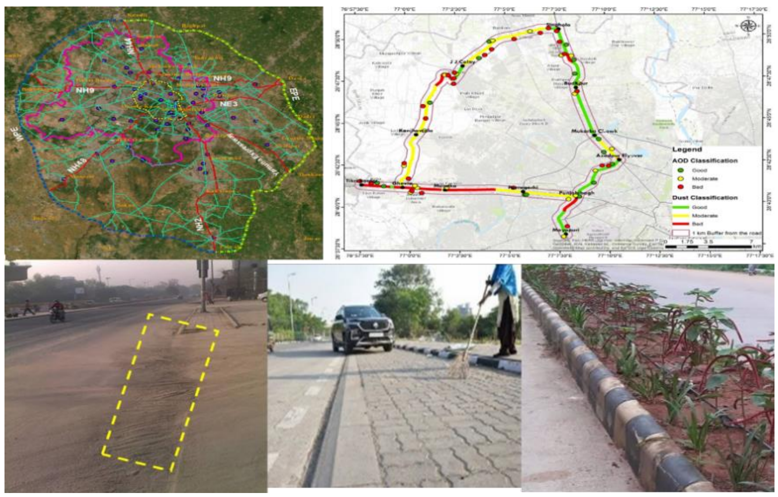
Final Report

Addressing Vehicular Traffic Induced Road Dust Re-Suspension with S&T based Action Plans for Air Quality Improvement in Delhi NCR



Submitted to

Commission for Air Quality Management (CAQM) in National Capital Region and Adjoining Areas

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

Chapter 1

Introduction

1.1 Background of the project

High air pollution level in Delhi NCR is one of the major concerns for the regulators as well as for the public. The severity of the problem persists more during post-monsoon and winter season followed by summer. Numerous studies were carried out in the past to quantify the contributions of different sources of air pollution in the city (NEERI, 2010; IIT Kanpur, 2016; TERI-ARAI, 2018). The findings of these studies indicated that the contribution of road dust re-suspension was very high in the city and responsible for increased particulate matter (PM_{10}/$PM_{2.5}$) concentration. The re-suspension of road dust is influenced by continuous dust deposition at the edges of road medians, poor road design/condition and its maintenance, limited dust management practices. The national air quality index of India considers Particulate Matter (PM_{10} or $PM_{2.5}$) in ambient air as an essential pollutant for its calculation. Being the critical parameter for air quality in Delhi city, it is necessary to reduce the PM levels in the city as well as in surrounding areas.

Considering the significant contribution of road dust re-suspension, the present study is undertaken to suggest the appropriate control options for the reduction of dust re-suspension from Delhi's roads. CSIR- NEERI Delhi Zonal Centre and CSIR- CRRI, Delhi have jointly discussed the issue with CAQM and submitted the proposal titled "*Addressing Vehicular Traffic Induced Road Dust Re-Suspension with S&T-based Action Plans for Air Quality Improvement in Delhi NCR*" to CAQM. Accordingly, the study was initiated after getting approval from the CAQM with a broad objective to suggest/delineate science and technology-based solutions to mitigate particulate matter pollution generated from the re-suspension of road dust in the study area.

1.2 Scope of Work

i. Mapping of Road Network (NHs & SHs) in Delhi NCR using GIS application

ii. AOD based pollution mapping of road network in Delhi NCR using Remote Sensing

iii. Review of status of design of roads considering traffic load, selection of construction materials, road divider and shoulder and suggestions for improvement in road design

iv. Assessment of traffic induced exhaust and non-exhaust air pollution through emission inventory on selected road type

v. Air quality impact assessment due to traffic induced air pollution through dispersion modeling on selected road types.

vi. Suggestions for control of road dust re-suspension from different types of roads in Delhi NCR.

The project activities started with a comprehensive brainstorming discussion among CAQM, CSIR- CRRI and CSIR- NEERI Delhi Zonal Centre during the project kick-off meeting. To achieve the defined scope of work, a comprehensive methodology adopted with detailed discussion among team member of CSIR-NEERI, CSIR-CRRI and CAQM, which are presented in form of process flow diagram in **Fig. 1.1**.

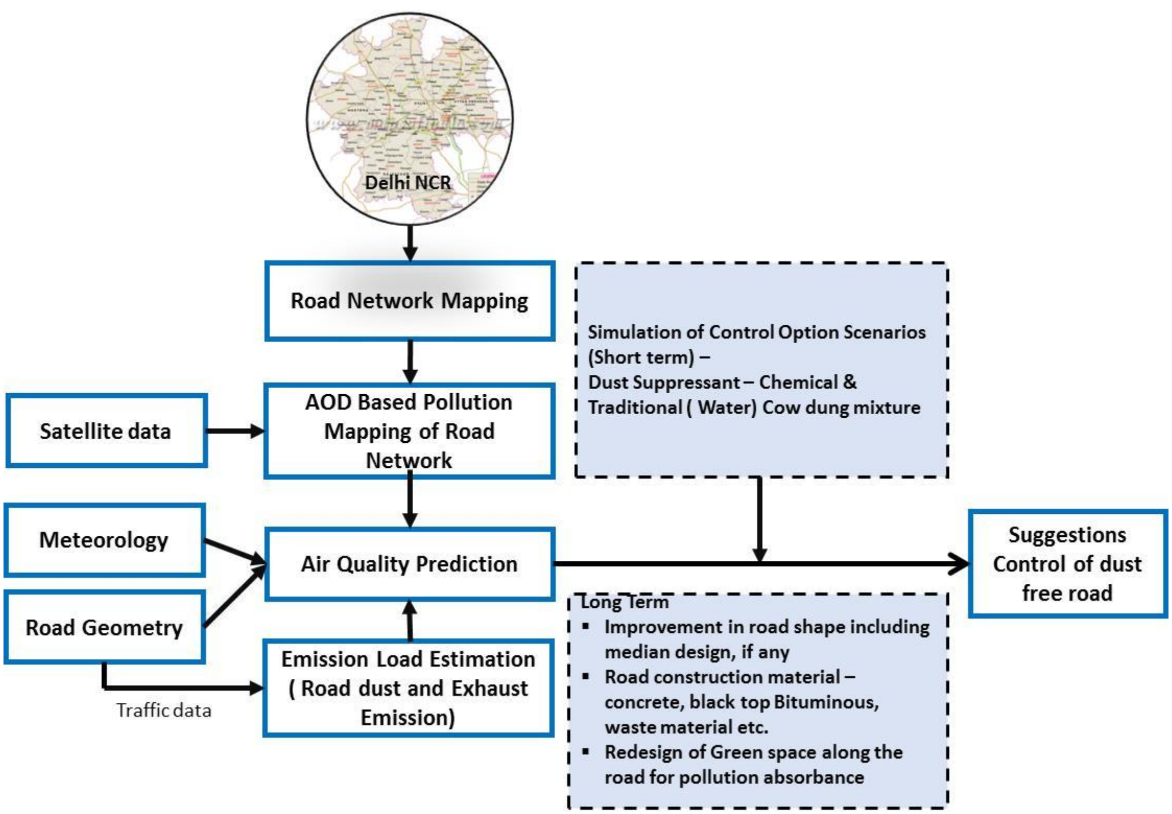


Fig. 1.1: Process flow chart of the adopted methodology

1.3 Study Area

The study area is restricted to the boundary of the Eastern and Western Peripheral Expressway (EPE and WPE) as per the decision made during the project progress meeting held on September 6, 2023 at CAQM office. The major roads including National Highways (NH), Arterial Roads (AR), and Sub-Arterial Roads are mapped in the study area using Geographic Information System (GIS) application. The total area coming within the EPE and WPE boundary is around 4977 km^2 including area of Delhi (1488 km^2), Uttar Pradesh state (1108 km^2) and Haryana state (2381 km^2).

Further, shape (.shp) file and Google map (.kml) file were also prepared for further analysis and which can be used for other studies by CAQM**.** The total length of the EPE and WPE is found to be ~135 km and ~136 km whereas, the length of ring road is ~ 50 km. The total length of National Highways in the study area is found to be ~282 km whereas sub-arterial road length is ~1642 km. The detail of road network length and study area map including Delhi boundary is shown in **Fig. 1.2** and described in **Table 1.1.**

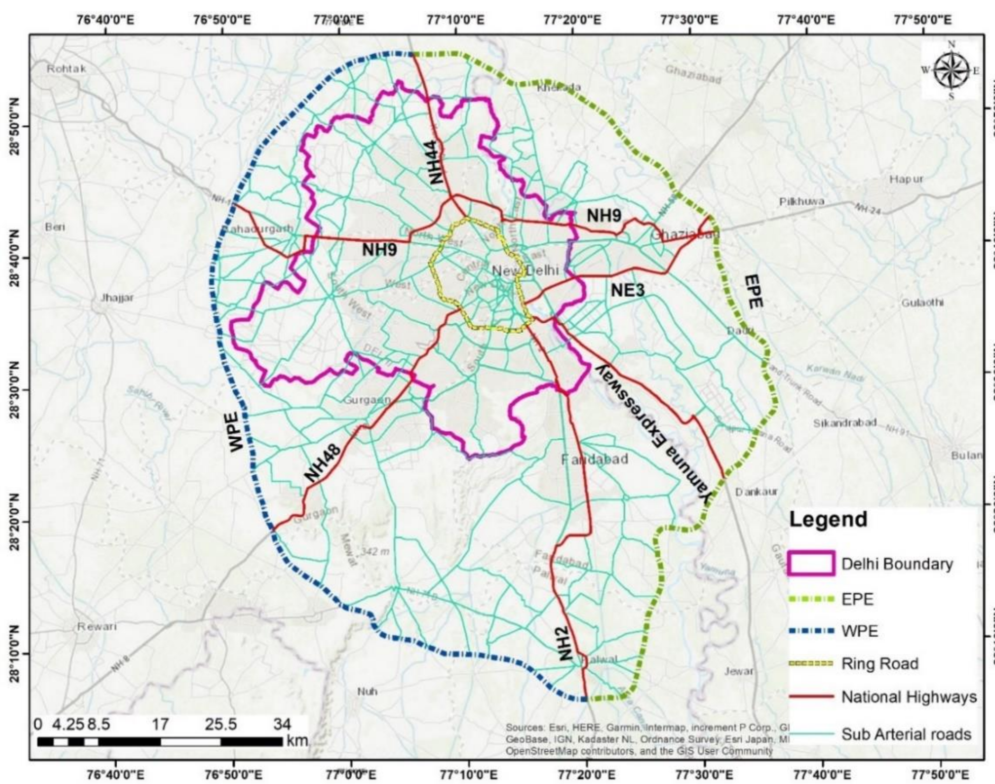


Fig. 1.2: Geo-coordinated map of road network within Eastern and Western Peripheral Expressway (EPE-WPE) boundaries

Table 1.1: Details of major roads in the study area

Sr. No.	Road Name	Category of Road	Length (km)
1.	Eastern Peripheral Expressway (EPE)	Expressway	135
2.	Western Peripheral Expressway (WPE)	Expressway	136
3.	Yamuna Expressway (DND to Dankaur)	Expressway	39
4.	NH-2 (Ashram Chowk to Palwal)	Highway/Arterial Road	62
5.	NH-9 (Dasna to Bahadurgarh)	Highway/Arterial Road	82
6.	NH-44 (Shalimar bagh to Kundli)	Highway/Arterial Road	24
7.	NE-3 (Sarai Kalekhan to Dasna)	National Expressway	31
8.	NH-48 (Dhaula Kuan to Manesar)	Highway/Arterial Road	44
9.	Ring Road	Arterial Road	50

The whole data analysis and findings of the study are presented in this report, which has six chapters. **Chapter 1** covers basic information about the study, its need, objective and scope of work, the adopted methodology and the study area. Whereas, **chapter 2** describes the status of road conditions and dust deposition for the selected road stretch(pilot study) and identifies the potential hotspot of dust deposition. **Chapter 3** of this report includes the quantification and dispersion of re-suspension of road dust over a selected road stretch and compares it with CAAQMS monitored values. **Chapter 4** provides the application of Aerosol Optical Depth (AOD) data analysis for pollution mapping along the road stretch. **Chapter 5** covers the effective control measures to mitigate re-suspended road dust pollution. These include strategies to reduce dust generation, such as paving unpaved shoulders and medians and creating green spaces, as well as techniques to lift dust from roads using mechanical and manual methods. Additionally, the chapter also covers the use of suppressing agents to control dust re-suspension and the potential for utilizing wastewater from the Delhi Metro Rail Corporation (DMRC) to water road medians and edge plantations. **Chapter 6** presents summary of study and few suggestions for road dust control/management. Further, the review of literature on dust suppressant application and findings on experiments conducted in the CSIR-NEERI laboratory are enclosed in **Annexure A.**

Chapter 2

Status of Road Condition and Dust Deposition

The selection of control options depends on the status of the road condition on which it is going to be applied/implemented. It also affects the efficiency and effectiveness of control strategies. Therefore, it is very important to first understand the road condition using predefined parameters. Accordingly, this chapter is designed, which majorly cover:

i) Assessment of road condition of a selected road stretch/Pilot study
ii) Silt loading rate measurement along the road stretch
iii) Particle size distribution of road dust samples at different sections of selected road stretch

2.1 Assessment of Road Condition

2.1.1 Selected Road Stretch for Pilot Study

Considering the study objectives, a road stretch has been selected to carry out field survey/ investigations as a pilot study. All the data analysis including particle size distribution, traffic count, emission load estimation, dispersion modelling and selection of control options has been performed for the selected road stretch. The considered road stretch of 82.5 km starts from Mayapuri (Ring Road) → Punjabi Bagh (NH-10) → Jahangirpuri → Singhu Border → Ghevra, Tikri Border → Mundka → Peergarhi → Punjabi Bagh. The road stretch studied is shown in **Fig. 2.1.**

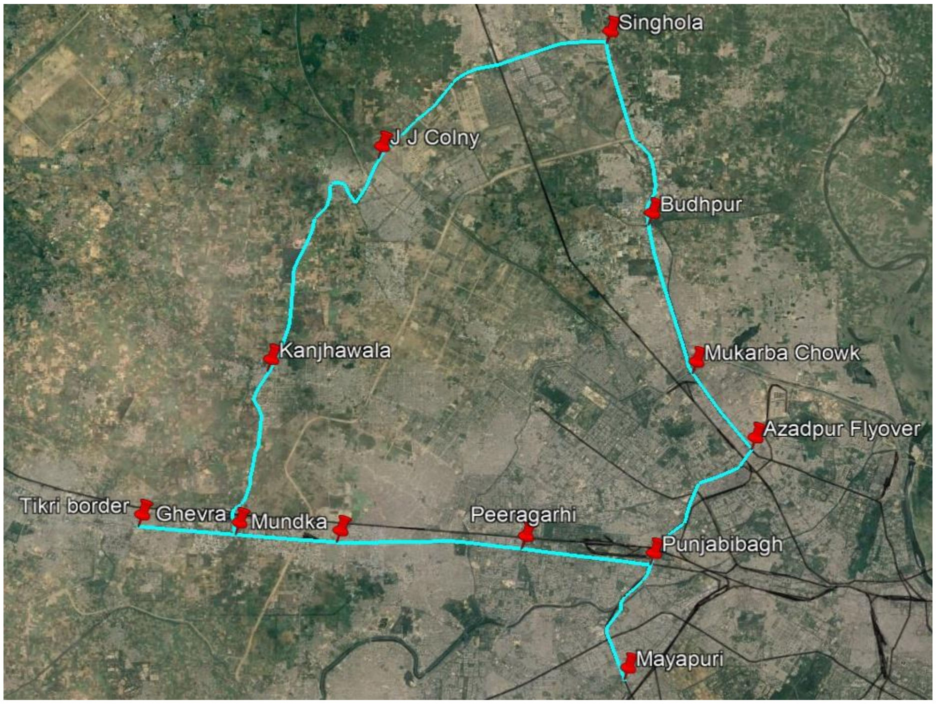


Fig. 2.1: Map showing selected road stretch considered for pilot study

2.1.2 Field Visits/ Surveys

To assess the road conditions, the first step was to visit the selected road stretch and note down the observations. During the survey, field team noted down road classification, its features, surface conditions, road width etc. The study team has also conducted photography, videography along the selected road corridor including dust hotpots, which passes from urban and semi urban area. Efforts were made to note down all the possible reasons for source of dust on road. Additionally, few parameters are noted down with the alignment of the Indian road congress (IRC) guidelines.

As per the Indian Road Congress (IRC SP:118-2018) guidelines, roads are defined and classified based on their width, Right of Way (RoW) and shoulders. Urban Roads are also classified based on surface pavement construction materials. It is mandatory that all roads should be designed and developed as per IRC guidelines considering the traffic demand and safety norms. As per IRC, roads can be classified into Urban Expressways (width 45-75 m), Arterial Roads (45-60m), Sub-arterial roads (30-45m), Collector Roads (15-30 m) and local streets (10-15m). IRC has defined the vehicle carrying capacity of each type of road based on the space needed by each vehicle in terms of Passenger Car Unit (PCU). Further, a road can be classified as ‘with paved shoulder’, ‘with unpaved shoulder’ or ‘without shoulder’. Based on construction material, it can be concrete road or Bitumen Road. Therefore, each road type has its own air pollution-generating potential.

Generally, unpaved shoulder has a large potential to generate dust as compared to paved shoulders due to vehicular motion. In terms of dust emission control, experts recommend concrete roads over bitumen roads due to surface roughness properties (Siew-Ann Tan et al., 1992). **Plate 2.1** shows a sample of different types of roads with paved and unpaved shoulders.

	
Concrete Road	Bitumen Road
	
Unpaved Shoulder	Paved Shoulder

Plate 2.1: Photographs showing examples of typical road surface types

During the road condition assessment survey, the prime focus was to understand the root cause of dust generation over roads. Each potential cause was thoroughly investigated and pointed out and recorded in a pre-designed format. Team also looked at the traffic volume and type of vehicles on the roads. Heavy vehicles were found causing more re-suspension of dust.

A brief information about each section of selected road of 82.5 km starting from Mayapuri (Ring Road) → Punjabi Bagh (NH-10) → Azadpur → Mukarba Chowk → Budhpur → Singhola → Kanjhawala →Ghevra, →Tikri Border → Mundka → Peergarhi → Punjabi Bagh is given in **Table 2.1**. The observations were made regarding impact of roadside activities, which includes littering, construction waste dumping, domestic waste dumping spots, vegetation cover on road edge and median and unpaved areas. These hotspot areas were capable of becoming potential sources of dust generation.

Table 2.1: Physical condition of road and deposited dust on selected road stretch

Sr. No.	Road Stretch	Road Conditions		
1.	Ring Road (Mayapuri Metro Station – Punjabi Bagh Metro Station)			**Very Dusty** Dust spread nearly 1m away from road edge/ shoulder and 0.25 m from median
2.	Ring Road (Punjabi Bagh Metro Station - Azadpur Flyover)			**Dusty Road** Dust spread evenly throughout the road from median to edge.
3.	NH-44 (Azadpur Flyover-Sanjay Gandhi Transport nagar)			**Moderately dusty** Some parts of the stretch have heap of dust at intersections but generally it was less dusty
4.	NH-44 (Sanjay Gandhi Transport nagar -Loha Pul Narela Indl. Area)			**Slightly dusty** Most of the part of this section has flyovers and was generally clean.

Sr. No.	Road Stretch	Road Conditions		
5.	Narela Bawana Road (Loha Pul Narela Indl. Area -Bawana Sec-1)			**Slightly Dusty** Median was well maintained with ~5m width plantation but poor conditions prevail at edge of road.
6.	Narela road (Bawana Sec-1- Ghevra Metro Station)			**Moderately dusty** Some parts were dusty and very congested road
7.	NH-9 (Ghevra Metro Station- Tikri Border)			**Severely dusty** Open heap of soil on the road, open dusty road, with 2-3 m dust available from road edge.
8.	NH-9 (Ghevra Metro Station-Punjabi Bagh Metro Station)			**Severely dusty** Dust can be seen clearly up to 2m from the road edge and 0.5m from a median of road.

In summary, the deposition of dust at a few road stretches was found to be high and a few stretches it was very less. The levels of dust deposition varied significantly along the selected road stretches. For example, the high deposition was observed on road stretches between Mayapuri Metro station and Punjabi Bagh Metro station, and also between Ghevra

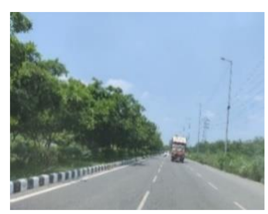
Metro Station and Tikri Border. The less dusty stretches were at NH-44 between Sanjay Gandhi Transport Nagar and Loha Pul Industrial Area, and the Narela Bawana Road between Loha Pul Industrial Area and Bawana Sec-1. Every major/busy road in Delhi should be evaluated in similar fashion before application of control measures.

2.1.3 Mapping of road conditions using GIS

The selected road stretch is 82.5 km long and broadly segmented into 8 sub stretches of nearly 10 km of each and covers feature of National Highway, Arterial Road and sub-arterial road. Its features in terms of road conditions related to dust depositions on median or road edge and surface quality of road in qualitative form i.e., broken, pot hole, cracks and rutting were noted down during the survey. A mobile based road tracking app (Track My Trip) was used during survey for tracking of route and also in ground truthing of road mapping prepared through GIS.

The road condition as recorded during the field survey was mapped using GIS in different category such as Good/Satisfactory, Moderate and Poor/Unsatisfactory which are represented by Green, Yellow and Red colour, respectively. The criteria for evaluation of road condition in Good, Moderate and Poor is given in **Table 2.2**. This categorization is on qualitative basis as per the observation noted by field team.

Table 2.2: Criteria for qualitative assessment of road condition for mapping

S. No	Colour Code	Road condition description	Road Edge/ Shoulder	Median
1		**Good/Satisfactory:** Slight dust is at staggered locations, which can easily be controlled with minor treatments/ efforts. The condition of the road is good, even if there are signs of normal wear and tear. No maintenance is required.		
2		**Moderate:** Moderate level of dust available at shoulder and edge. Dust is clearly visible on road and median. Deposition of dust above the median retaining wall.		

3		**Bad/Poor:** High level of dust is available at both shoulder and edge and it can be picked up manually first after that any control option will work out at these stretches. High loose soil observed above the median retaining wall.		

Based on the above data, the map was prepared for the selected road corridor of 82.5 km of length as shown in **Fig. 2.2**. Out of the total road stretch, 69.92 km of data was recorded in the app (track my trip), 24% (16.70 km) of the road length was found under bad category, 42% (29.78 km) was in moderate condition and only 34% (23.44 km) are properly maintained which is basically part of the NH - 44. The proportion of each category is shown in **Fig. 2.3.**

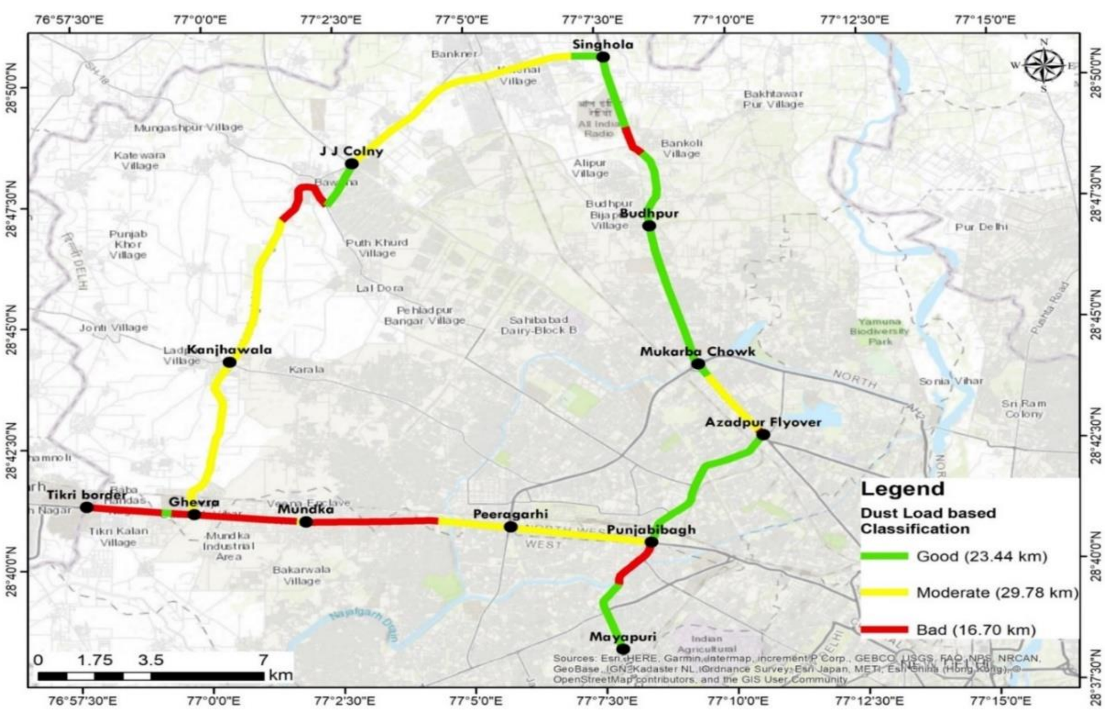


Fig. 2.2: Mapping of road conditions using GIS and Mobile App

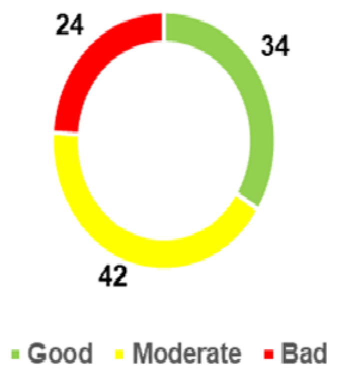
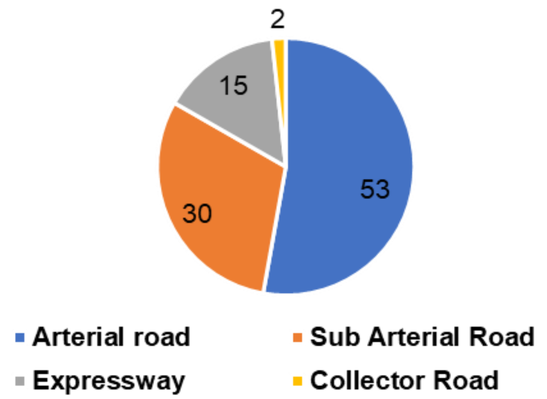
	
Condition of the road (%)	Proportion of Road types (%) as per IRC classification

Fig. 2.3: Status of road condition and its classification of selected road

As per IRC guidelines, the considered road network of 82.5 km is classified as Arterial roads, which constitute 53% of the total length, followed by sub-arterial roads (30%), urban expressways (15%), and collector roads (2%). This distribution highlights the dominance of larger and higher-capacity roads.

2.2 Particle size distribution for a selected road stretch

2.2.1 Collection of dust samples along the selected road

The road dust samples were collected twice during the study period from different locations along the road. First time, the road dust was collected from 5 locations on July 23rd, 2023. **Fig. 2.4** shows the location of samples from where dust samples were collected i.e., Mayapuri (L1), Azadpur (L2), Mukarba chowk (L3), Narela (L4) and Tikri border (L5).

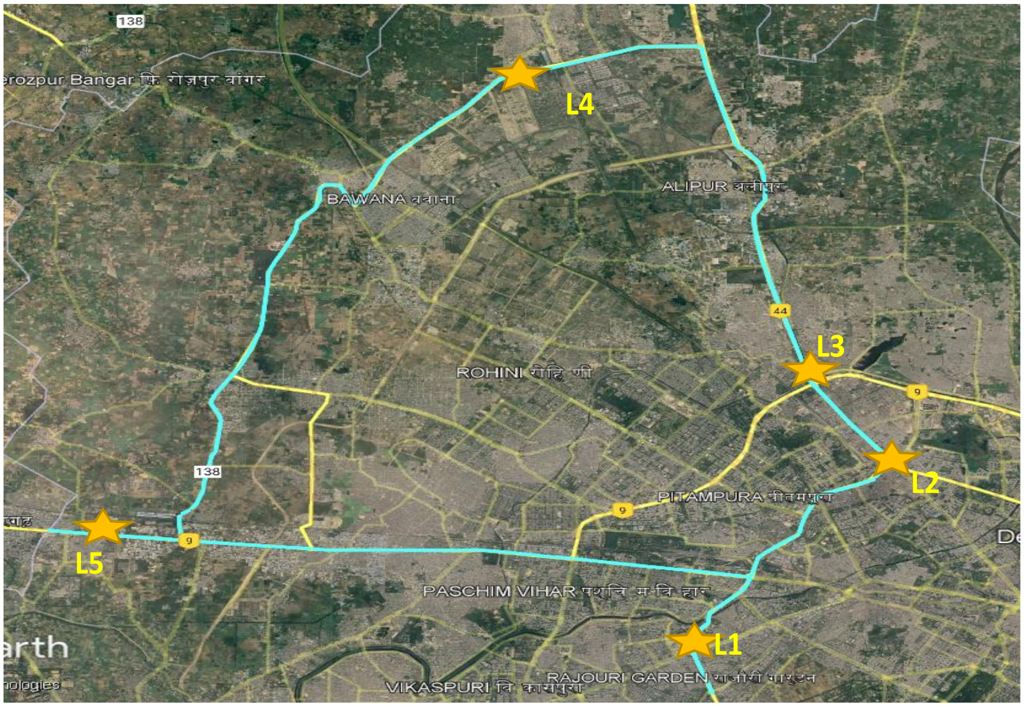


Fig. 2.4: Map showing locations of road dust sample collection

Dust was collected with the help of a portable vacuum cleaner from 1 x 1 m^2 designated area, some samples were collected from road edge side and other near to median. The dust particle size analysis was carried out by sieving method, using sieves of size 710 µm, 420 µm, and 178 µm respectively. The sieve analysis findings in terms of different size particle proportion are given in **Table 2.3**.

The finding indicates that ~ 50% of the sampled dust collected from 5 different locations along the selected road gets passed through a 178 µm sieve. The road stretch between Tikri Border and Mundka has a high percentage of dust deposition whose particle diameter is ≤176 µm on roads, followed by Mukarba Chowk, Mayapuri, Azadpur and Narela. This might be due to a combination of factors, i.e. poor condition of roads, irregular maintenance of roads and insufficient dust management practices. Implementation of suitable dust control options will reduce the high dust loading from these locations.

Table 2.3: Particle size distribution analysis (sieve analysis) of collected dust samples

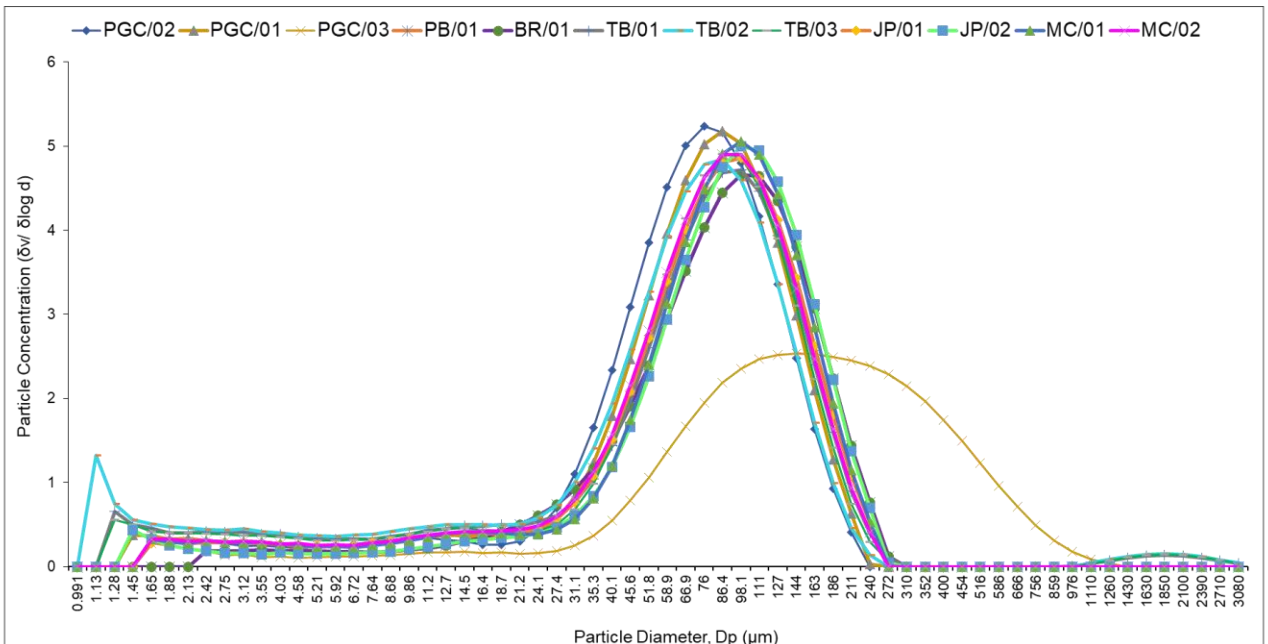
Sr. No	Road Dust from different locations in Delhi	Coordinate	Dust Collected Weight (g/m^2)	Dust >710 µm (g/m^2)	Dust of particle size between (g/m^2)		Dust <178 µm (g/m^2)	Dust < 178 µm (%age)
					420-710 µm	178 – 420 µm		
1.	Mayapuri (L1)	28°40'0.771" N 77°08'7.026" E	143.2	8.8	4.0	56.2	74.2	52%
2.	Azadpur (L2)	28°42'15.801" N 77 10' 15.358" E	245.4	33.0	21.0	66.0	125.4	51%
3.	Mukarba Chowk (L3)	28°44'9.015" N 77°09'18.279" E	99.4	5.8	3.8	29.0	60.8	61%
4.	Narela (L4)	28°50'14.062" N 77°05'52.562" E	325.8	26.2	27.2	145.2	127.2	39%
5.	Tikri Border (L5)	28°41'17.693" N 76°57'47.898" E	91.2	7.0	2.6	22.0	59.6	65%

Later, on February 9, 2024, the study team has again collected dust samples from different road stretch for particle size analysis including previous two sites. Dust was collected from the road edge, middle lane and near to median to understand the mass and size of particle of dust deposited along the cross section of the road. Samples were collected from various stretch of selected road. Sampling was conducted from a designated area of 1x1 m^2 using a portable vacuum dust collector at six different locations including Peeragarhi and Narela-Bawana Road (Arterial Road); Mahatma Gandhi Road and Jhangirpuri Road (Sub Arterial Road); and Mukarba Chowk NH-44 and Tikri NH-09 (National Highway). The collected dust samples were analyzed for particle size distribution using Malvern particle size analyzer. The particle size distribution pattern of collected road dust sample is given in **Table 2.4.** The dust volume %age of dust particles of size ≤76 µm and ≤10 µm were found in the range of 13.6%-42.68 % and 1.2% - 3.7 %, respectively. The dust particle below ≤76 µm are considered as silt mass, which is being re-suspended in the ambient due to vehicle's movement (Jose et al., 2021). However, it is only on the edge side of road surface area and not spread on whole road surface area with same loading rate and accordingly considered in the calculation of the particulate matter emission load from the re-suspension of the road dust

Table 2.4: Particle size distribution analysis of different road dust samples of a selected road

Sr. No.	Road Name	Coordinate	Sample Location	Sample code	Dust weight collected (g/m^2)	Dust weight (g/m^2)			
						<310 µm	<144 µm	<76 µm	<10 µm
1.	Punjabi Bagh Flyover	28°40'15.78"N 77° 8'20.07"E	Edge Side	PB/01	23.6	23.6	20.3	9.6	0.7
2.	Jahangir puri	28°43'34.97"N 77° 9'44.24"E	Edge Side	JP/01	5.4	5.4	4.3	1.8	0.1
			Median Side	JP/02	7.4	7.4	5.5	2.0	0.1
3.	Mukarba Chowk	28°44'15.00"N 77° 9'16.31"E	Edge Side	MC/01	5.0	5.0	3.9	1.5	0.1
			Median Side	MC/02	7.6	7.6	6.1	2.6	0.2
4.	Bawana	28°50'1.41"N 77° 4'45.45"E	Edge Side	BR/01	15.6	15.6	11.6	4.7	0.2
			Median Side	BR/02	9.8	9.8	8.0	3.3	0.2
5.	Tikri Border	28°41'13.10"N 76°58'26.30"E	Edge Side	TB/01	23.0	22.4	18.0	7.8	0.7
			Middle Lane	TB/02	8.0	7.8	6.7	3.3	0.3
			Median Side	TB/03	16.4	15.9	13.1	5.6	0.5
6.	Peera -garhi	28°40'45.58"N 77° 5'50.77"E	Edge Side	PGC/01	35.0	35.0	29.6	13.2	0.8
			Middle Lane	PGC/02	8.2	8.2	7.2	3.5	0.2
			Median Side	PGC/03	15.4	10.8	5.6	2.1	0.2

Further, the size distributions of particles are best described by lognormal distributions which is shown in **Fig. 2.5,** which displays the distribution of different particle size range for a typical urban road dust sample. The particle size distribution test was conducted on different road stretches starting from Mayapuri (Ring Road) → Punjabi Bagh (NH-10) → Azadpur → Mukarba Chowk → Budhpur → Singhola → Kanjhawala → Ghevra, →Tikri Border → Mundka -→ Peergarhi → Punjabi Bagh. It was observed that Tikri border (TB) road was having a high amount of dust loading. At TB/02 (middle lane) has high proportion of fine dust (particle size ranging < 2 µm) compared to edges. Similarly, Peeragarhi road (PGC) road edge side has high contribution in large size particle along with the median side (PGC/03) with particle size range between 76 – 310 µm. Further, majority of dust particles size lies in range of 35 µm – 211 µm, which helps in re-suspension of road dust and contributes to disintegration of dust into finer particles after repeated crushing due to movement of vehicles.



TB/01 - Tikri Border (Edge Side)	**TB/02 -** Tikri Border (Middle Lane)	**TB/03 -** Tikri Border (Median Side)
MC/01 - Mukarba Chowk Road (Edge Side)	**MC/02 -** Mukarba Chowk Road (Median Side)	**PGC/01 -** Peeragarhi (Edge Side)
PGC/02 - Peeragarhi (Middle Lane)	**PGC/03 -** Peeragarhi (Median Side)	**JP/01 -** Jahangirpuri (Edge Road)
JP/02 - Jahangirpuri (Road Median)	**BR/01 -** Bawana (Road Edge)	**BR/02 -** Bawana (Median Side)
PB/01 - Punjabi Bagh Flyover (Edge Side)		

Fig. 2.5: Particle size distribution of collected dust samples from various stretches of the selected road

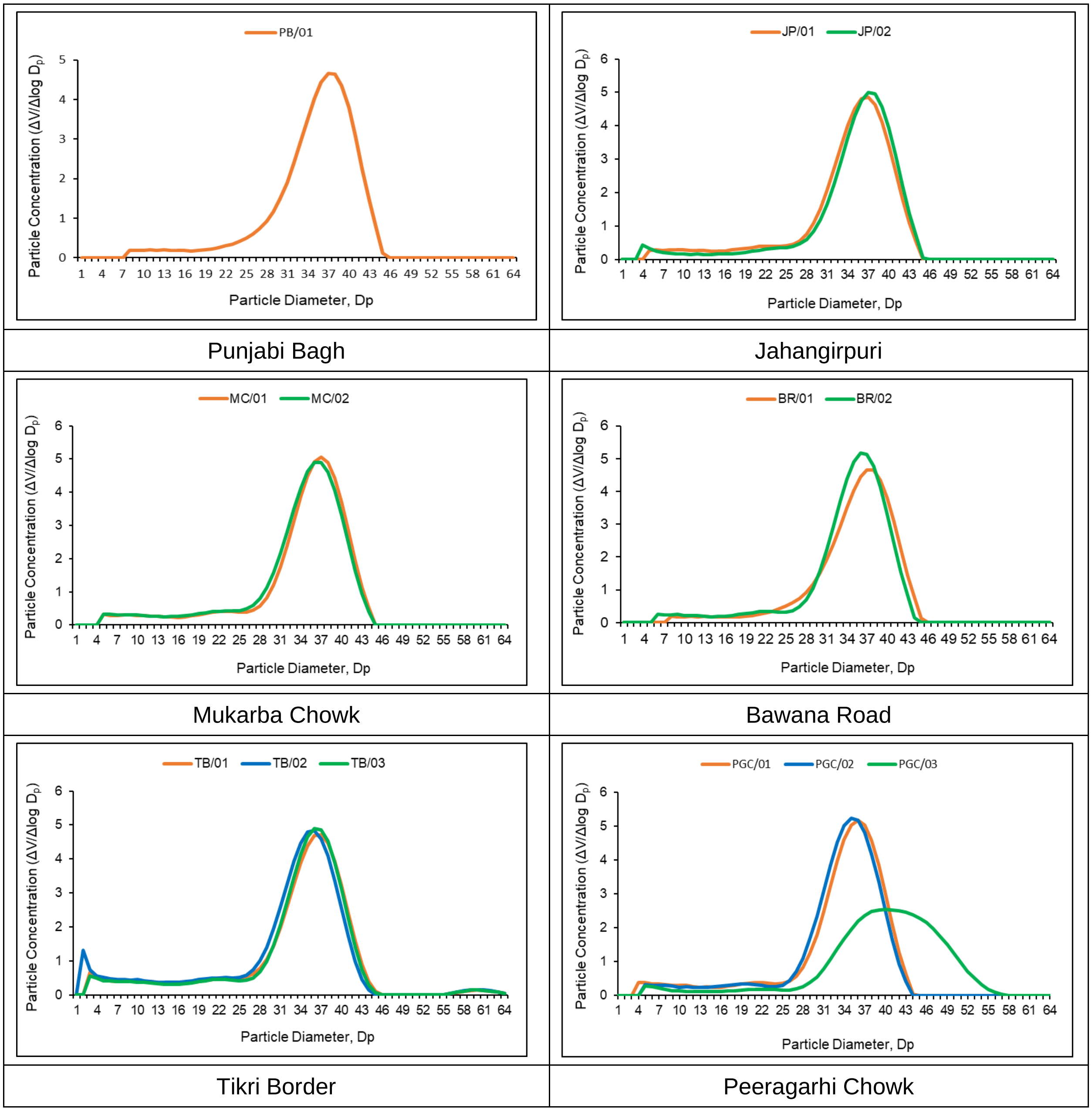


Fig. 2.6: Particle size distribution of collected dust samples for each selected stretch of road

Plate 2.2, shows dust deposition across different cross section of Peeragarhi road i.e., road edge, middle lane and near median side. Dust on the road edge side and near to median is significantly at higher side as compared to middle lane of the road. The majority of middle lanes had relatively less dust, but the lane closest to the median was found loaded with higher dust which might be because of overburden loose soil that becomes turbulent as vehicles passes nearby to it or spills from the median plantation. Further, a comparison of particle size distribution was done between the road edge, middle lane and road median for six different locations, as given in **Table 2.5.** It is found that Peeragarhi and Tikri border road has significant amount of fine dust (< 10 µm) accumulated near the road edge and median as compared to middle of the road.

Lat: 28.679327°, Long: 77.097437°		
Edge / shoulder side	Middle lane	Near Median Side

Plate 2.2: Photographs showing Road dust collection from Peeragarhi (NH-9) for particle size analysis

Table 2.5: Dust deposition at road edge, middle lane and near to median of different stretch of selected road corridor

Sr. No.	Road Dust from different locations in Delhi	Dust below particle size <76 µm (g/m²)			Dust below particle size <10 µm (g/m²)		
		Road edge	Middle lane	Near median	Road edge	Middle lane	Near median
1.	Punjabi Bagh Flyover	32.03	-	-	2.91	-	-
2.	Jahangirpuri	26.06	-	21	2.2	-	1.46
3.	Mukarba Chowk	22.97	-	27.1	2.15	-	2.28
4.	Bawana Road	23.93	-	25.85	1.33	-	1.71
5.	Peeragarhi	13.2	3.5	2.1	0.8	0.2	0.2
6.	Tikri Border	7.8	3.3	5.6	0.7	0.3	0.5

The findings of this chapter are summarized below:

- A road stretch of length 82.5 km was selected for the pilot study. This road section starts from Mayapuri, Ring Road and goes to Shalimar Bagh, Jahangirpuri, Singhu Border, Ghevra, Tikri Border, Mundka, Peeragarhi, and finally back to Punjabi Bagh.
- To understand the physical condition of road and to identify hotspots enhancing re-suspension of road dust issues, field survey was conducted and observation on road condition were noted and dust samples were collected.
- Road dust levels varied across the stretch with higher deposition near to road median and road edge and low deposition on road middle lane. The dust volume %age of dust particles of size ≤76 μm and ≤10 μm were found in the range of 13.6%-42.7 % and 1.2-3.7% respectively.
- The highest road dust deposition was observed near Peeragarhi, Tikri Border, Bawana, and Punjabi bagh areas respectively.

Chapter 3

Re-suspension of Road Dust: Quantification and Dispersion

This chapter includes an estimation of PM_{10} and $PM_{2.5}$ emission load from road dust re-suspension due to the movement of traffic along the selected road stretch and its dispersion in the surrounding environment and contribution on nearby continuous air quality monitoring stations (CAAQMS).

3.1 Traffic Count Data

The traffic count data for eight major locations/ intersections was collected by CSIR-CRRI, Delhi on an hourly basis for the complete 24 hours. The traffic data was extracted from the recorded video footage for six distinct vehicle categories, namely, Two-Wheeler (2W), Three-Wheeler (3W), Car/Jeep/Taxi (4W), Light Commercial Vehicle (LCV), Bus, and Truck. **Fig. 3.1** shows the traffic monitoring location map where traffic recording was done by CSIR-CRRI.

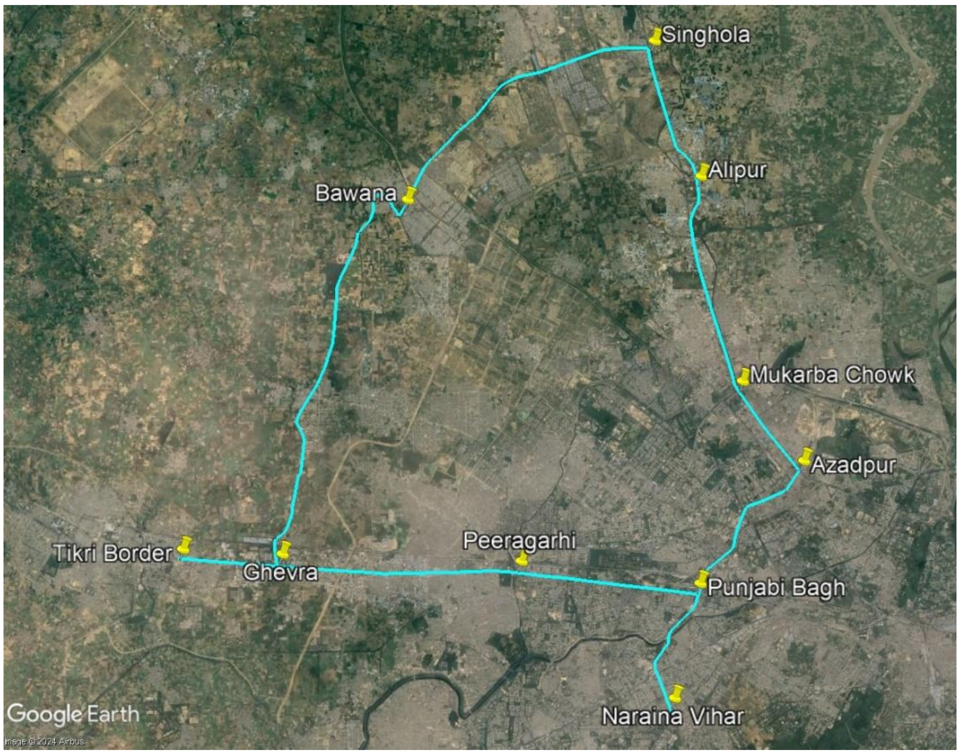


Fig. 3.1: Traffic monitoring locations along the selected road

The 24-h traffic fleet composition for to and fro vehicle movement at 8 locations for a typical weekday is shown in **Fig. 3.2** and road stretch name given in **Table 3.1**. On an average basis, two-wheelers (2-Ws) accounted for 26% of the total traffic fleet, while four-wheel cars (4-Ws) made up to 62%. Additionally, three-wheelers (3Ws) comprised 6% of the total fleet, while light commercial vehicles (LCVs) were around 2%. Buses and trucks constituted 3% and 2%, respectively, across all locations. It is also observed that vehicles movement are highly influenced during the day and night time as shown in diurnal profile plot in **Fig. 3.3.** The diurnal profile of traffic movement indicates major movement during the daytime with peak between 7:00 am to 11:00 am and 5:00 pm to 8:00 pm.

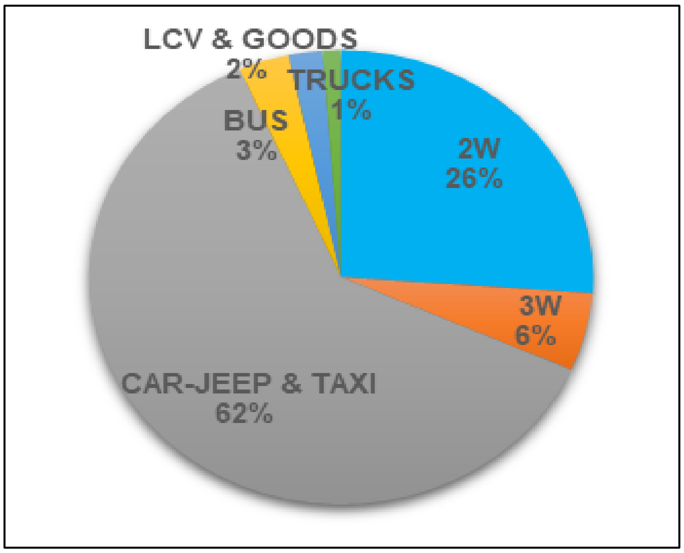


Fig. 3.2: Average traffic fleet composition of the collected data along the selected road

Table 3.1: Road stretches and their code used in a pilot study

Sr. No.	Road Code	Origin	Coordinates	Destination	Coordinates
1.	R1	Naraina Vihar	28°37'23.6"N 77°08'07.5"E	Punjabi bagh	28°40'34.7"N 77°08'26.9"E
2.	R2	Punjabi Bagh	28°40'34.7"N 77°08'26.9"E	Azadpur	28°42'53.1"N 77°10'19.0"E
3.	R3	Azadpur	28°42'53.1"N 77°10'19.0"E	Mukarba Chowk	28°44'06.5"N 77°09'21.1"E
4.	R4	Mukarba Chowk	28°44'06.5"N 77°09'21.1"E	Alipur	28°48'23.2"N 77°08'26.5"E

Sr. No.	Road Code	Origin	Coordinates	Destination	Coordinates
5.	R5	Alipur	28°48'23.2"N 77°08'26.5"E	Singhola	28°51'28.3"N 77°07'28.2"E
6.	R6	Singhola	28°51'28.3"N 77°07'28.2"E	Bawana	28°44'15.8"N 77°00'27.1"E
7.	R7	Bawana	28°44'15.8"N 77°00'27.1"E	Ghevra Metro	28°41'07.3"N 76°59'40.9"E
8.	R8	Ghevra Metro	28°41'07.3"N 76°59'40.9"E	Punjabi Bagh	28°40'24.8"N 77°08'27.1"E

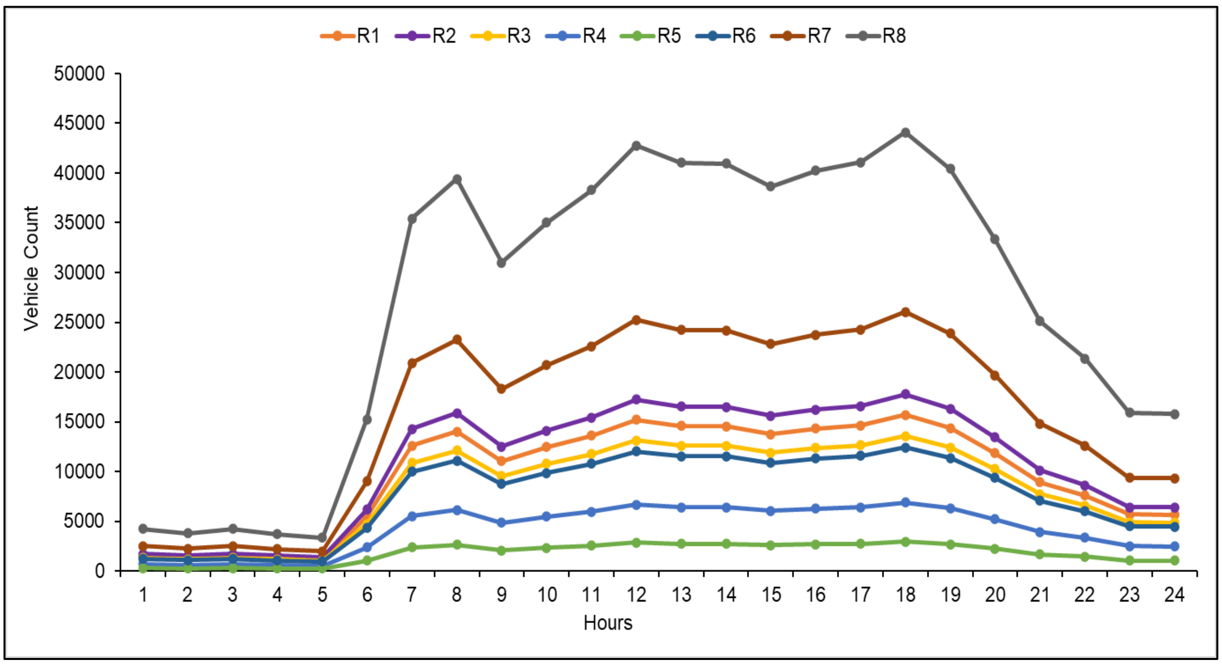


Fig. 3.3: Diurnal variation of traffic flow at different stretches along the selected road

3.2 Emission Load Estimation from Road Dust Re- suspension along the selected road

The re-suspension of road dust by motorized transport is one of the major sources of pollution along with the exhaust emissions. These emissions are known to vary with silt loading rate, vehicle type, road type, pavement type, vehicular speed, average vehicular weight etc.

Further, the quantity of dust emissions and the final emission load from different vehicular types has been determined using following set of equations from EPA's AP-42 (1-2).

$$EF_{(j)} = k \times (sL)^{0.91} \times W^{1.02} \qquad (1)$$

$EF_{(j)}$ = Emission Factor of j^{th} pollutant (g/VKT), j = pollutant (PM_{10} and $PM_{2.5}$), k = particle size multiplier, 0.62 g/ VKT for PM_{10} and 0.15 g/ VKT for $PM_{2.5}$, sL = silt loading rate (g/m^2), W = average vehicular weight (tons)

$$E_{(j)} = \frac{\sum_{h=1}^{24} N \times L_{(i)} \times EF_{(j)}}{1000} \qquad (2)$$

$E_{(j)}$ = Emission of j^{th} pollutant (kg/day), h = hour, N = Total number of vehicles, $L_{(i)}$= Road Length (km), $EF_{(j)}$= Emission Factor for j^{th} pollutant as calculated from (1) (g/km)

The overall estimated emissions from vehicle movement for PM_{10} and $PM_{2.5}$ are **33.83 tons/day** and **8.16 tons/day,** respectively. **Table 3.2** shows Ghevra to Punjabi Bagh West Road (NH-9) shows alarmingly high levels of PM_{10} and $PM_{2.5}$ emissions with values of 1450.5 kg/day/km and 349.5 kg/day/km respectively, which are significantly very high for any city roads. Bawana to Ghevra metro (NH-9) also exhibits elevated PM levels, with PM_{10} at 834.9 kg/day/km and $PM_{2.5}$ at 202.0 kg/day/km.

Table 3.2: Estimated PM_{10} and $PM_{2.5}$ Emission load due to re-suspension of road dust along the selected road

Road Code	Road Stretch	Total No. of Vehicles in a Day	Road Length (km)	PM_{10} (Kg/day/ km)	$PM_{2.5}$ (kg/day/ km)	Emission Load (PM_{10}) (kg/day)	Emission Load ($PM_{2.5}$) (kg/day)
R1	Naraina to Punjabi Bagh	2,32,904	10.6	291.1	70.4	3085.7	746.2
R2	Punjabi bagh to Azadpur	2,63,836	5.1	104.5	25.3	533.0	129.0
R3	Azadpur to Mukarba Chowk	2,01,259	5.4	77.8	18.8	420.1	101.5
R4	Mukarba Chowk to Alipur	1,02,032	9.2	39.6	9.6	364.3	88.3
R5	Alipur to Singhu Border	43,728	6.2	17.0	4.1	105.4	25.4

Road Code	Road Stretch	Total No. of Vehicles in a Day	Road Length (km)	PM_{10} (Kg/day/ km)	$PM_{2.5}$ (kg/day/ km)	Emission Load (PM_{10}) (kg/day)	Emission Load ($PM_{2.5}$) (kg/day)
R6	Singhu Border to Bawana	1,84,126	24.6	102.9	24.9	2531.3	612.5
R7	Bawana to Ghevra Metro	3,86,345	6.9	834.9	202.0	5760.8	1393.8
R8	Ghevra to Punjabi Bagh	6,54,286	14.5	1450.5	349.5	21032.3	5067.8
Total			**82.5**			**33832.9**	**8164.6**

Fig. 3.4 shows PM_{10} and $PM_{2.5}$ emission load per kilometer in a day at different road stretches and it was observed that Ghevra-Punjabi Bagh (R8) which passes through Peeragarhi generated maximum load. Lower emissions were observed on the road stretch between Alipur GT Road and Singhola (R5).

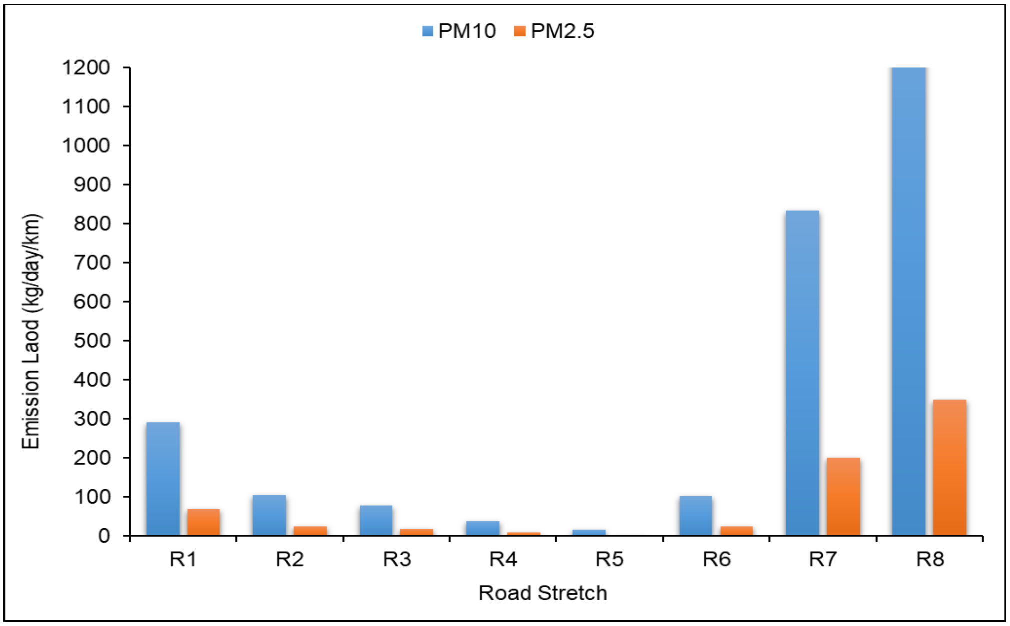


Fig. 3.4: Comparison of PM_{10} and $PM_{2.5}$emission load at various stretches along the selected road

Further, **Fig. 3.5** and **Fig. 3.6** show diurnal variations with hourly average of PM_{10} and $PM_{2.5}$ emission load (Kg/day) at different roads of study area. Emission levels are generally higher during peak hours (7:00 am-11:00 am and 5:00 pm- 8:00 pm) and lower during night hours (11:00 pm – 5:00 am) which is directly correlating with pattern of number of vehicles.

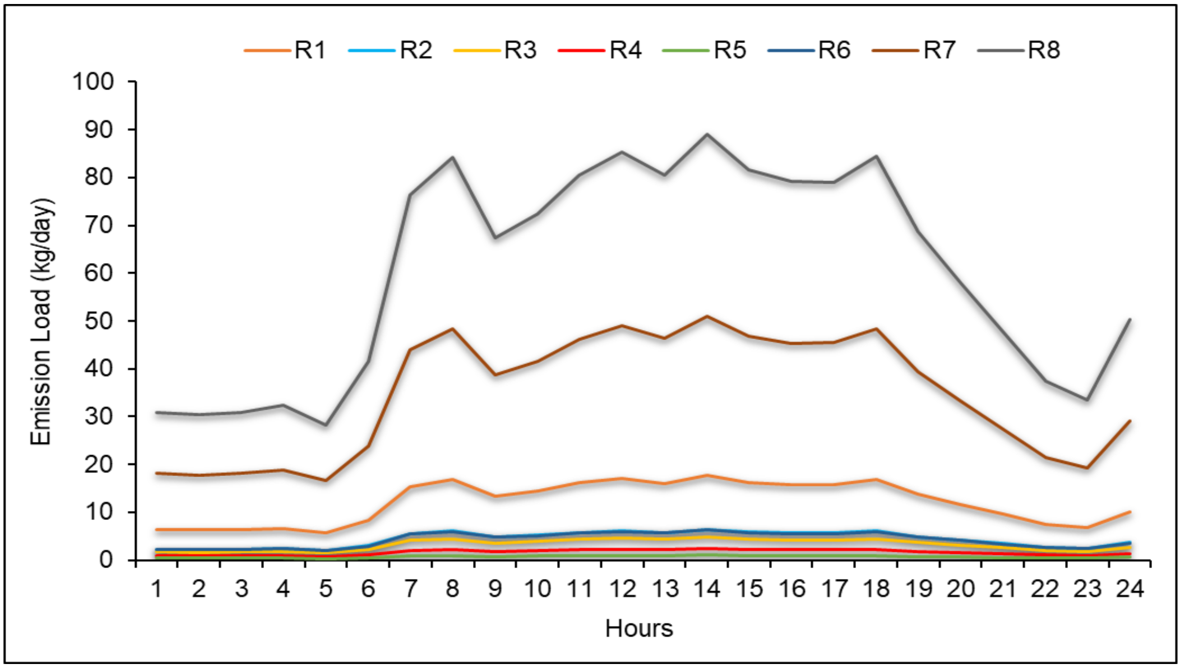


Fig. 3.5: Hourly variation of PM_{10} at different locations along the selected road

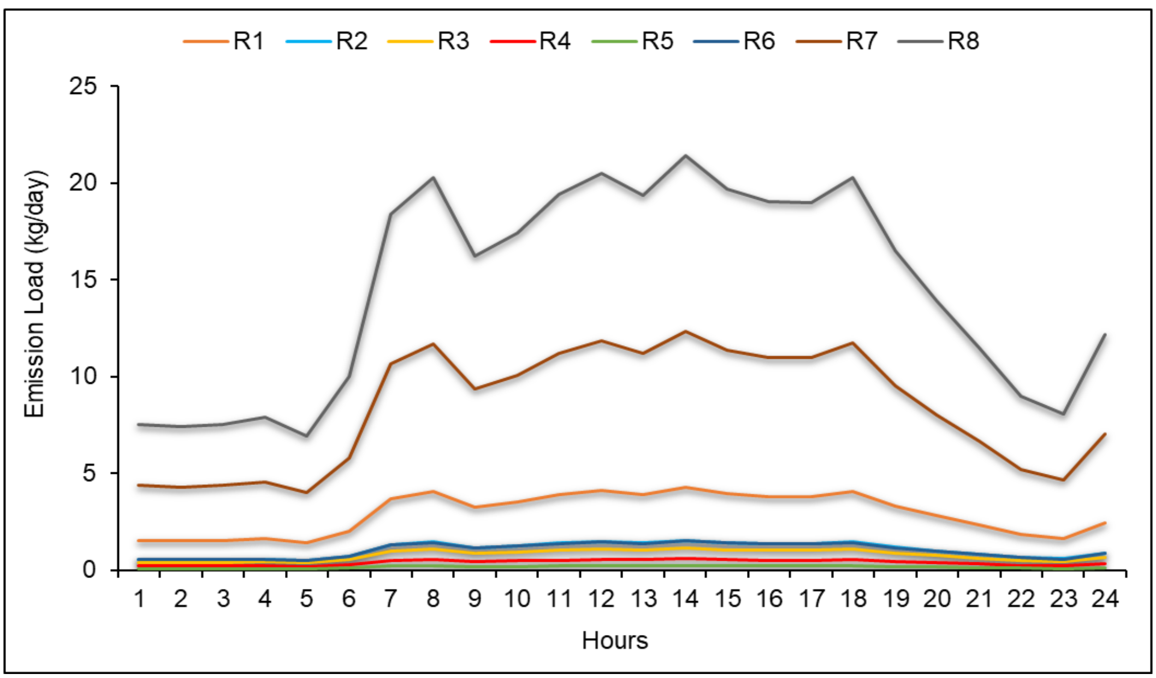


Fig. 3.6: Hourly variation of $PM_{2.5}$ at different locations along the selected road

3.3 Prediction of Particulate matter concentration due to Re-suspension of road dust

This section discusses the air quality dispersion modeling for the study area considering line source emission. The section includes an understanding of the meteorological profile of the study area and dispersion of the particulate matter emitted from vehicle exhaust and re-suspension of road dust. The contributions of road transport emissions at monitored locations were quantified through dispersion modeling.

3.3.1 Meteorology conditions

Meteorological conditions play an important role in dispersion of air pollutants emitted from various sources. Meteorological parameters vary from day to day and hour to hour. The meteorological conditions during winter season are not conducive for dispersion of pollutants and results in build-up of pollution levels. The meteorological parameters such as wind speed, ambient temperature, relative humidity, solar radiation, precipitation and pressure have been studied from 1st January – 28th February, 2024. It is observed that the ambient temperature lied in the range of 9.9ºC - 15.8ºC and relative humidity in the range of 51% - 81%.

Figs. 3.7-**3.8** shows the diurnal profile of the meteorological parameters including relative humidity, ambient temperature, wind speed and solar radiation. The wind was found blowing mainly from the East- northeast direction with wind speed ranging from 0.50-3.60 m/s, however, calm conditions prevailed only 44.5% of the time. The dominant wind speed was in the range of 0.50-2.10 m/s (51.1%), and **Fig. 3.9** shows the wind rose and frequency distribution chart of the same. The average temperature on hourly basis was observed, maximum temperature observed during day time was 15-16ºC between 2:00 pm - 3:00 pm and minimum temperature observed was 10 ºC during early mornings from 6 am - 7 am.

Relative humidity was observed less during the day time ranging from 50% - 60% during 1:00 pm - 4:00 pm and highest during early 5:00 am - 7:00 am mornings ranging from 75% - 80%. Maximum hourly wind speed observed was in between 1.6 -1.8 m/s and it was observed during time close to 4:00 pm. Solar radiation was observed maximum during 1:00 pm and its value lies between 200 -250 W/m^2.

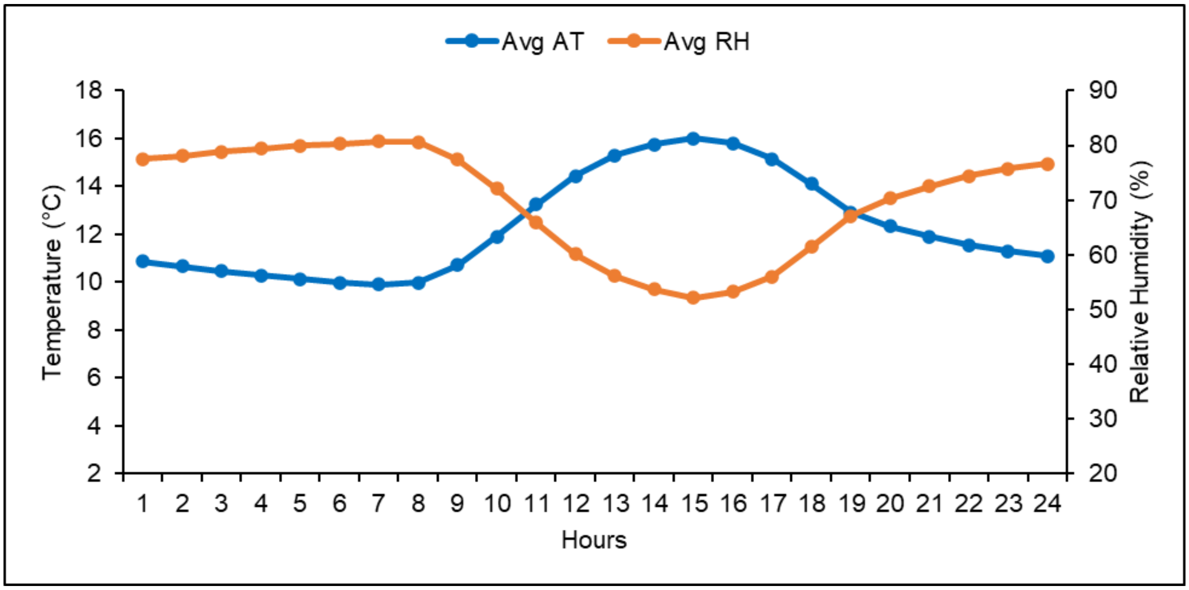


Fig. 3.7: Diurnal profile of ambient temperature and relative humidity

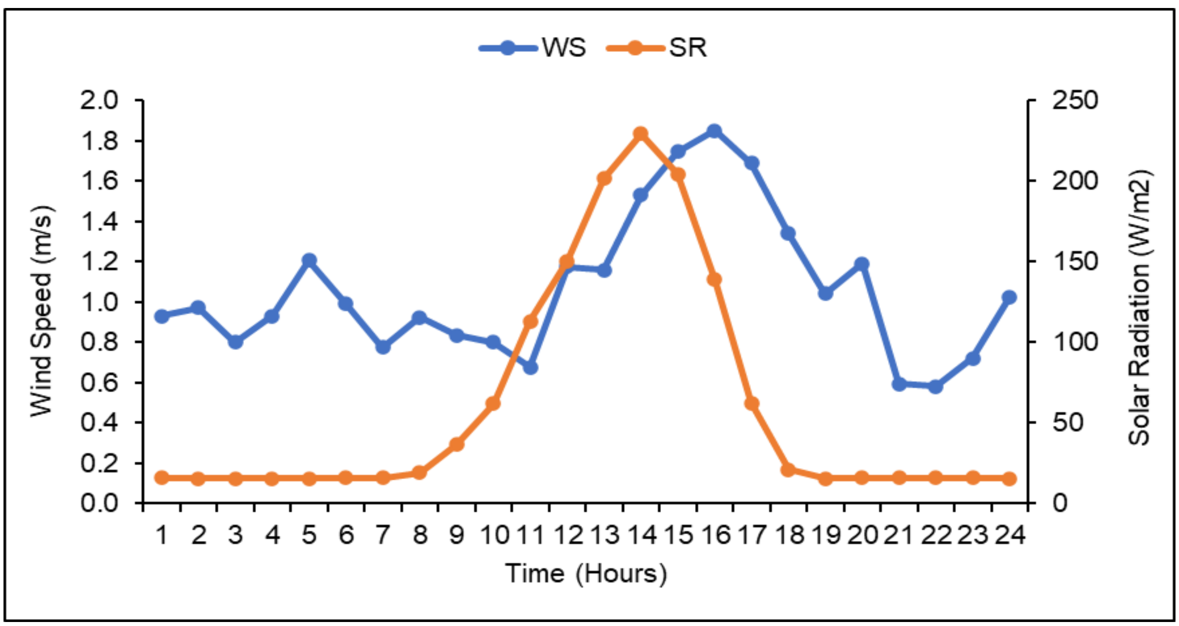
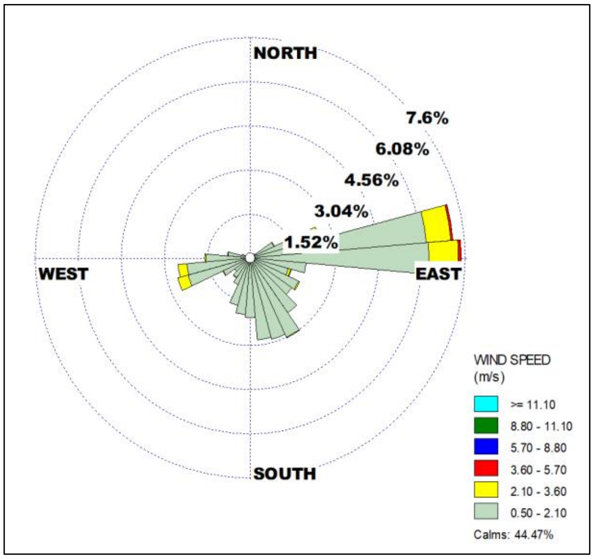
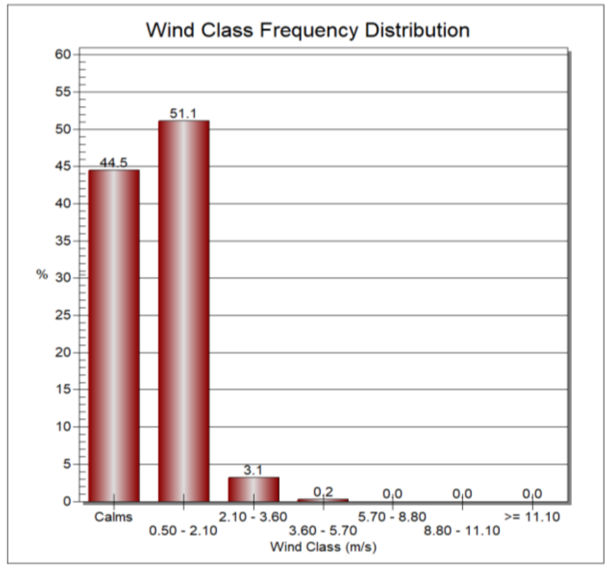


Fig. 3.8: Diurnal profile of wind speed and solar radiation



Wind Rose



Frequency Distribution

Fig. 3.9: Wind rose and frequency distribution chart at Mundka during 1st January - 28th February, 2024

3.3.2 AERMOD - Model Setup and Run

Air quality dispersion modelling is carried out using AERMOD model. AERMOD was developed by AMS/EPA Regulatory Model Improvement Committee (AERMIC). It is a steady-state plume model. It is applicable to rural and urban areas, flat and complex terrain, surface and elevated releases and multiple sources (including point, area and volume sources). The AERMOD has two pre-processors for meteorological data and surface data. AERMET calculates the planetary boundary layer (PBL) parameters and these parameters are transferred to AERMOD to further calculate the vertical turbulence parameters of the atmosphere. The terrain pre-processor AERMAP uses gridded terrain data to calculate a representative terrain-influence height (h_c), also referred to as the terrain height scale. It is the advancement over the ISCST3 model and is also recognised by the MoEF&CC. The run stream setup file contains the selected modeling options as well as source locations and parameter data, receptor locations, meteorological data file specifications and output options. It is widely used in air quality prediction through various kinds of sources for decision-making and other regulatory purposes.

The model has been run for default option for regulatory purpose with output as concentration of pollutant. The source is considered as line area source as per classification mentioned in the AERMOD. The model ran for representative days of the critical winter period i.e., January 2024 by using meteorological data of Mundka CAAQMS. Model also need upper air meteorological data which is not being monitored in Delhi, in this case, the upper air estimation option as suggested in the AERMOD guideline used to generate upper air data considering the surface meteorological parameters. The receptor grids are used at an interval of 250 m x 250 m cell size with a total number of grids as 1024 covering all road sections within the grid. The receptor points falling under the road width were removed as per air quality modelling guidelines. The flat terrain is considered in the model option. Further, **Figs. 3.10- 3.11** shows modelling domain setup over the study map, sources and receptor grid points used in the present study.

Fig. 3.10: AERMOD modeling domain showing selected road as line area source

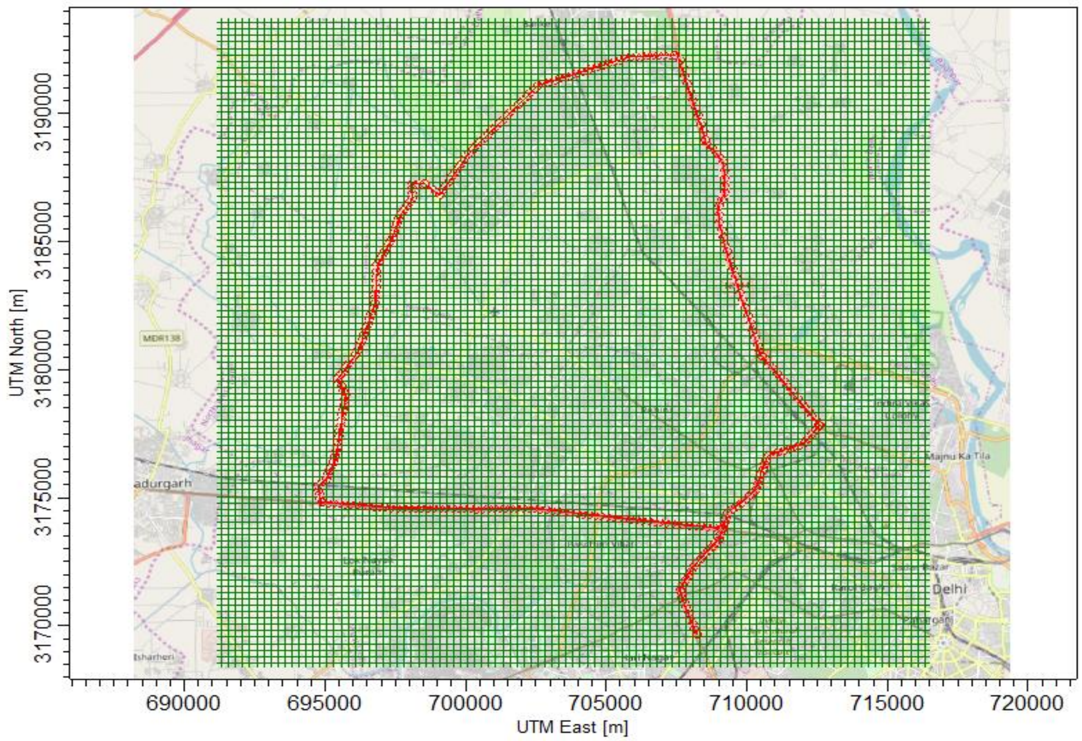


Fig. 3.11: Receptor grid points used in the modeling for the present study

3.3.3 PM_{10} and $PM_{2.5}$ Prediction

The isopleth of 24-hour average predicted PM_{10} and $PM_{2.5}$ concentration emitted from re-suspension of road dust due to movement of vehicles on the selected road is shown in **Fig. 3.12** and **Fig. 3.13**. The maximum PM_{10} and $PM_{2.5}$ were predicted along the road stretch from Ghevra to Punjabi Bagh with peaks near to Mundka area i.e. 1867 µg/m^3 and 450 µg/m^3, respectively. The pollutant concentration decreases rapidly as we move away from the road. For $PM_{10,}$ it is found that the road stretch from Ghevra to Punjabi Bagh has high traffic density which emits higher PM_{10}, i.e. 1700 µg/m^3 up to 10 m distance from the road. As we move away from the road, PM_{10} concentration starts decreasing and at a 500 m distance, it remains 100 µg/m^3. Similar trends have been observed on other roads with lower concentrations. It is observed that PM_{10} dispersed along the road and did not travel far away as indicated in isopleth as given in **Table 3.3.** For $PM_{2.5,}$ it is found that the road stretch from Ghevra to Punjabi Bagh has high traffic density which emits higher $PM_{2.5}$, i.e. 450 µg/m^3 up to 10 m distance from the road. As go away from road, $PM_{2.5}$ concentration starts decreasing and at 500 m distance it remains 40 µg/m³. Similar dispersion trends have been observed on other roads with less concentrations. It is observed that $PM_{2.5}$ disperse along the road and did not travel far away as indicated in isopleth as given in **Table 3.4.**

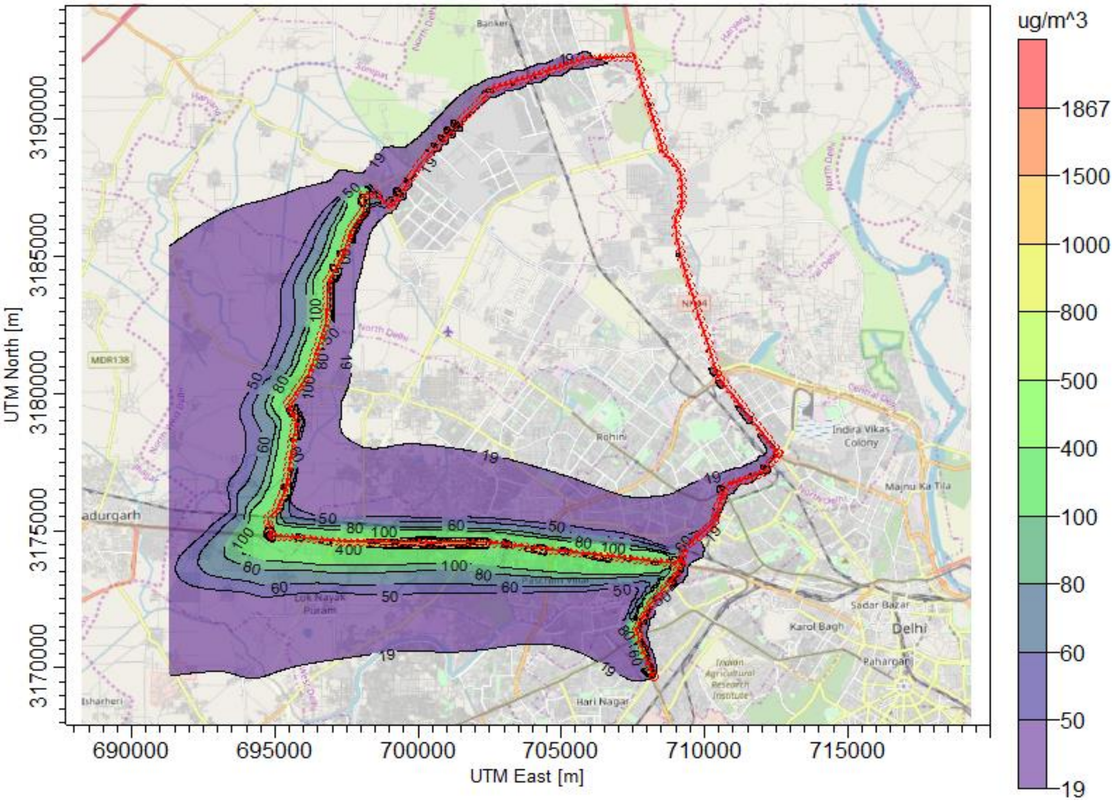


Fig. 3.12: Isopleth showing predicted PM_{10} concentrations from re-suspension of road dust

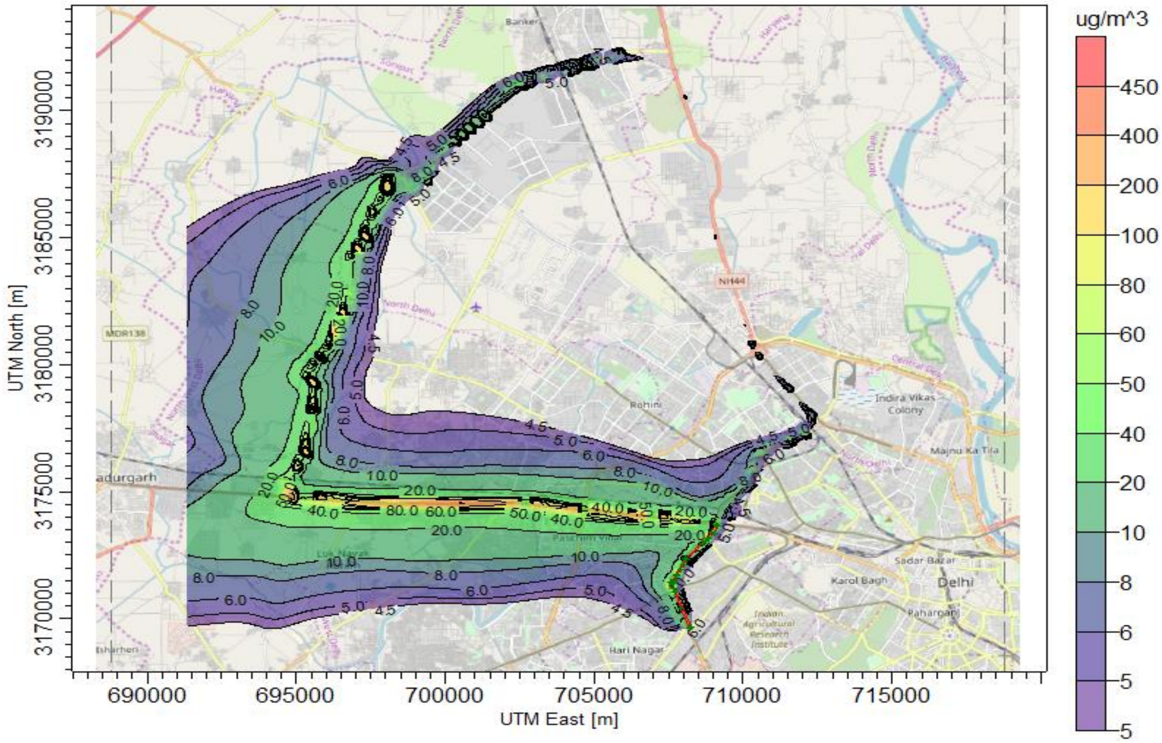


Fig. 3.13: Isopleth showing predicted $PM_{2.5}$ concentrations from re-suspension of road dust

Table 3.3: Predicted PM_{10} concentration emitted from Re-suspension of dust along the selected road stretch

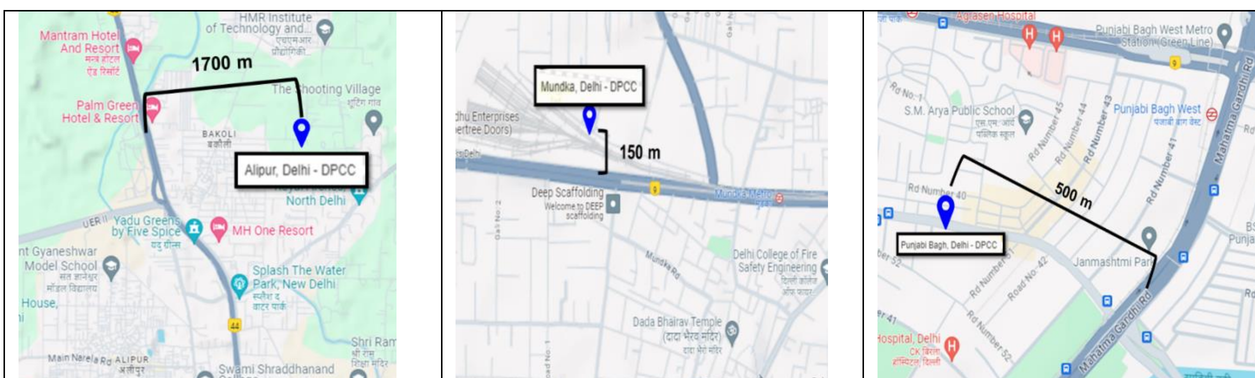
Sr. No.	Road Name	Vehicle Count	Dispersion of PM_{10} (in µg/m^3) from road dust re-suspension at various distances (in m) from line source						
			10	20	30	50	100	200	500
1.	Naraina to Punjabi Bagh	2,32,904	550	540	535	530	300	150	50
2.	Punjabi bagh to Azadpur	2,63,836	40	42	43	45	55	65	35
3.	Azadpur to Mukarba Chowk	2,01,259	24	25	29	28	25	14	10
4.	Mukarba Chowk to Alipur	1,02,032	12	12.8	13	15	19	18	9
5.	Alipur to Singhu Border	43,728	21	20.5	20	19	16	6	4
6.	Singhu border to Bawana	1,84,126	107	106	105	102	85	15	0
7.	Bawana to Ghevra Metro	3,86,345	310	305	302	290	270	230	130
8.	Ghevra to Punjabi Bagh	6,54,286	1700	1690	1680	1650	1500	300	100

Table 3.4: Predicted $PM_{2.5}$ concentration emitted from Re-suspension of dust along the selected road stretch

Sr. No.	Road Name	Vehicle Count	Dispersion of $PM_{2.5}$ (in µg/m^3) from road dust re-suspension at various distances (in m) from source emission						
			10	**20**	**30**	**50**	**100**	**200**	**500**
1.	Naraina to Punjabi Bagh	2,32,904	140	135	135	130	70	30	10
2.	Punjabi bagh to Azadpur	2,63,836	10	11	11.5	12	15	14	4
3.	Azadpur to Mukarba Chowk	2,01,259	8.4	8	7.8	7.6	7	5	3
4.	Mukarba Chowk to Alipur	1,02,032	5.2	5.1	5	4.8	4.5	2.5	1
5.	Alipur to Singhu Border	43,728	5.4	5.3	5.1	5	4.5	3.5	2
6.	Singhu border to Bawana	1,84,126	26	25	24	23	17	2	1
7.	Bawana to Ghevra Metro	3,86,345	111	109	105	101	100	60	25
8.	Ghevra to Punjabi Bagh	6,54,286	450	448	445	442	400	80	40

3.3.4 Comparison between Monitored (CAAQMS) and Predicted (AERMOD) Concentration

Further, the particulate matter concentration from road transport was predicted at the nearest monitoring stations along the selected road stretch. A total of three CAAQMS are located along the road stretch in the study area. These CAAQMS are Alipur (1700 m in East side of road), Mundka (150 m in North side of road) and Punjab Bagh (500 m from road in west side) as shown in **Fig. 3.14.**



Alipur CAAQM Station	Mundka CAAQM Station	Punjabi Bagh CAAQM Station

Fig. 3.14: Map showing distance of CAAQM stations from selected road

Table 3.5 describes the average PM_{10} and $PM_{2.5}$ concentrations monitored by CAAQMS stations and average contribution of PM_{10} and $PM_{2.5}$ by AERMOD for the Mundka stations in the study area during the study period. Out of three, maximum concentrations were observed at Mundka followed by Punjabi Bagh and Alipur. This pattern is matched with the predicted concentrations of PM_{10} and $PM_{2.5}$ by AERMOD as discussed in the previous section.

The contribution of particulate matter by vehicle movement at Mundka CAAQMS and prediction by AERMOD dispersion modelling has been studied and it has been observed that 73.4 % of PM_{10} and 27.6 % of $PM_{2.5}$ is contributed by vehicular movement (Exhaustive + re-suspended). At Alipur CAAQMS, the contribution from exhaustive emission and road dust re-suspension in PM_{10} and $PM_{2.5}$ concentration was estimated to be 5.5 % and 1.3 %, respectively. Further, for Punjabi bagh CAAQMS, PM_{10} and $PM_{2.5}$ contribution is 19.8% and 6.0%, respectively.

Table 3.5: Contribution of Road Dust (PM_{10} and $PM_{2.5}$) Predicted at nearby CAAQMS

Sr. No.	Particulars	CAAQMS Station Locations		
		Alipur	Mundka	Punjabi Bagh
1.	Distance from study road	1700 m	150 m	500 m
2.	Avg PM_{10} (µg/m^3)	216	313	302
3.	Avg $PM_{2.5}$ (µg/m^3)	154	217	216
Predicted Concentration from Re-Suspension of Road Dust				
4.	PM_{10} (µg/m^3)	12	230	60
5.	$PM_{2.5}$ (µg/m^3)	2	60	13
Estimated Contribution due to Re-suspension of road dust				
6.	PM_{10}	5.5 %	73.4%	19.8%
7.	$PM_{2.5}$	1.3%	27.6%	6.0%

The findings of this chapter are summarized below:

- Traffic data of 24 hours was provided by CSIR-CRRI for 8 intersections in the study area. It shows two peak traffic times – mornings (7:00 am - 11:00 am) and evenings (5:00 pm - 8:00 pm). Vehicles were categorized as two/three-wheelers, four Wheelers, buses, and light commercial vehicles.

- The total estimated PM emission load for the 82.5 km road from re-suspension of road dust was estimated to be 33.83 tons/day for PM_{10} and 8.16 tons/day for $PM_{2.5}$ at the time of the study.
- The predicted particulate matter concentrations would be highest near the selected road and decrease rapidly with increasing distance away from the source. The maximum predicted PM_{10} and $PM_{2.5}$ concentration due to re-suspension of road dust were 1700 $\mu g/m^3$ and 450 $\mu g/m^3$, respectively (10 m away from road) in Mundka area at the time of the study.
- The particulate matter due to vehicular movement contributes about 73.4 % of PM_{10} and 27.6 % of $PM_{2.5}$ (re-suspended) at Mundka CAAQMS at the time of the study.

Chapter 4

Aerosol Optical Depth (AOD) Data Analysis

This chapter has described the use of satellite data and its scientific attributes like Aerosol Optical Depth (AOD) for understanding the existing air quality in an area or region. AOD has its relevance in air quality studies because it closely associates with $PM_{2.5}$ or PM_{10} concentrations. AOD for the region has been estimated and studied with a strategic mapping to identify probable sources of air pollution. In this study, dust loading using AOD was studied in EPE-WPE region of Delhi and along the selected roadside. This is important to note that from 100 km buffer to 1 km buffer or road stretch AOD was used to understand the air quality without any monitoring cost. The integration of satellite data in air quality is important now as lot of data is available and at whatever location desired it is mostly available provided there no atmospheric anomalies.

4.1 General Aspects and Data used

4.1.1 About Aerosol Optical Depth (AOD)

Aerosol Optical Depth (AOD) is the measure of aerosols (e.g., urban haze, smoke particles, desert dust, sea salt) distributed within a column of air from the instrument (Earth's surface) to the top of the atmosphere. It is a measure of the attenuation of sunlight due to scattering and absorption by aerosol particles in the Earth's atmosphere. It quantifies the degree to which aerosols in the atmosphere prevent the transmission of solar radiation through the atmosphere to the Earth's surface. It is an important parameter for assessing air quality, particularly in relation to the presence of atmospheric aerosols, which can have significant implications for human health, visibility, and environmental quality. It is closely related to the concentration of airborne particulate matter, especially fine particulate matter ($PM_{2.5}$) and coarse particulate matter (PM_{10}). High AOD values typically indicate elevated levels of atmospheric aerosols, which can include pollutants such as dust, smoke, soot, and other particulate matter. Elevated levels of aerosols, as indicated by high AOD values, can reduce visibility by scattering and absorbing sunlight, leading to haze and decreased visual clarity. During poor air quality episodes, inhalation of aerosols, particularly fine particulate matter ($PM_{2.5}$), can have adverse health effects, including respiratory and cardiovascular problems. AOD observations from satellite sensors, ground-based instruments, and air quality monitoring stations provide valuable information for assessing pollution levels, identifying pollution sources, and developing air quality forecasts and alerts.

4.1.2 AOD Measurement

AOD is measured using remote sensing techniques, such as satellite-based or ground-based instruments. Satellites equipped with radiometers and spectrometers can observe the atmosphere across different wavelengths of light, allowing for the estimation of AOD. It is a dimensionless quantity, represented as a single value or a spatial distribution across a geographical area. It is typically expressed as a decimal number, ranging from 0 to higher values, where higher values indicate greater aerosol loading. AOD values closer to zero indicate a cleaner atmosphere with fewer aerosol particles, while higher AOD values indicate increased aerosol concentrations. AOD values can vary significantly depending on factors such as location, time of year, weather conditions, and sources of aerosol emissions. Elevated AOD levels are often associated with poor air quality and adverse health effects.

4.1.3 Satellites for AOD measurement

Several satellites equipped with sensors are capable of measuring AOD and have been launched over the years. These satellites provide valuable data for monitoring atmospheric aerosols, studying air quality, and understanding their impacts on climate and the environment. The Moderate Resolution Imaging Spectroradiometer (MODIS) instruments onboard NASA's Terra and Aqua satellites provide global observations of AOD at multiple wavelengths. The Ozone Mapping and Profiler Suite (OMPS) Aerosol Index (AI) instrument onboard the Suomi National Polar-orbiting Partnership (Suomi-NPP) satellite measures the presence of aerosols and other pollutants in the atmosphere. The Tropospheric Monitoring Instrument (TROPOMI) onboard the European Space Agency's (ESA) Sentinel-5P satellite measures AOD and other atmospheric trace gases with high spatial resolution. All these satellites have senor installed for measuring AOD at different wavelengths and have different spatial and temporal resolution. In this study MODIS data is used. MODIS data for Aerosol product has resolution of 1 km, 3 km, and 10 km with temporal resolution as daily, 8-day, 16-day, monthly, quarterly, yearly.

4.1.4 Data used and study period

In this study, MODIS Aqua product with 3km resolution for afternoon pass from 1 pm to 2 pm Indian Standard Time (IST) has been used for analysis of AOD in study area. The 3km product was processed for May, 2022 (Pre-Monsoon) and November, 2022 (Post-Monsoon). The data was downloaded from https://ladsweb.modaps.eosdis.nasa.gov/ maintained by NASA, Goddard Space Flight Center. The data was downloaded in form of *.hdf files which were processed using Python and analysis of AOD values in study region was done in ArcGIS. The data was processed over high configuration systems for 3 km resolution *.hdf file and obtained vector data was clipped for 100 km buffer. The 3 km file was processed from 1st May to 31st May, 2022 and from 1st Nov. to 30th Nov., 2022 to capture the seasonal variation in air quality along the roads and other areas between EPE and WPE as shown in **Table 4.1**. In analysis for 100km buffer in November for some days AOD values were not available because of presence of clouds. The clouds can form at the top of mixed layers, and at the bottom of stable boundary layers which means there is less vertical movement.

4.1.5 Dust loading identification using AOD

Dust loading using AOD measurements involves analyzing changes in AOD values associated with the presence of airborne dust particles in the atmosphere. Dust events often exhibit distinct temporal characteristics, such as sudden increase in AOD followed by gradual decrease as the dust disperses or settles. Dust storms studies done for Indo-Gangetic Plain (IGP) and Northern India have correlated AOD values with different activities such as industrial pollution, crop burning, dust loading (stone crushers, brick kilns etc.) and dust storms events. AOD values of 0.65 has been attributed to activities like stone crushers, brick kilns, thermal power plants (Bandyopadhyay et al., 2021). In IGP, during pre-monsoon (April-June) AOD value of 0.8 to 0.9 are observed during dust storms (Prasad and Singh, 2007). For severe dust storms in Delhi AOD values ranged from 0.96 to 2.5 (Srivastava et al., 2014, Srivastava et al., 2011). In this study, the delineation of major roads and highways and analysis of AOD in vicinity of roads for identification of dust loadings in region has been conducted.

4.2 AOD Mapping Over Study Area Between EPE & WPE

AOD values were analyzed for Eastern and Western Peripheral Expressway (EPE-WPE) for May, 2022 and November, 2022. The analysis was done to compare pre-monsoon and winter season AOD levels for identifying the dust loading. The daily AOD values in EPE-WPE for May and November are shown in **Table 4.1.**

Table 4.1: Daily mean AOD values for May and November 2022

Sr. No.	Day	Aerosol Optical Depth (AOD) (Mean)			
		May, 2022		November, 2022	
		EPE-WPE	Total points available	EPE-WPE	Total points available
1.	1	0.86	156	1.38	16
2.	2	0.81	261	DNA	DNA
3.	3	DNA	DNA	DNA	DNA
4.	4	1.45	134	2.06	109
5.	5	DNA	DNA	1.62	9
6.	6	1.80	214	1.49	9
7.	7	1.02	136	0.75	126
8.	8	1.10	175	DNA	DNA
9.	9	1.00	198	1.05	328
10.	10	1.52	23	DNA	DNA
11.	11	1.15	408	0.68	474
12.	12	DNA	DNA	DNA	DNA
13.	13	DNA	DNA	DNA	DNA
14.	14	DNA	DNA	DNA	DNA
15.	15	0.65	268	1.35	9
16.	16	1.60	27	0.45	291
17.	17	1.47	72	0.79	13
18.	18	1.57	168	0.58	430
19.	19	DNA	DNA	DNA	DNA
20.	20	1.27	382	0.75	294
21.	21	DNA	DNA	0.41	121
22.	22	0.9	257	0.49	263
23.	23	DNA	DNA	0.36	254
24.	24	DNA	DNA	0.47	118
25.	25	DNA	DNA	0.54	401
26.	26	1.33	70	0.69	8
27.	27	1.45	368	DNA	DNA
28.	28	1.54	52	0.63	71
29.	29	1.34	258	1.04	137
30.	30	DNA	DNA	0.74	162
31.	31	1.80	184	-	-
Mean		**1.28**	**191**	**0.87**	**173**

*DNA: Data Not Available

The mean AOD value obtained in EPE-WPE region is 1.28. The average data points obtained on daily basis in EPE-WPE are 191 in number. The retrieval algorithm for AOD suffers from some shortcomings over bright areas and errors of cloud detection in heavily polluted areas (Chi et al., 2020). The AOD retrieved for May in EPE-WPE showed that on 11 May, 2022 maximum number of AOD points values were available and could be retrieved as shown in **Fig. 4.1.** It is clear that whole EPE-WPE is dominated by dust-laden aerosols (AOD>0.8).

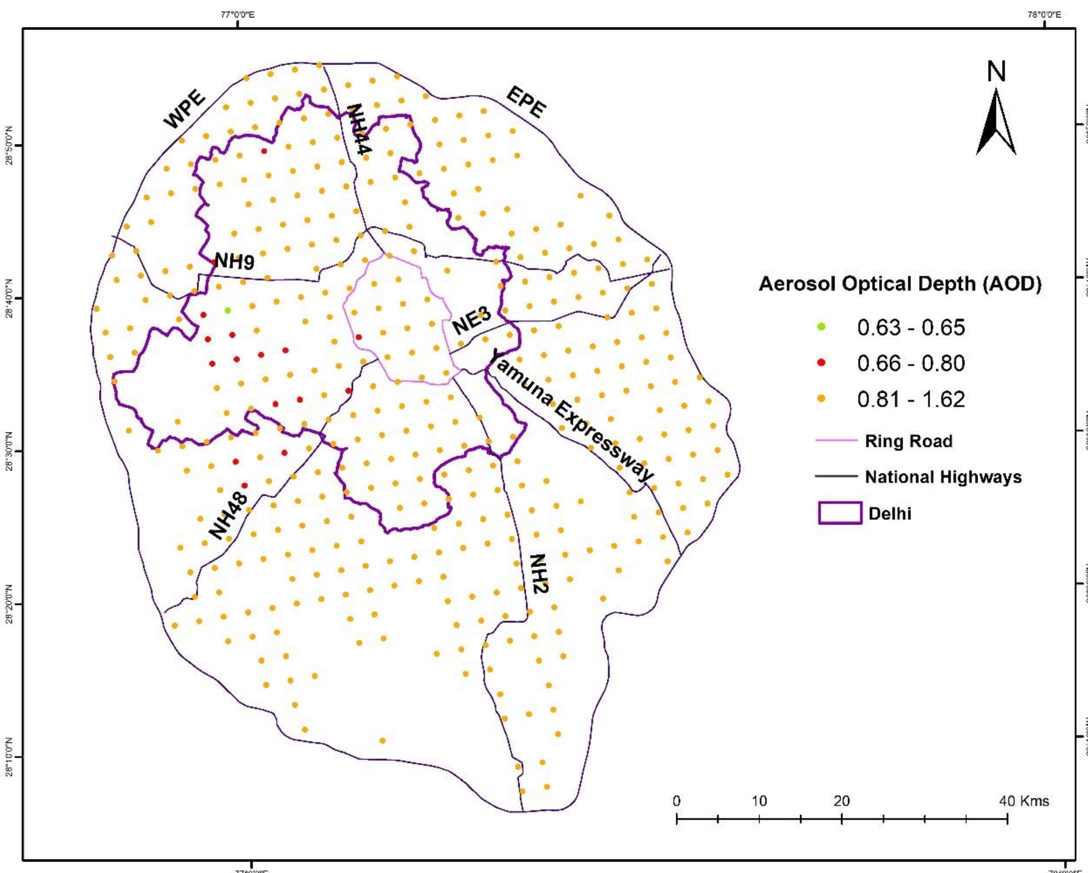


Fig. 4.1: AOD on 11th May 2022 in EPE-WPE

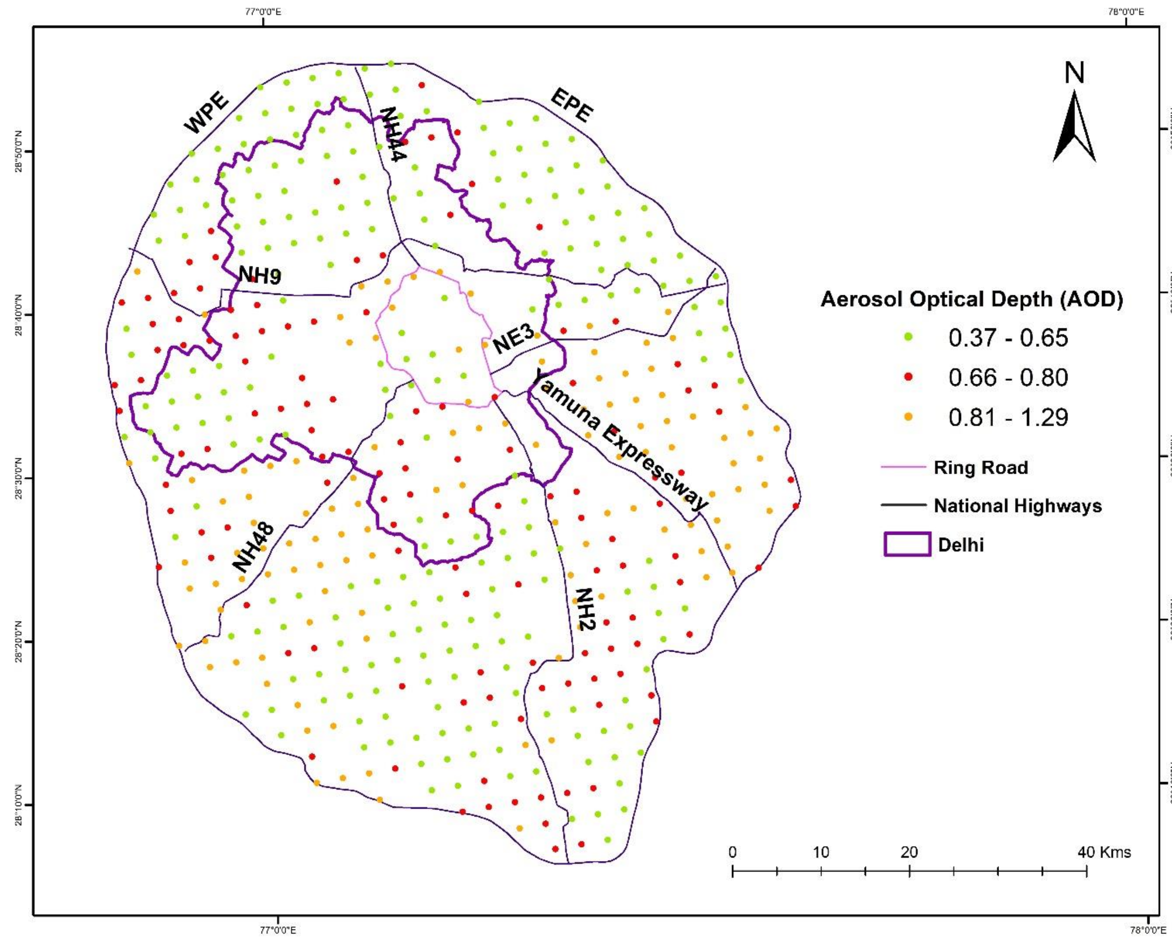


Fig. 4.2: AOD on 11th November 2022 in EPE-WPE

From **Fig. 4.2**, it can be observed that in the month of November, EPE-WPE is affected by anthropogenic activities (AOD ~0.37-0.65). On 11th November, the maximum number of data points were obtained and hence selected for representing the scenario. On comparing the AOD values of May and November in EPE-WPE it has been found that in the month of May, dust is the major source of pollution while in November other anthropogenic/combustion activities dominate in the region. In EPE-WPE, the number of dusty days in May, 2022 were 19. This indicates that EPE-WPW is affected by dust aerosols.

4.3 AOD vs $PM_{2.5}$

$PM_{2.5}$ is a major criteria pollutant and affects the environment, climate and health. Understanding of $PM_{2.5}$ can only be clear if monitoring values are available. Having a monitoring station at every desired place is not feasible and economical. Thus, it is important to derive

$PM_{2.5}$ concentrations using AOD values so that, the concentration of $PM_{2.5}$ is known even when there are no monitoring stations at desired place. There are 2 methods to estimate $PM_{2.5}$ from satellite AOD. Regression or machine learning models and others is through the estimation of scaling factor $'\eta'$ i.e. ratio of $PM_{2.5}$ and AOD.

For deriving the scaling factor, the global database generated from the Global Burden of Disease (GBD) study used a chemical transport model. The scaling factor using the model was derived at 2° × 2.5° resolution and was interpolated to match with AOD resolution. However, having a national database that is tuned against local surface measurements will be a better representative of the local conditions. Furthermore, the database can be updated as per the national requirement and used for policy. The study done for India by Dey et al., 2020 used AOD at 1 km resolution and MERRA-2 data to derive equations for estimating satellite-derived $PM_{2.5}$.

For understanding the $PM_{2.5}$ levels in the EPE-WPE region, the equations (1) and (2) available for India in the different regions are used.

$$\eta = 0.85 \times \frac{PM_{2.5}\ (CAAQMS)}{AOD} + 46.88 \quad (1)$$

$$PM_{2.5}\ (\text{satellite-based}) = \eta \times AOD \quad (2)$$

4.3.1 CAAQMS stations and $PM_{2.5}$ in EPE-WPE region

In boundary of Eastern and Western Peripheral Expressway, there are total 59 CAAQM stations. These stations are taken as reference sites for understanding the measured $PM_{2.5}$ concentration in the region. Satellite derived $PM_{2.5}$ was calculated using MODIS AOD data at 3 km resolution in EPE-WPE region for May,2022. The satellite $PM_{2.5}$ was estimated by assuming buffer of 0.5 km radius around monitoring station. The AOD values in this buffer were extracted and equation (1) and (2) were used to calculate satellite derived $PM_{2.5}$. The extracted stations with AOD value in 0.5km buffer are shown in **Table 4.2**.

Table 4.2: Comparison of $PM_{2.5}$ and satellite derived $PM_{2.5}$ for May, 2022 in EPE-WPE region

Sr. No.	Station Name	$PM_{2.5}$	Satellite derived $PM_{2.5}$	Distance between station and satellite-derived $PM_{2.5}$ location (meters)	Date (May, 2022)
1	Alipur	57	39.16	279.6	11
2	Anand Vihar	128	64.66	444	20
3	Ashok Vihar	40.25	47.65	212.6	27
4	Aya Nagar	53.66	65.10	272.5	27
5	Aya Nagar	56.22	43.56	136.6	9
6	Bawana	68.5	46.89	344.8	2
7	Burari Crossing	37.15	38.69	145.9	27
8	Chandni Chowk	89.5	66.07	370.4	11
9	DTU	164	39.71	270.8	11
10	Dwarka-Sector 8	58	67.44	398.8	28
11	Indirapuram, Ghaziabad UPPCB	29.75	50.05	375	11
12	Indirapuram, Ghaziabad UPPCB	33.5	32.45	135.1	2
13	Jawaharlal Nehru Stadium	58	51.49	425.2	22
14	Knowledge Park - III, Greater Noida UPPCB	66.25	76.35	444.8	17
15	Lodhi Road	127	83.23	392.5	18
16	Major Dhyan Chand National Stadium	128.5	79.86	405.9	6
17	Narela	48.75	82.75	404.4	18
18	New Industrial Town, Faridabad - HSPCB	2.6	47.73	366.7	11
19	NISE Gwal Pahari, Gurugram IMD	36.29	64.65	348.5	29
20	Punjabi Bagh	82.25	44.08	349.3	11
21	Sector-116, Noida UPPCB	63.25	90.62	254.3	28
22	Shadipur	86.95	49.47	246.2	20
23	Shyam Nagar, Palwal HSPCB	12	43.00	247.5	11
24	Sirifort	73.25	59.98	440.5	8
25	Sirifort	73.73	57.25	307.8	10
26	Sirifort	73.25	59.70	218.4	8
27	Sonia Vihar	67.75	54.16	304.8	9
28	Sri Aurobindo Marg	48	57.17	181.4	27
29	Sri Aurobindo Marg	87.75	86.10	292.6	16

30	Teri Gram, Gurugram - HSPCB	117.3	50.50	73.1	20
31	Vikas Sadan, Gurugram - HSPCB	87.04	52.89	98.6	26
32	Vikas Sadan, Gurugram - HSPCB	58.75	60.26	440.2	18

The scaling factor was calculated for each day at which the AOD value was available using equation (1) and then the satellite derived $PM_{2.5}$ was calculated using equation (2). The satellite derived $PM_{2.5}$ varied between ±20% from monitored $PM_{2.5}$ for majority of monitoring stations but stations like New Industrial Town, Faridabad – HSPCB, Shyam Nagar Palwal – HSPCB reported higher values of satellite derived $PM_{2.5}$ while station like Teri Gram, Gurugram – HSPCB and DTU reported higher values of $PM_{2.5}$ at monitoring stations. This is also important to note the distance between the satellite derived $PM_{2.5}$ location and $PM_{2.5}$ at monitoring stations. This analysis is helpful in understanding that with satellite data it is possible to estimate $PM_{2.5}$ at other locations where monitoring station is not present. **Figure 4.5** shows $PM_{2.5}$ concentration variation at different stations and satellite derived $PM_{2.5}$ concentrations for May, 2022.

4.4 AOD along the selected road stretch

AOD levels greater than 0.8 indicate dust aerosols in environment. When AOD values are analyzed along roadside in 1km buffer, it is to capture the status of dust alongside road using AOD. The AOD values for road stretch for May, 2022 and November, 2022 were extracted and analyzed as shown in **Table 4.3**. The mean AOD values along roadside with 1 km buffer in May, 2022 was 1.17 and in November, 2022 is 0.69. For May, total 16 days AOD was analyzed for 1km buffer along roadside and out of those 16 days for 13 days AOD was more than 0.8. For November, 13 days AOD was analyzed and for 4 days AOD was more than 0.8. This can be concluded that in winters it is only the poor road conditions that are significant for dust load in their vicinity and is not carried forward. The higher AOD values in May are also because there is background heavy dust load in environment.

As MODIS Aqua has 3 km resolution it is possible to get no values for road and 1km buffer along roadside during satellite pass thus not detected (ND).

Table 4.3: Daily mean AOD values along roadside in May, 2022 and November, 2022

Day	Aerosol Optical Depth (AOD) (Mean), May 2022		Aerosol Optical Depth (AOD) (Mean), November 2022	
	Monitored stretch	Total points available	Monitored stretch	Total points available
1	0.81	6	DNA	-
2	0.78	16	DNA	-
3	DNA	-	DNA	-
4	1.52	4	DNA	-
5	DNA	-	DNA	-
6	DNA	-	DNA	-
7	DNA	-	0.91	5
8	1.1	9	DNA	-
9	1.06	9	1.13	10
10	DNA	-	DNA	-
11	1.08	20	0.67	17
12	DNA	-	DNA	-
13	0.71	16	DNA	-
14	DNA	-	DNA	-
15	0.68	8	DNA	-
16	1.45	4	DNA	-
17	1.42	3	DNA	
18	1.49	9	0.64	13
19	DNA	-	DNA	-
20	1.22	14	0.89	1
21	DNA	-	0.41	7
22	1	8	0.45	9
23	DNA	-	0.42	9
24	DNA	-	0.49	4
25	DNA	-	0.55	13
26	DNA	-	DNA	-
27	1.19	14	DNA	-
28	DNA		0.59	3
29	1.36	8	1.05	3
30	DNA	-	0.74	4
31	1.86	11	-	-
Mean	**1.17**	**10**	**0.69**	**8**

*DNA: Data Not Available

The analysis of AOD values for roadside with road conditions for May, 2022 and November, 2022 is shown in **Fig. 4.3** and **Fig. 4.4** respectively. It is clear from **Fig. 4.3** that road with moderate and bad condition is dominated by AOD values greater than 0.8 which is a dust load indication and this is visible in 1 km buffer. It can be seen that higher AOD values are at bad or moderate road condition. If good condition road stretch is sandwiched between moderate and bad, the overall dust loading is also seen in good patch as well.

From **Fig. 4.4**, it can be said that it is only poor road condition that is contributing to higher AOD (>0.8) values and this is not dispersed farther. The dust in November does not disperses as compared to May and the effect of road dust is not much on either sides i.e. in 1 km buffer of road. For November, it can be seen that dust arising due to poor road condition does not necessarily effect the dust load in good condition of road.

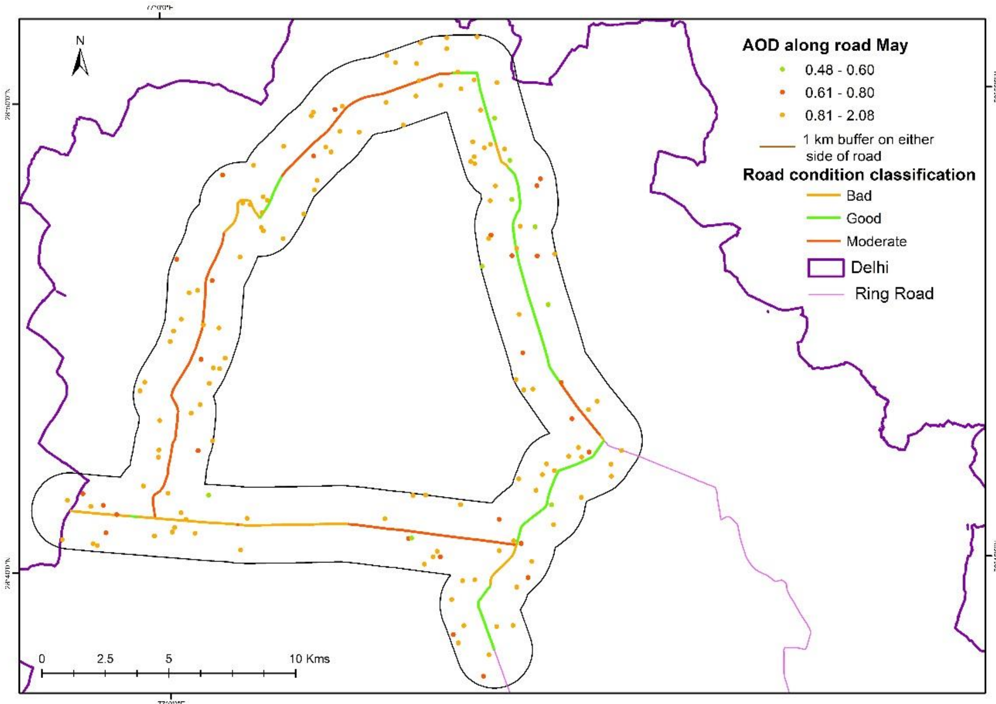


Fig. 4.3: AOD values in May for roadside and 1km buffer

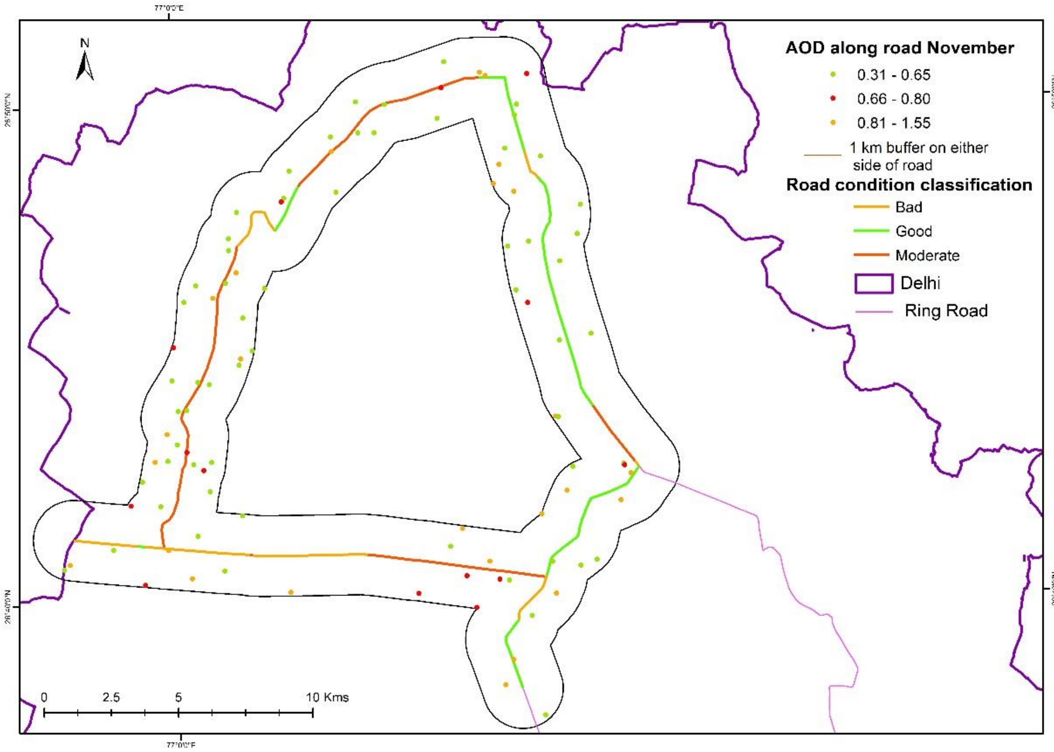


Fig. 4.4: AOD values in November for roadside and 1km buffer

It can be concluded that AOD values are helpful in monitoring the dust load in any region. For May, 2022 the dust loading was more when compared to November, 2022. The AOD values indicate the source of pollution as dust which is from local sources like road dust and its re-suspension and also dust storms. Analysis of AOD values can help in monitoring of dust due to roads and its condition. The ability of satellite data to detect dust plumes is limited by several factors, such as the large spatial distribution of aerosols and heterogeneous aerosol field over areas affected by dust plumes, the reflectance properties of the dust and the underlying land/ocean surface, the cloud presence, the density of the dust plume, and the algorithms used in the satellite data retrievals. Therefore, dust monitoring is better achieved by the combined use of satellite remote sensing and ground-based measurements of aerosol properties in conjunction with surface meteorological data, such as wind speed and visibility.

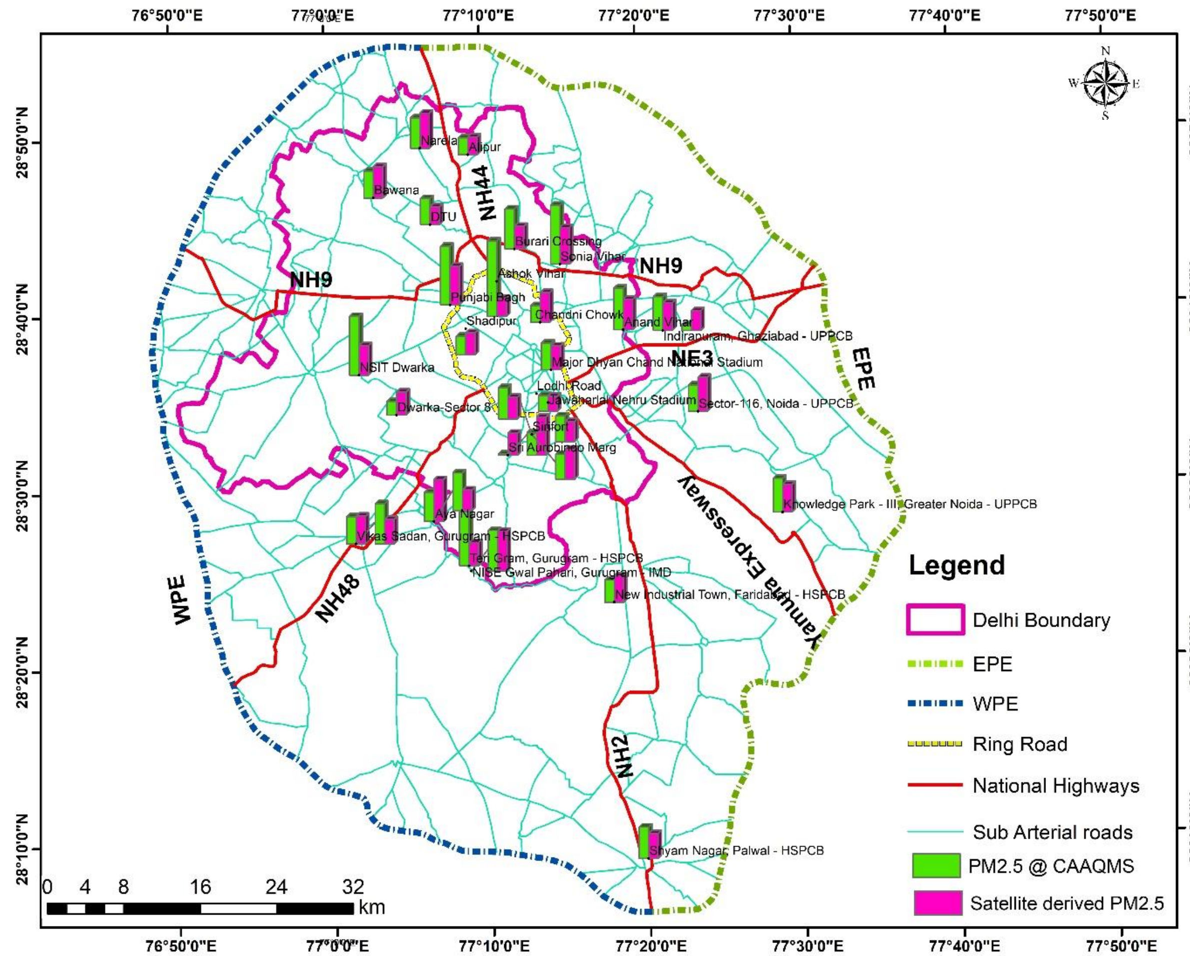


Fig. 4.5: Comparison of monitored $PM_{2.5}$ and satellite derived $PM_{2.5}$ at CAAQMS in EPE-WPE

Summary

Based on this study the following conclusions are drawn:

- The EPE-WPE in month of May is dominated by dusty environment and high dust load can be seen in vicinity of roads with AOD >0.8.
- The poor and bad road condition in month of May, disperses the dust farther and even good road condition stretch is under dust loading.
- The EPE-WPE in month of November has lesser dust loading effect as compared to May but other anthropogenic activities contribute to air pollution (AOD<0.6).

- The satellite derived $PM_{2.5}$ concentrations can be used at any location and can be used as a basic idea for PM levels in that region or area.

Based on above conclusions the following recommendation can be made:

- AOD values can be used for monitoring of air quality in an area or region.
- The road condition needs to be improved mainly during summer months.
- A detailed study can be done to map AOD values for sources of pollution to develop a tentative AOD scale.
- The control sites should be identified only for dust monitoring and portable sunphotometer to be used for AOD values so that air quality deterioration specific to dust can be understood clearly.
- Higher AOD resolution (1km) data can always be used to understand local air quality variations.

Chapter 5

Selection of Control Options for Reduction of Dust Re-Suspension along the Selected Road

The assessment of road dust contribution in the previous chapter indicates its high contribution in PM_{10} and $PM_{2.5}$ concentrations near the road. It is understood that road dust re-suspension is the dominant source of air pollution in the area and needs to be tackled carefully and effectively to improve the air quality. In view of this, the present chapter discusses the possible and suitable control options to reduce the pollution load from road dust re-suspension.

This chapter covers the following:

i. Listing of control options for reduction of re-suspension of dust from road
ii. Reduction in generation of dust at road via pavement of the unpaved shoulders and median, development of green spaces etc.
iii. Lifting of dust from road via various mechanical machines and manual methods
iv. Control of dust re-suspension through dust suppressing agent.
v. Possibility of utilization of waste water from DMRC for watering the road median and edge plantation.

Road dust re-suspension is the process of dust particles that have been deposited on the road surface to become airborne. This process is influenced by several factors, such as including traffic movement, wind force, and construction activities. There are several ways to control road dust re-suspension, including watering, graveling, chemical treatment, vegetation, green belt, redesigning road features and water mist systems. However, effective dust control can be designed after considering factors like traffic load on the road, the climatic conditions, and the resources available. In some cases, a combination of methods can be more effective instead of a single approach.

Considering the problem, a detailed review of the literature was carried out to find effective way of control options to stop the re-suspension of dust from the road. Considering the observations on road condition during field survey, the control options are suggested into three major categories.

i) Minimize dust generation at road
ii) Lifting of dust from road
iii) Suppression of dust at road for longer period

Further, all these categories are further sub-classified as shown in **Fig. 5.1**.

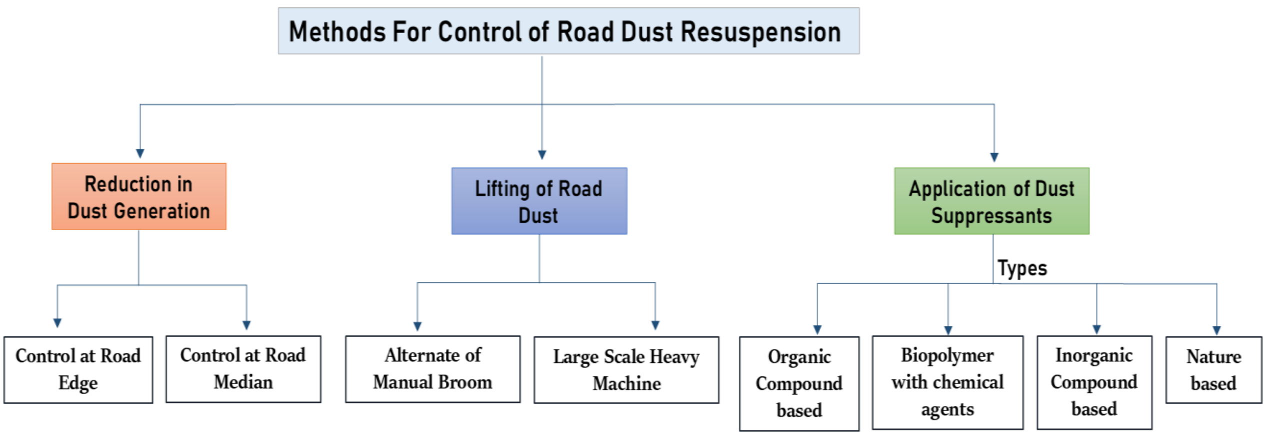


Fig. 5.1: Control options for road dust re-suspension reduction

5.1 Minimize generation of dust at road

To effectively reduce air pollution caused by road dust re-suspension, it is essential to address the sources that contribute to the release of dust particles. Dust re-suspension occurs due to various factors, including unpaved road shoulders, broken kerb stones, excess soil in medians, manual brooming, pot holes, construction activities without dust mitigation, and similar disturbances. These conditions contribute to the re-suspension of road dust after vehicular movement.

Dust generation can be minimized by improving the road maintenance practices. This involves things like fixing potholes, sweeping the road surface, developing green spaces on median or edges, clean drainage system and removing loose gravel from road sides. Different control options can be opted for roads according to their geometry. Improvements can be made on median and edges of roads so that re suspension of dust can be minimized from turbulence generated by vehicular tyre movement. They are further sub classified under two sections:

i) Control options for edges

ii) Control options for median

Fig. 5.2 shows example of methods which are adopted in different countries to stop the generation of dust at road. Both methods lead to reduction of dust level at road from median, edges/shoulders, and center of the pavement.

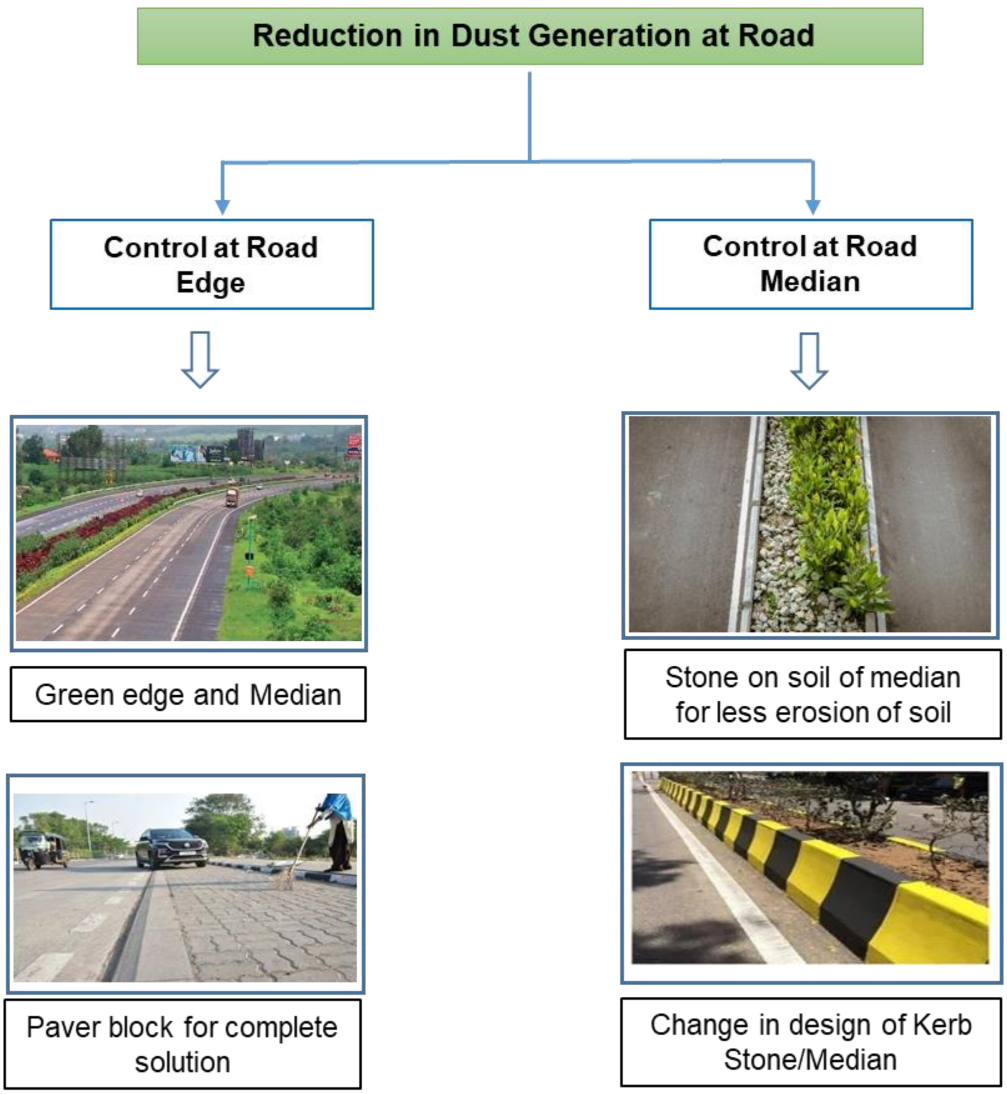


Fig. 5.2: Control options for minimizing dust generation at road

5.1.1 Control of dust generation from road Edge/Shoulder

Effective dust management starts with a well-built road. Dust control measures have been shown to be most effective on roads that have been properly graded and have compacted surface that is free of cracks and potholes. Due to turbulence generated by high-speed vehicle dust gets re-suspended and is displaced either at median or at the edge sides. Development of good road shoulder will lead to less generation of road dust. The ideal road conditions as per IRC should be adopted in designing and construction of road which ultimately control the dust generation from road edge. In light of the above conditions, two options can be suggested for controlling road dust at the edge are:

a) Green Belt Development

b) Paver Block System

a) Green belt/space development along the road: Green spaces along the road can be an effective way to strengthen / manage the loose soil at road edge as well as at median, if sufficient space available in later case. Additionally, the plantation mitigates adverse effects of air pollution by creating a barrier between road and nearby residential area (Lee et al., 2023). These barriers act as effective measures to capture, deposit, and bind dust particles, thereby reducing recirculation into the air. Incorporating green spaces into urban planning strategies can contribute to better air quality and healthier environments. Features of green space design is mainly dependent upon plant physiological characters like (leaf size, shape, and surface features). Growth of grass should be encouraged wherever possible as grass plays a vital role in binding the soil to prevent re-suspension of dust. Common Species that can be planted on road edge and median is given **Table 5.1**. Further, **Plate 5.1** shows examples of plantation along the road edge and median which can be adopted in Delhi NCR also for binding of loose soil.

Table 5.1: Common Species that can be planted on Highways/Roads in Delhi NCR

Sr. No.	Botanical name	Common name	Growth rate	Soil type	Canopy size (meters)
1.	*Azadirachta indica*	Neem	Moderately fast-growing	Sandy, loamy, and clayey soils	15 to 20
2.	*Terminalia arjuna*	Arjun	Moderately fast-growing	Sandy loam, clay loam, and red soils.	20 to 25

Sr. No.	Botanical name	Common name	Growth rate	Soil type	Canopy size (meters)
3.	*Syzygium cumini*	Jamun	Moderate growth rate	Clayey, loamy, and sandy soils.	15 to 25
4.	*Ficus religoisa*	Peepal	Fast-growing	sandy loam, loam, and clayey soils	15 to 25
5.	*Ficus bengalensis*	Bargad	Rapid growth rate	Clayey, loamy, and sandy loam soils.	20 to 30
6.	*Ficus virens*	Pilkhan	Moderate growth rate	Sandy, loamy, and clayey soils.	10 to 15
7.	*Cassia fistula*	Amaltas	Fast-growing	loamy, sandy, and clayey	10 to 15
8.	*Mangifera indica*	Aam	Moderately fast-growing	Well-drained, loamy soils.	15 to 30
9.	*Delonix regia*	Gulmohar	Fast-growing	Sandy, loamy, and clayey soils.	6 to 12
10.	*Dalberjia sisso*	Seesham	Fast-growing	sandy loam clayey	15 to 25




Road condition before green space development	Road condition after Green space development

Plate 5.1: Example of possible road conditions after green space development

b) **Paver Block System:** Road shoulders which are not paved lead to the generation of dust particles or give space for collection of road dust at various locations along the road edges or shoulder. As shown in **Plate 5.2** large amount of dust is deposited on the edges of road and used to get re-suspended due to turbulence. After paving roads edges with paver block, the amount of dust deposition reduces and will be accessible for cleaning. However, it will be desirable to sprinkle water before sweeping/cleaning to prevent re-suspension of dust.

	
High dust deposition at edge without paver block	Dust deposition reduction at edge after paver block

Plate 5.2: Reduction of road dust deposition by paver block at road edges

5.1.2 Control of dust at Road median

Generally, plants are grown on the road median in Indian cities irrespective of available space. It is also observed that most of the road median are overloaded with soil to provide support to the plant. However, during the watering, this soil gets loose and falls down on the road which later gets re-suspended after drying due to turbulence generated by vehicle movement. Therefore, it is very important to create freeboard to lessen the dust/loose soil over median, this facilitates proper watering and reduces the re-suspension. There are two possible scenarios to restrict the erosion of the dust from median surface.

a) **Stone/Boulder dressing over the surface of median soil:** Boulder dressing is a method of controlling dust at median of road by placing boulders on the surface of the soil. The boulders help to bind the soil particles together and prevent them from becoming airborne. Boulder dressing is a relatively inexpensive and effective method of dust control, and it is also environment friendly. As shown in **Plate 5.3,** boulder dressing will reduce the erosion of surface soil at median and will provide an aesthetically better landscape.

Dusty median without any cover	Median with vegetation and boulder cover

Plate 5.3: Median condition after boulder dressing

b) Redesigning of median: It includes increasing median width to accommodate more green space cover, which provides less soil erosion during dry conditions. An alternative option is to establish a sufficient (~ 6 inch) freeboard above the topsoil of the median, which would act as a barrier to prevent soil from spilling onto the road due to watering and traffic-induced turbulence. Bushes and trees can be planted along highways median and edges to reduce dust pollution. This can be minimized by plantation, which adheres to important characteristics such as height, thickness, and density, with full coverage from the ground to the top of the canopy (Deshmukh et al., 2018). Plantation on the median is shown in **Plate 5.4.**

	
2 – Tier plantation on median	Clean vegetated median

Plate 5.4: Redesigning of the median with plantation

c) **Watering sprinkling system for roadside median:** In the Delhi NCR region, the current method of irrigating plantation on road medians involves the use of water tankers equipped with pipes or sprinkler systems. This method of watering the plantation leads to soil erosion and re-suspension of dust due to the sudden impact of water force. Sometimes, it has been observed that excess watering leads to overspilling of water along with soil on the road which later gets re-suspended by vehicular movement over them. **Plate 5.5** shows the different practices of watering road median plantation.

	
Correct way of watering	Incorrect way of watering

Plate 5.5: Different watering methods on road median plantation

5.2 Lifting of dust from Road

The process of lifting road dust from the ground prevents road dust particles from becoming airborne. Both manual and mechanical approaches are suitable. A brief on available technologies is given below in **Fig. 5.3**:

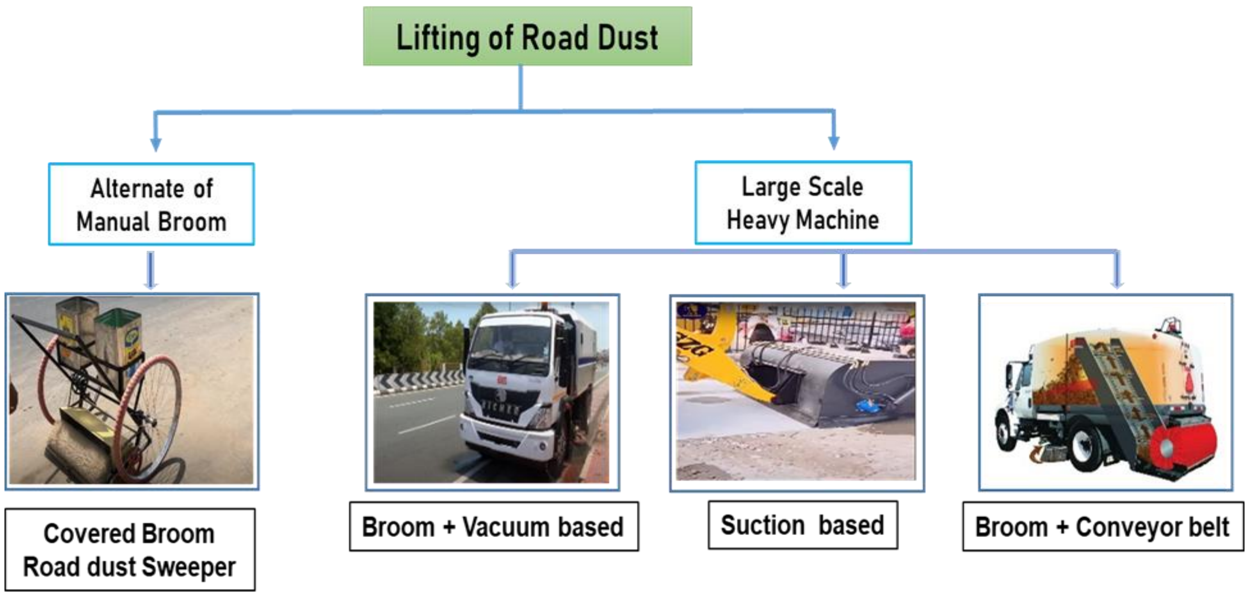


Fig. 5.3: Various methods for lifting of road dust

5.2.1 Alternate to manual brooming/ Cart Brooming

Cart brooming is a method of sweeping for areas such as sidewalks, parking lots, and picking up dust from edges and medians of collector roads. It involves using a long-handled broom that is attached to a cart. The cart allows the operator to move the broom easily and quickly, without bending over or stopping. This compact broom can cover a larger area than traditional manual sweeping and can easily serve smaller roads where larger heavy sweeping machines cannot access.

Cart brooms are typically made of polypropylene or nylon bristles, which are durable and can withstand heavy use. They are also designed to be lightweight and easy to manoeuvre. As shown in **Plate 5.6**, cart brooming is a more efficient way to sweep large areas than traditional brooming. It is also less physically demanding for the operator. As a result, cart brooming is becoming increasingly popular at commercial and industrial scale.

	
Manual sweeping	**Cart brooming**

Plate 5.6: Cart broom as an alternative to manual brooming

5.2.2 Application of Mechanical Road Sweeper for Large scale dust collection

Heavy-load dust lifting machines are used to remove dust from major roads and highways. They are typically used in areas with high traffic volumes, where road dust can be a major problem. There are a variety of road dust collection heavy machines available, each with advantages and disadvantages. Some of the most common types of road dust collection heavy machines include:

a) Vacuum Sweeper: Vacuum trucks are more effective at collecting fine dust particles than sweepers. They use a rotating broom to sweep the dust from the road surface. They use a powerful vacuum to suck up the dust after brooming from the road surface. Vacuum trucks are more expensive than sweepers, but they are more effective in collecting/sweeping dust.

b) Suction-based Sweeper: It is a Suction-based Road dust-collecting machine that uses a powerful suction fan to collect dust from the road surface. They are typically used on high-traffic roads and highways, where road dust can be a major problem. They typically have a large dust collection hopper that can hold a significant amount of dust. They can be equipped with a water sprayer that can be used to wet the road surface and prevent dust from becoming airborne.

c) Conveyor belt-driven mechanical sweeper: Road sweepers that use conveyor belts to collect dust from the road surface are known as conveyor belt-based road dust collection equipment. To remove the dust off the road's surface, they utilize a revolving brush. They often have a large dust collection hopper that has a huge capacity to collect dust. The photographs of different types of road dust-sweeping machines are shown in **Plate 5.7.**

Road condition with deposited dust

Vacuum Sweeper

Suction based sweeper

Conveyor belt-driven mechanical sweeper

Plate 5.7: Different types of road dust sweeping machines

5.3 Suppression of Road Dust through Dust Suppressing Agent

A dust suppressant is a material that is applied to road surfaces/over loose soil to prevent dust from becoming airborne. Dust suppressants can be liquids, semisolids and solids. They work as binders to the dust particles and make them heavier and sticky to the surface to restrict them instead of staying suspended in the air.

In India, sprinkling of water on the road (road washing) is one of the measures for road dust control. The manual and mechanical cleaning of deposited road dust is also being practiced in many cities. Presently, water is one of the most primitive agents which is being used as a dust control measure in India. But it is less efficient as compared to other dust suppressants. Basically, the efficiency of any dust suppressant application depends on its adhesive and hygroscopic properties. Dust suppressant enhances the binding force between the road surface and dust and also makes the dust wet for a longer period which inhibits re-suspension.

Numerous types of dust suppressants are being tested/experimented/demonstrated in the world to suppress road dust. The classification of dust suppressants is shown in **Fig. 5.4.** The dust suppressant can be categorized into 4 major groups namely, i) Organic compound-based, ii) Biopolymer with chemical agents, iii) Inorganic compound-based and iv) Nature-based. Further, their sub-classification has been done based on chemical properties considering their advantages and disadvantages.

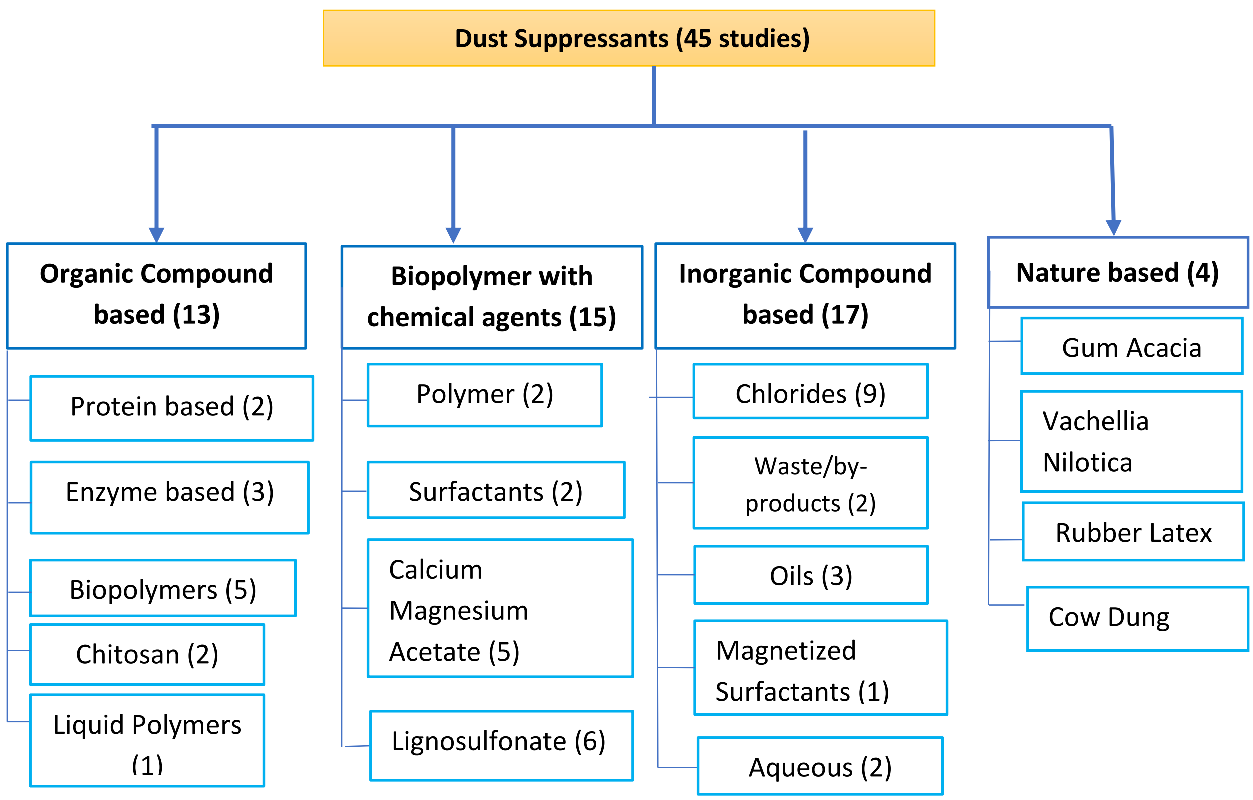


Fig. 5.4: Classification of dust suppressant and number of studies reviewed for respective dust suppressant

Numerous chemical dust suppressants of different variety are described in literature to suppress the fugitive dust emissions, but they are more expensive than that of water, though they are more effective in suppressing dust and are applied much less often compared to water. While the application of water and chemical dust suppressants are proven and effective options for mitigating dust, they have to be used judiciously. Their usage can trigger hazardous environmental consequences which should be considered before deciding on the extent of its application and doses.

5.3.1 Summary and Recommendations for Dust Suppressing Agent (DSA)

From the literature review of previous studies, there are 50 potential dust suppressants but only 15 dust suppressants had Material Safety Data Sheets (MSDS) readily available. Based on the review of MSDS document, seven chemicals were identified as potentially suitable for dust suppression, i.e. Magnesium Chloride ($MgCl_2$), Calcium Chloride ($CaCl_2$), Sodium Alginate, Guar gum, Cow Dung (Natural), MixChem (Polysaccharides and mixture of other chemicals), and Calcium Magnesium Acetate (CMA).

The selection of application of dust suppressants was based on toxicity to health and environment, fire susceptibility, ease of availability and exposure controls to minimize any side effect on human health. Based on these factors, only $MgCl_2$, and $CaCl_2$, MixChem, Sodium Alginate and Cow dung were easily available for testing in lab. CMA and Gaur gum were not available in India on large scale. The details about the dust suppressant experiments are given in **Annexure A.**

The summary and recommendations on Dust Suppressing Agent is given below:

i. The dust suppressant experiments involved preparing solutions, spreading road dust on a clean surface, applying the solution, applying a turbulence force, and collecting and weighting the leftover dust. The dust was then exposed to a wind force similar to the traffic generated at the road median and edge. The efficiency of the dust suppressant was calculated by subtracting the weight of leftover dust from the initial weight and dividing by the initial weight.

ii. In the first experiment, which was conducted indoors with controlled conditions to compare the efficiency to hold the road dust particle after application of dust suppressant prepared by addition of sodium alginate, calcium chloride, magnesium chloride, and water. Results shown that sodium alginate retained the most dust particles (87.2%), demonstrating its superior binding capacity. Magnesium chloride offered moderate effectiveness (60%), while calcium chloride (39.2%) and water (39.2%) were the least effective. In another experiment which was conducted in outdoors, to test the efficacy of dust-suppressing agent like sodium alginate, cow dung, and MixChem against the water.

Similar to the indoor experiment, sodium alginate retained the highest percentage of road dust (78.4%), followed by cow dung (72.4%), MixChem (50.8%) and water (38.4%).

iii. The application of dust suppressing agents was also tested with traffic movement after dust suppressant application on the road at the office entrance gate of NEERI. In this experiment, dust suppressants were sodium alginate, MixChem, and water. After the application of dust suppressants, 26 vehicles were moved over the experimental setup and then retained mass was collected. The findings show that sodium alginate maintained the highest dust suppression efficiency (80.8%) along with MixChem offered moderate effectiveness (66.9%), while water remained the least effective suppressant (55.1%).

iv. Sodium alginate and Cow Dung have shown promising dust suppressants that can be effective in controlling the re-suspension of road dust due to traffic movement. Details of present experimental details and past studies carried out by NEERI on $MgCl_2$ as dust suppressant with EPRI-NEERI-CPCB and past study on Sodium Alginate with CRRI and Nitto Denko Pvt. Ltd. are given in **Annexure A**

v. A Standard Operating Procedure (SOP) for the application of dust suppressants on roads to reduce dust re-suspension has been prepared. It emphasizes the importance of assessing road conditions and identifying dust sources to choose the most suitable control measures. Brief details about the procedure include selecting a suitable road and preparing the homogeneous dust suppressant for its smoother application via manual or mechanical methods. The best time for application is between March and before the monsoon season for warm weather locations. The frequency can be increased up to four days in winter, windy, and dry conditions. Monitoring application rates is crucial to ensure adequate coverage without product pooling or runoff and the development of a governance model for the implementation and sustainability of dust suppressants.

5.4 Dust control through plantation at edge and median through drip irrigation system using treated wastewater from metro station

Effective watering on plants of road medians is a huge challenge for any urban local bodies. At present, watering in roadside plantations is being practiced through a tanker-based system without any efficient nozzle-size sprinkling system, in which water is forcefully applied from a particular height which results in wastage through spillage and displacement of median soil on the road which later becomes airborne when dry. This problem can be eliminated by adopting drip irrigation, a method of delivering water directly to the roots of plants through small tubes and emitters. It can provide additional benefits such as the proper supply of water to every plant, water conservation, and reduces re-suspension of road dust. However, this approach brings lots of complexity in piping and road digging and may not be effective on every road. But easily feasible on the road median below the metro rail corridor. In this case, wastewater generated from each of the nearest metro stations can be treated up to a desirable level and distributed to the plant through the pipeline under the metro as shown in **Fig. 5.5.**

Ideology for application: Every elevated metro station on the road should be connected with a drip irrigation system to discharge water into median plants. Wastewater generated by metro stations through sanitary discharges can be treated and used for irrigation of green space developed.

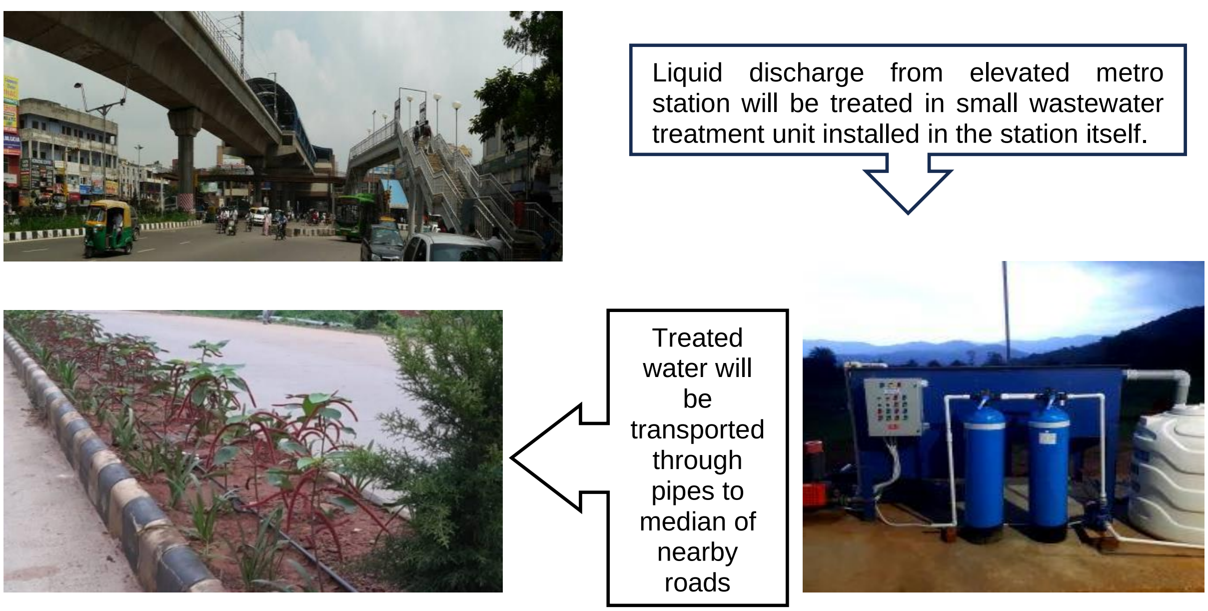
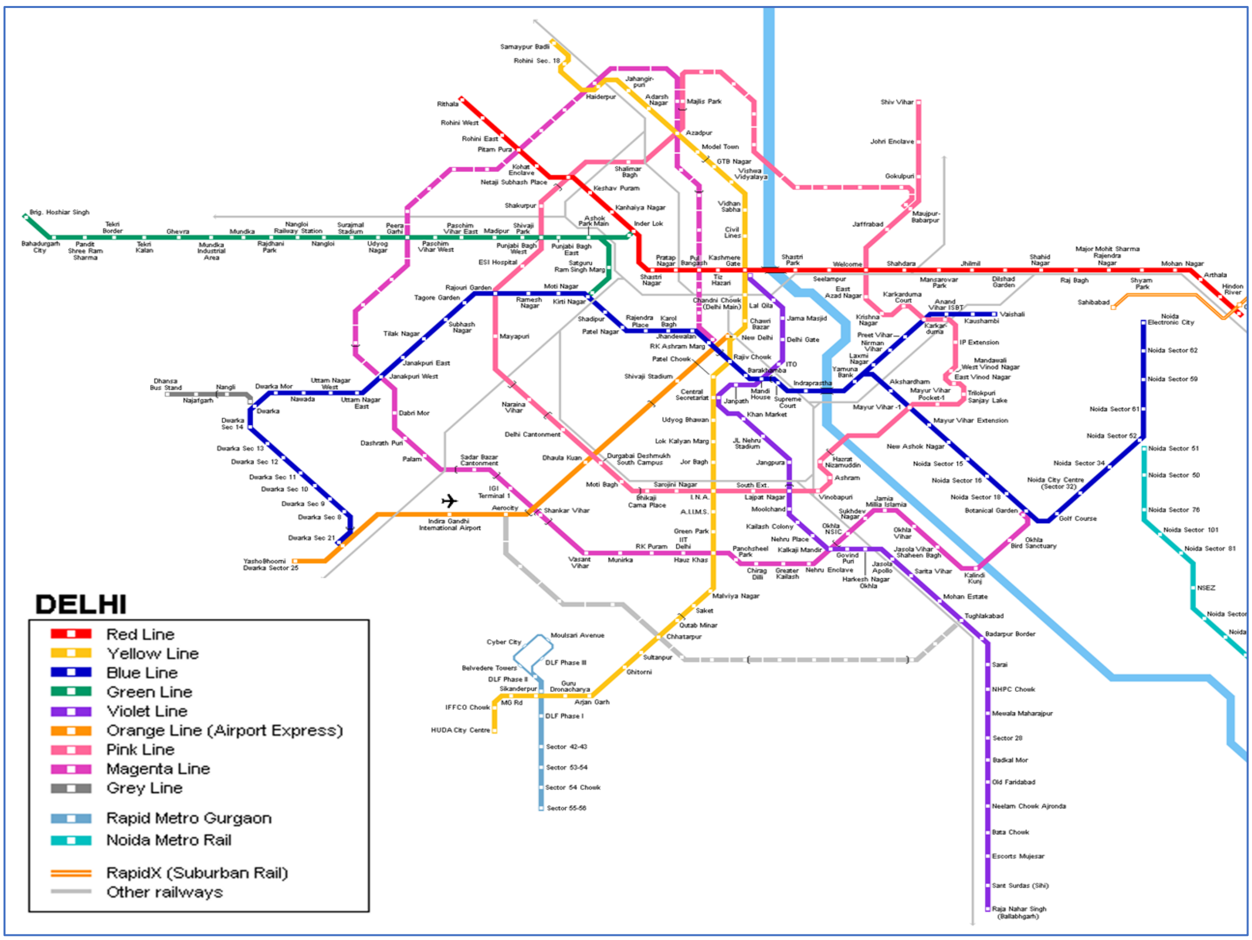


Fig. 5.5: Proposed work process of drip irrigation system for utilization of metro station generated wastewater on road median/edge

Delhi Metro Rail Network: For the application of the proposed ideology, the team has checked the metro line length of DMRC in the city and the number of stations on each line. It can be useful for the planning and development of a drip irrigation network under the elevated metro stations of DMRC. The feasibility of its application will be majorly dependent on the extent to which treated water can be provided by DMRC for watering the plants on the median of roads under their metro pillars. **Fig 5.6** shows a network of DMRC rail lines across Delhi city by majorly covering all the areas of the city. A summary of the total length of DMRC lines is given in **Table 5.2**. The total length of the DMRC rail network is about 334 km and 252 stations including underground, at-grade and elevated lengths of metro rails. The feasibility of the application of ideology on a large scale can be worked on. There is a scope of pilot study which can be done by DMRC.



Source: https://delhimetrorail.com/map

Fig. 5.6: DMRC rail network in Delhi

Table 5.2: DMRC rail network across various routes

Sr. No.	Metro Line	Origin Station Name	Terminating Station Name	Length of Metro Line (km)	No. of stations
1.	**Blue Line - Noida**	Noida Electronic City	Dwarka Sec-21	55.6	50
2.	**Blue Line - Vaishali**	Vaishali	Yamuna Bank	8.2	8
3.	**Green Line**	Inderlok	Brig. Hoshiyar Singh	27.9	24
4.	**Violet Line**	Kashmiri Gate	Raja Nahar Singh	45.0	34
5.	**Pink Line**	Shiv Vihar	Majlis Park	57.4	38
6.	**Magenta Line**	Botanical Garden	Janakpuri West	34.1	25
7.	**Orange Line**	New Delhi	Dwarka Sec-25	24.9	7
8.	**Red Line**	Shaheed Sthal	Rithala	33.5	29
9.	**Yellow Line**	Samaypur Badli	Millenium City Centre Gurugram	47.2	37

From the perspective of the utilization of treated wastewater, the study team has conducted a survey based on questionnaires through verbal discussion with DMRC staff, a small survey was conducted on the facilities of three metro stations regarding wastewater generation on an average daily basis, usage and treatment unit if they have any.

a) The first survey station was Naraina Vihar Metro Station, which is on the Pink Line, is an underground station with a water storage capacity of 70 KL. It has one public urinal facility. The source of water inlet is from a borewell and DJB. The outlet for discharge is a sewer line. However, there was no treatment facility inside the station.

b) Second station was Patel Nagar Metro Station which is an elevated station on the Blue Line. It has a water storage capacity of 60 KL and has two public urinal facilities. The source of water inlet is a borewell and the outlet for discharge is a sewer line. Similar to Naraina Vihar, Patel Nagar station also does not have any treatment facilities inside the station.

c) The third station was Shadipur Metro Station, another elevated station on the Blue Line, has the highest water storage capacity among the three, at 90 KL. It also has two public urinal facilities. The source of water inlet is a borewell and the outlet for discharge is a sewer line. Unfortunately, this station also lacks treatment facilities inside the station. Summary of data is presented through **Table 5.3.**

Table 5.3: Survey of DMRC metro stations on freshwater utilization

Sr. No.	Metro Station	Line	Type	Water Storage Capacity (KL)	Public Urinal Facility	Source of Water Inlet	Outlet for Discharge	Treatment facilities Inside Station
1.	Naraina Vihar	Pink	Underground	70	1	Borewell and DJB	Sewer Line	No
2.	Patel Nagar	Blue	Elevated	60	2	Borewell	Sewer Line	No
3.	Shadipur	Blue	Elevated	90	2	Borewell	Sewer Line	No

From the survey data of different metro stations, it includes information about the station's potential average wastewater generation, source of water inlet, outlet for discharge, and whether there are treatment facilities inside the station. This information makes it necessary to establish wastewater treatment facilities at every elevated metro station that is capable of providing public amenities. If implemented it will lead to utilization of treated water in growth of plants on road median and edge. This is further illustrated in **Fig. 5.7.**

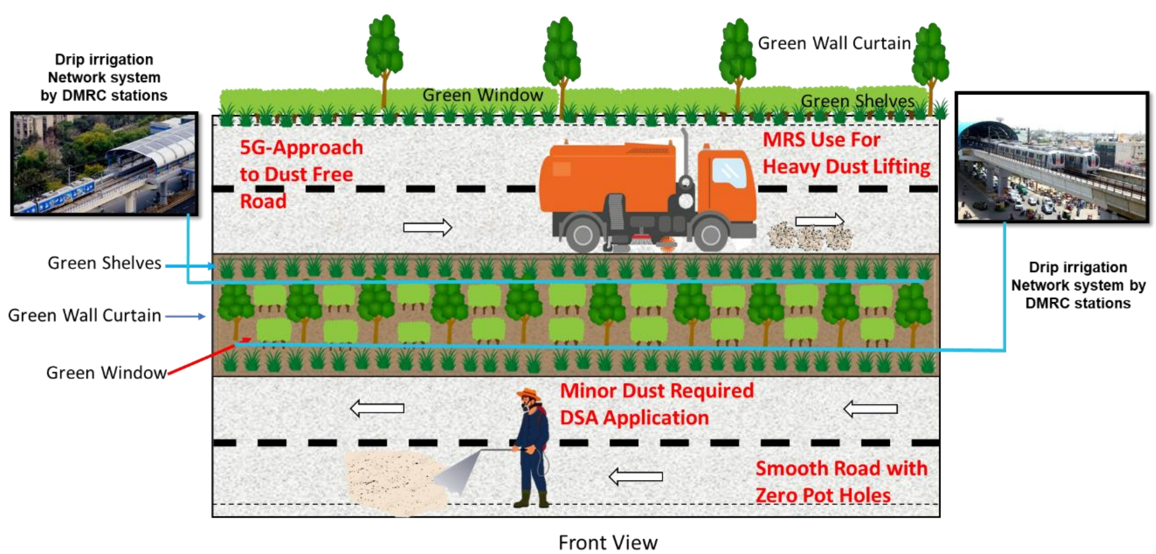


Fig. 5.7: Wastewater utilization on roads under metro line

The utilization of wastewater generated by elevated DMRC stations after treatment can be transferred through drip irrigation pipes to road medians under the metro line. 3 Three-tier plantations can be designed with this water, which includes small shrubs called Green windows, small canopy trees which will be called Green wall curtains and small grasses that will hold the soil will be called Green shelves as shown in **Plate 5.8**. Other operations like Mechanical Road Sweepers (MRS) and DSA applications can also be done according to the deposition of silt/ dust on the road. For the maintenance of the plantation caretakers will be needed, they will also help in reporting the potholes and illegal dumping of waste/litter to local urban bodies about the timely operation of the MRS system.

Systematic pattern on the roadside plantation

Plate 5.8: Plantation on the median, Edge in 3 Tier pattern

- **Drip irrigation watering** on median is a method of irrigating plants on the road divider using small tubes and emitters that deliver water directly to the roots of plants. Drip irrigation watering on median is a steady and continuous process of watering at the root of plants, which ensures optimal water usage and plant growth. It can reduce water loss due to evaporation, runoff, or deep percolation, and can also prevent soil erosion salinization and no soil is lost in this process on the median, it has a low maintenance cost and is economical to operating agencies. Drip irrigation can also be easily automated and controlled by timers or sensors, which can enhance the efficiency and reliability of the system.
- **Tanker-based watering** on the median is a method of irrigating plants on the road divider using a water tank mounted on a vehicle. Tanker-based watering on the median is a fast and old practice. Tanker-based watering on the median does not require any installation or maintenance of pipes, tubes, or emitters, which can reduce the initial and operational costs. However, this system puts a high-pressure watering system, which can lead to erosion of deposited soil on the median. The eroded soil can come to the road and re-suspend. Tanker-based watering on the median is an irregular watering system, which means that some plants receive water in abundance and others in scarcity. This can affect the growth and survival of plants, as well as the aesthetic and ecological value of the median. Tanker-based watering on the median can induce traffic jams due to its slow movement alongside the road median. The tanker vehicle can block the traffic flow and create congestion, especially during peak hours. Tanker-based watering on the median has a high cost of water and tanker, which can be a burden on the agency responsible for maintaining the median. The cost of water can vary depending on the availability and quality of water sources, and the cost of tankers can include fuel, maintenance and labour. Tanker-based watering on the median is a source of exhaustive air pollutants.

The findings of this chapter are summarized below:

- Reduction in road dust generation at the road by providing improvements in road maintenance by fixing potholes and regularly sweeping. The development of green spaces along the road medians and edges will help bind soil particles from becoming airborne. Paving the unpaved road shoulders would reduce the potential dust generation hotspot. Proper watering of the median plantation and providing freeboard to median soil from the top will help to reduce soil erosion.

- Lifting of road dust from the road can be achieved by manual cart brooming for smaller areas by urban local bodies and mechanical road sweepers for large-scale dust collection through vacuum-based trucks, suction machines, or a combination of both.
- Suppression of dust with dust suppressant is another option for controlling very fine road dust particles. A literature review of various chemical road dust suppressants has been made available in Annexure – A. After screening various dust suppressants based on MSDS only Sodium alginate and cow dung were found promising in various conducted tests.
- Watering the median plantation along the roadside with a tanker-based system generates lots of soil re-suspension in the air. The use of treated wastewater from metro stations with the help of drip irrigation to water roadside plantations can also be explored in future.

Chapter 6

Overall Summary and Suggestions

Background

High air pollution levels in Delhi NCR are one of the major concerns for the regulators as well as for the public. Earlier studies reported that the contribution of road dust re-suspension was very high in the city and responsible for increased PM_{10} and $PM_{2.5}$ concentration (NEERI, 2010; IIT Kanpur, 2016; TERI-ARAI, 2018). The re-suspension of road dust is influenced by continuous dust deposition at the edges of road medians, unsuitable road infrastructural designs including poor road design and maintenance, insufficient dust management practices.

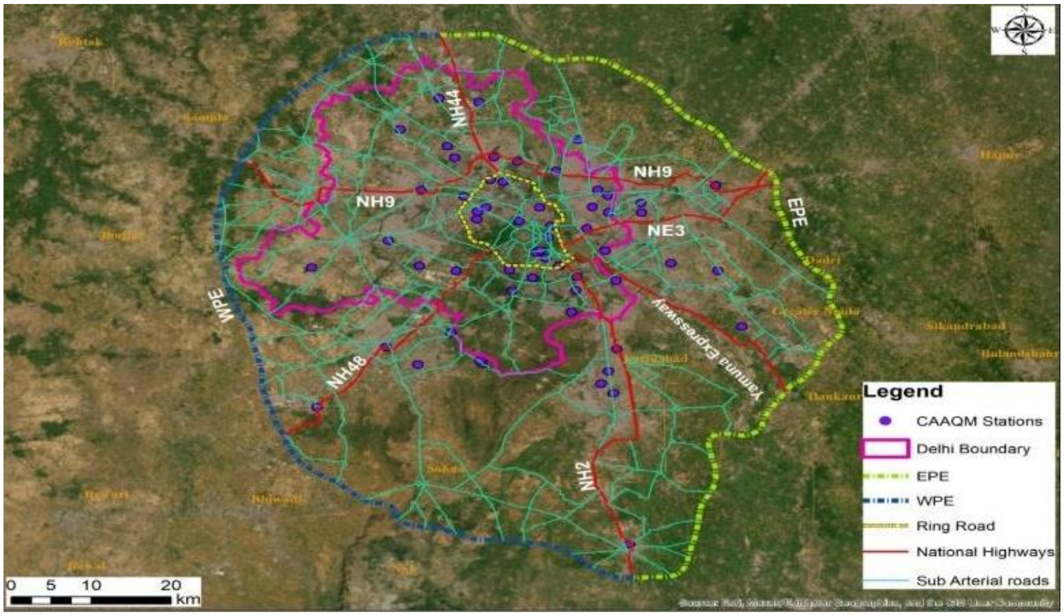
Considering the significant contribution of road dust re-suspension, CSIR- NEERI Delhi Zonal Centre and CSIR- CRRI, Delhi have jointly discussed the issue with CAQM and carried out this study titled "*Addressing Vehicular Traffic Induced Road Dust Re-Suspension with S&T-based Action Plans for Air Quality Improvement in Delhi NCR*".

The study covered detailed field surveys on the selected road route (including a stretch of Ring road, National highway, sub-arterial road and collector road), dust samples collection & its particle size distribution, Particular matter emission load estimation from re-suspension of road dust and its contribution on the nearest air quality monitoring stations using dispersion modelling, mapping of aerosol optical depth at the study area, comprehensive review of road dust suppressant application and lab scale experiment on the efficiency of the dust suppressant. The findings of the data analysis in the present study suggest the appropriate control options for reducing dust re-suspension.

Summary of Study findings and Recommendation:

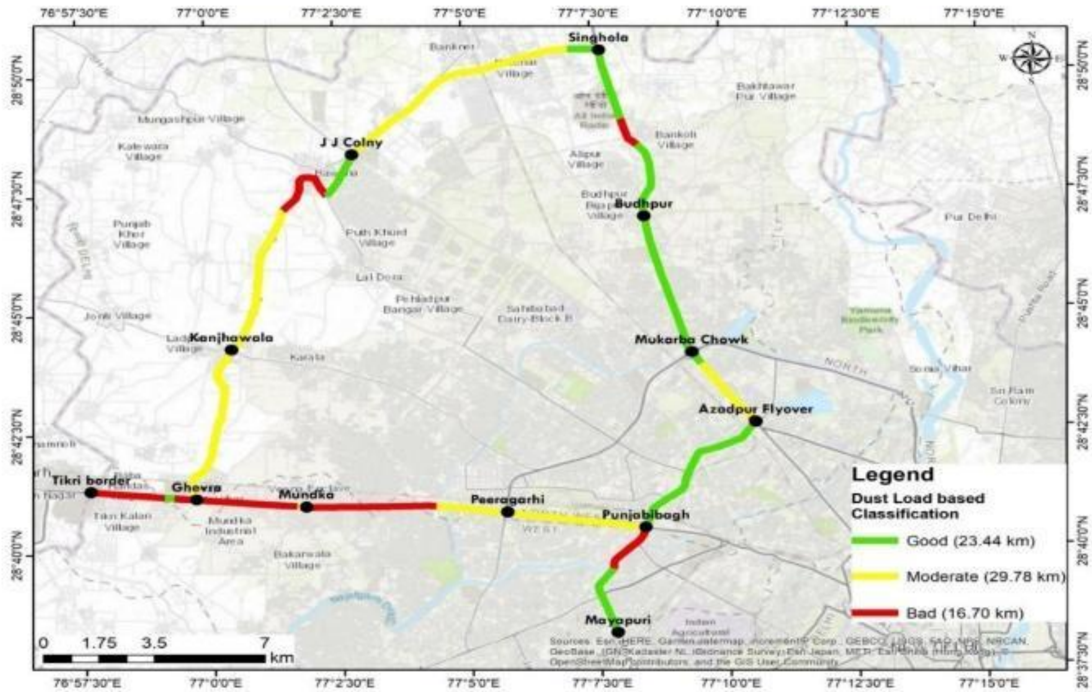
i. **Mapping of Roads between EPE & WPE:** The shape and KML files (compatible with GIS & Google earth) were prepared for major roads like National Highways, Arterial Roads, and Sub-Arterial Roads for the study area within the boundary of EPE and WPE including the whole of Delhi, partially Uttar Pradesh, and some parts of Haryana. The total length of the Expressway (EPE & WPE) is 271 km, the length of the Ring Road is

50 km, the total length of National Highways is 282 km, and the total length of Sub-Arterial Roads is 1642 km. The shapefile and KML file are available for further analysis. *This exercise further needs to be scaled for the whole Delhi NCR by adding more sub-arterial road as well as collector roads*.



ii. **Road Condition Survey & its Mapping:** The field survey of 82.5 km road stretch covering route from Mayapuri (Ring Road) → Punjabi Bagh (NH-10) → Azadpur → Mukarba Chowk → Budhpur → Singhola → Kanjhawala →Ghevra, →Tikri Border → Mundka → Peergarhi → Punjabi Bagh are mapped using GIS for status of road condition. It is revealed that the road condition of 24% of road length was found under the bad category, 42% were in moderate condition and only 34% was in Good condition.

Similar mapping of road conditions for the whole Delhi city's roads should be done along with major roads of Delhi NCR. The road maintenance agencies should be sensitized to preparing such types of road condition map and then its updation after the repair of the road. A checklist/format should be prepared to evaluate/categorise the road condition.

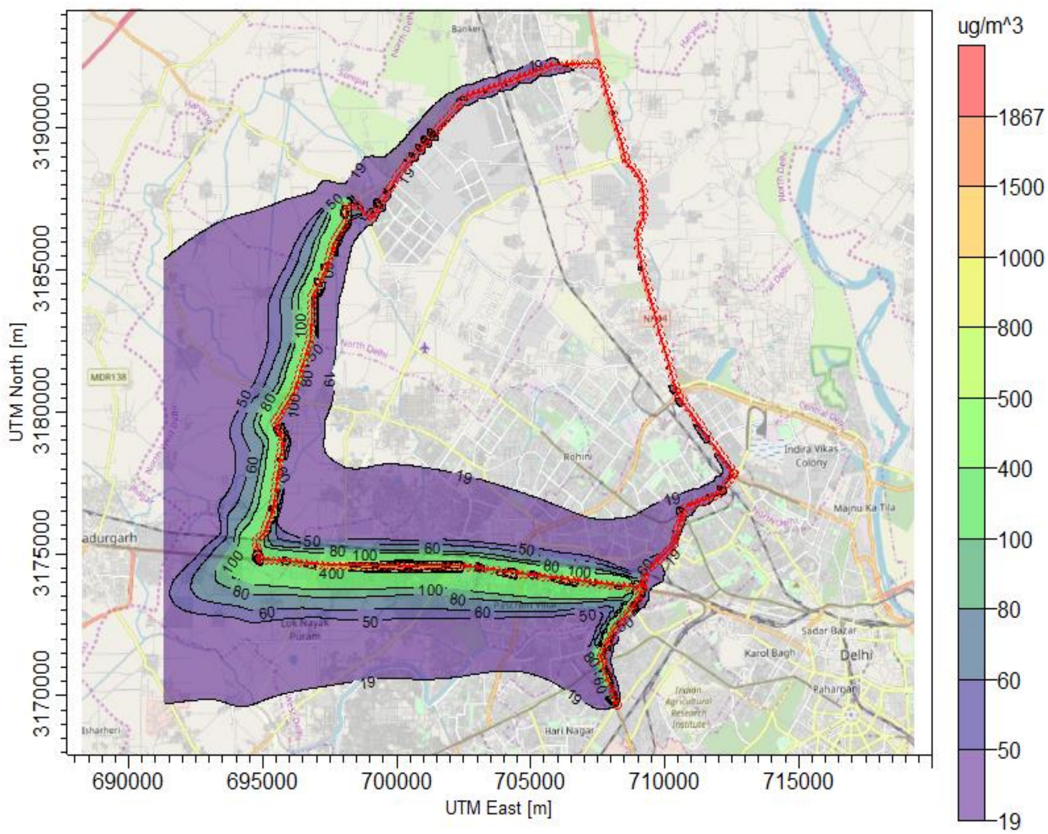


iii. **Dust Particle Size Analysis:** The Particle size distribution analysis of road dust samples revealed that most of the particles were between 35 and 211 µm in diameter. The dust accumulated (g/m^2) was more along the edges and median of the roads as compared to the centre lanes. The proportion of finer particles in deposited dust is higher at the centre compared to the edge. There is a need to design the road-sweeping machine in such a way that it lifts-up the dust properly near the road median.

There is a need to prepare a standard operating procedure (SOP) for the operation of mechanical road sweepers on a particular type of road based on scientific study. The preparation of SOP should consider the data analysis on the frequency of MRS application, its efficiency for lifting of the deposited dust, particle size analysis of lifted dust, PM_{10} & $PM_{2.5}$ concentrations before, during and after the MRS application etc.

iv. **Traffic Count Data Analysis and Dispersion Modeling:** The traffic count data for eight major locations/ intersections was collected for different roads in Delhi for a pilot study on hourly basis for a complete 24 hours. The total PM emissions for the 82.5 km stretch of road due to re-suspension of road dust is estimated as 33.83 tons/day and 8.16 tons/day for PM_{10} and $PM_{2.5}$ respectively. The emission load was highest along the Nangloi Road (NH-9) to Peeragarhi road stretch. Air quality dispersion modelling analysis revealed that the contribution of road dust was more on nearby CAAQMS compared to the far located CAAQMS. The PM levels were predicted higher along the road stretch of poor condition compared to good condition roads even with the same traffic movement.

The findings indicated that *improvement in road condition as well as creating green barriers along the road edge will help in the reduction of the impact of road dust re-suspension on surrounding air quality*.



v. **AOD Data Analysis:** The study analyzes AOD values to understand dust load patterns in the region during May 2022 and November 2022. AOD values indicate pollution sources like road dust and dust storms. Satellite data's ability to detect dust plumes is limited by factors like spatial distribution, reflectance properties, cloud presence, density, and algorithms. Therefore, dust monitoring is better achieved by using satellite remote sensing and ground-based measurements.

vi. **Dust Control/Management Strategy:** Through field visits and surveys of the selected road stretch, road conditions have been recorded and a literature review on strategies for reducing the re-suspension of road dust has been done. Management strategies lie broadly into three categories:

i) Reduction in dust generation at roads,

ii) Lifting of road dust and

iii) Suppression of dust through the application of dust suppressants.

The above three categories should be prioritized based on the status of road conditions as per the suggested map in point no. 2. The selection of a cost-effective control option is highly dependent on the road condition. A list of control options for each of the above three options should be done and shared with the road maintenance agency/road cleaning agency and training should be given to them.

vii. The application of dust suppressants should be the last priority for the control and re-suspension of dust on roads. It should only be applied on the open area on the median and road edge where there is very little possibility of vehicle tyre movement.

viii. Green spaces along roads help strengthen loose soil and reduce air pollution by creating barriers between roads and residential areas. A 3-tier plantation system can improve air quality and capture road dust. Possible plants include Spider Lily, Herbs/Small Shrubs, and Short/Medium sized trees.

ix. Potential use of DMRC wastewater for watering road median and road edge plants under the elevated metro lines. One of the possible outcomes from this would be treating wastewater at metro stations and distributing treated water through a drip irrigation system, reducing water wastage and soil displacement, and covering approximately 180 km of elevated metro routes.

x. The efficiency of any control measures for road dust management may be evaluated through particulate matter monitoring before, during and after its application using drones/ vehicle-mounted low-cost sensors.

xi. The R&D work on application of dust suppressants should continue with the inclusion of more nature-based dust suppressants like bio-char and Geotextile. It is also suggested to carry out the health exposure impact analysis of dust suppressants used, if any.

The detailed survey conducted within Delhi and its surrounding area reveals that the condition of major roads (carriage way + both side margins) needs proper maintenance on a regular basis. A proper mechanism/framework needs to be developed to ensure proper maintenance of all types of roads, making them dust-free roads and smooth movement of vehicles.

Considering the status of conditions of selected roads in the study, it is recommended to develop a unified framework for paving and greening urban roads in Delhi NCR to ensure consistent implementation of best practices across NCR. It is also recommended to carry out digital mapping of all roads of Delhi NCR, including the mapping of road conditions for road management, maintenance, optimization of the operation and deployment of the Mechanical Road Sweeping Machines (MRSM) and other dust control strategies.

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Annexure A

Study on Dust Suppressants

A 1. Literature Review

In developed countries, studies have been conducted for testing of application of dust suppressants on the road with the aim of reducing particulate pollution from road dust re-suspension.

The summary of studies conducted on Organic compounds-based dust suppressants is given in **Table A.1.** It is observed that Organic compound-based dust suppressants primarily consist of organic compounds that are extracted from plants, bacteria, fungi, etc., and are biodegradable in nature. Although not used as stand-alone suppressants, the organic dust suppressants may intermittently be coupled with synthetic polymers to enhance the dust suppression performance. For example, commonly used suppressants in this category are i) Protein-based, ii) Enzyme based, iii) Bio polymer-based, iv) Chitosan and v) Liquid polymer.

Table A.1: Summary of Organic compounds-based dust suppressants

Sr. No.	Name of Chemical	Location, Types of Application	Quantity of chemical applied (g or Ltr m^{-2}), Concentration.	Frequency of Application	PM_{10} Emission Reduction (%)	Study
A.	**Protein Based**					
1.	SDS-SPI*	China, Lab Test	At 2 L/m^2	-	92.13%	Jin et al., (2019)
2.	Molasses protein	Australia, Field Test	5% to 95% v/v at $5L/m^2$	weekly		John and Usher (2008)
B.	**Enzyme-Based**					
3.	Bacteria-based	Canada, Field Test	50,000 CCU per gram at 5,000 to 10,000 gallons per km	weekly	<60%	David and Gilmour (2012)
4.	CCL**	China, Lab Test	(10g $C_{12}H_{22}O_{11}$ + 3g Na_2HPO_4) at $1L/m^2$	5 days	<94%	Zhan et al., (2016)
5.	EICP***	USA, Lab Test	0·05 M of EICP at 5-100gm/L	-	75%	Hamdan et al., (2016)

Sr. No.	Name of Chemical	Location, Types of Application	Quantity of chemical applied (g or Ltr m^{-2}), Concentration.	Frequency of Application	PM_{10} Emission Reduction (%)	Study
C.	**Biopolymers**					
6.	OCS#	(Chengdu) China, Lab test	20mL per 50g dust	-	78.7%	Dang et al., (2016)
7.	PDS##	(Xi'an) China, Lab test	2.0 g/L	3 h	98.8%	Lai et al. (2011)
8.	Co-polymerized Corn starch	(Qingdao) China, Lab test	6% sol^n per 100gm	3h	81.2-89.8%	Bao et al., (2018)
9.	Guar gum	(Arizona) USA, Lab test	4 g/m^3 at 0.5-4.5 L/m^2	5 days	-	Chen et al., (2015)
10.	GGTCS###	Qingdao, China, Lab test		5 days	60%	Zhang et al., (2018)
D.	**Chitosan**					
11.	HTCC+	(Qingdao) China, Lab test	-	-	74.05%	Liu et al., (2017)
12.	Poly (METAS+++)	USA	3-50% of poly (metas) chitosan polymer at 1.81 L/m^2	-	-	Raab et al., (2019)
E.	**Liquid Polymer**					
13.	PEG++	(Arizona) USA, Lab test	7 v/v% PEG aqueous	weekly	87%	Lee et al., (2019)

* *SDS-SPI – Sodium dodecyl sulfonate (SDS), Soybean Protein Isolate (SPI)*
** *CCL- Calcite Consolidation Layer*
****EICP- Enzyme- Induced Carbonate Precipitation*
#*OCS- Oxidised Corn Starch*
##*PDS- Polymer Dust Suppressant (starch-based monomer)*
###*GGTCS- Gaur Gum (straight chain galactomannan with galactose on every other mannose unit)*
+*HTCC-chitosan quaternary ammonium salt*
++*PEG- Poly Ethylene Glycol*
+++*METAS- Methacryloyloxy ethyl trimethyl ammonium methyl sulfate*

Biopolymers can be combined with other chemicals to create hybrid dust suppressants. **Table A.2** summarizes different hybrid dust suppressants that have been synthesized by researchers in the past. The summary includes brief overview of each dust suppressant in terms of location where it was applied and quantity used, and its frequency of application with efficiency of PM_{10} emission reduction.

Table A.2: Summary of Biopolymer combined with Chemical agent-based dust suppressants

Sr No	Name of Chemical	Location, Types of Application	Quantity of chemical applied (g or Ltr m^{-2}), Concentration.	Frequency of Application	PM_{10} Emission Reduction (%)	Study
A.	**Polymer Based**					
1.	Polymer-based aqueous#	Xuzhou, China, Lab test	0.5 g/L to 10 g/L,	24 h	-	Inyang et al., (2016)
B.	**Surfactant-Based**					
2.	Combination of phospholipids, surfactants, and additives	(Patent), Lab test	10-40% by Wt of phospholipid,20-80% by Wt of surfactant, 1-20% by Wt of additive at 1-	4-48 h	-	Devi et al., (2013)
3.	SSC*	Taiyuan, China, Field test	-	-	87.7% - 89.2%	Liao et al., (2018)
C.	**Calcium Magnesium Acetate (CMA) Based**					
4.	CMA##	Horn Lane, Manor Road (UK), Sweden, Spain, Field test	40-60 g/m^2 at	Daily	31–59%	Norman et al., (2006), Amato et al., (2014), Amato et al., (2016), Barrette et al., (2012), Barrette et al., (2012)
D.	**Lignosulfonate (L.S.)**					
5.	Lignosulfonate	Colorado, USA, Field test	2.3L/m^2	Daily	50–70%	Sanders et al., (1997), Breum et al., Sanders et al., (2015)
6.	L.S.-based dust palliative	South Africa, Field test	0.244 mg/m^3		53%	Du Plessis et al., (2016)
7.	Molasses stillage	Zimbabwe, Field test	4L/m^2	14 days	77% - 83%	Gotosa et al., (2015)
8.	Modified L.S. (SLS cross-linked with AAM** and MAB***)	Qingdao, China, Lab test	2 g of SLS+0.1 g of ammonium persulfate +0.2 g of MBA+7 g of AAM at 0.2 ml/0.05 g of coal dust	-	-	Fan et al., (2018)

** SSC- Surfactants, Synergist Ions, Cellulose; ** AAM- acrylamide; *** MAB- NN'-methylene diacrylamide*
#sodium carboxymethyl cellulose (CMC A), polyacrylamide (PAM B) and polyethylene oxide (PEO A)
##CMA Calcium Magnesium Acetate

Inorganic compound-based dust suppressants are derived from non-living sources, such as minerals and chemicals. They are the most common type of dust suppressants, accounting for about 75-80% of the market (Parvej et al. 2021). This class of dust suppressants includes a wide variety of materials, such as chloride salts, silicates, and surfactants. **Table A.3** summarizes different inorganic dust suppressants and studies on their effectiveness in controlling fugitive dust.

Table A.3: Summary of Inorganic compounds-based dust suppressants

Sr. No.	Name of Chemical	Location, Types of Application	Quantity of chemical applied (g or Ltr m^{-2}), Concentration.	Frequency of Application	PM_{10} Emission Reduction (%)	Study
A.	**Chlorides**					
1.	$MgCl_2$ and $CaCl_2$	UK, (Colorado) USA, Trondheim (Norway), Norwegian tunnel (Norway), Roadway (Netherland) Sweden, Helsinki (Finland), Field test	0.6-2 mg/m^3 (MgCl2) and 0.2-3 mg/m^3 (CaCl2) at 1- 2.3 L/m^2	Daily	50–70%	Sanders et al., (1997), Berthelson et al., (2003), Edvardsson (2010) Gustafsson et al., (2010), Kupiainen et al., (2011), Sanders et al., (2015)
2.	Sodium Poly acrylate+ Sodium Carbonate+ Polyethylene Glycol+ Alkyl Glycoside	(Beijing) China, Lab Scale	(0.08%$C_3H_3NaO_2$) + (15% Na_2CO_3) + (2% PEG) + (0.15% APG)/500mL at 2L/m^2	10 Days	95-97.62%	Huang Z et al., (2021)
B.	**By Products and Waste Products**					
3.	Petroleum refinery waste	(Aliaga – Izmir) Turkey, Lab test	0.5-2% waste per L	20 min	Up to 80%	Dixon-Hardy et al., (2008)
C.	**Inorganic Oil–Chemical Combination**					
4.	Synthetic triglycerides	U K	0.05 - 2.5% by W/W pellet	-	50-80%	Hey et al., (2008)
5.	Glycerol	Brazil, Lab test	pure glycerol and H_2SO_4, with molar ratio equal	120 min	8-14%	Medeiros et al., (2012)

Sr. No.	Name of Chemical	Location, Types of Application	Quantity of chemical applied (g or Ltr m^{-2}), Concentration.	Frequency of Application	PM_{10} Emission Reduction (%)	Study
			to 3% at 10 mL per 250g			
6.	PE*, PEP**, and NHCO***	(California) USA, Field test		12 months	83% (PE), 44% (PEP), and 95%(NHCO) efficiency	Gillies et al., (1999)
D.	**Magnetized Surfactants**					
7.	Surfactant	(Beijing) China, Lab test	Triton solution Conc^{n} 0.02%~0.03%	-	-	Ding et al., (2011)
E.	**AQUEOUS-BASED**					
8.	Foam-sol	(Tianjin) China, Lab test	foam–sol (2 g)/coal dust (10 g)	-	~70%	Xi et al., (2014)

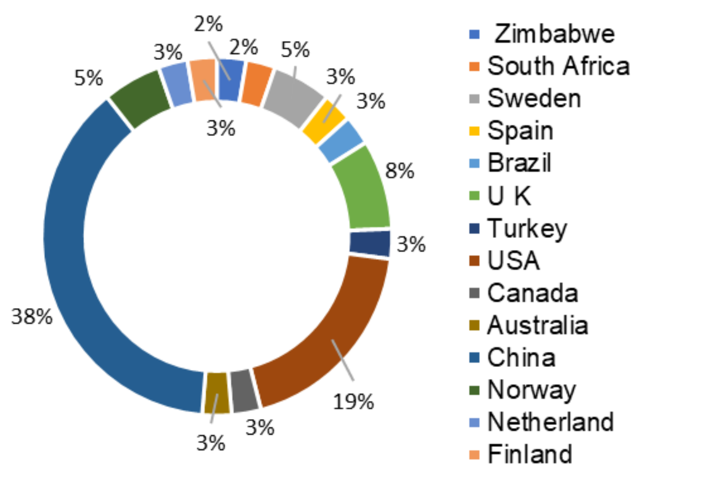
* *PE- Polymer Emulsion*
*******PEP- Petroleum Emulsion with Polymer*
****NHCO- Non-Hazardous Crude Oil Containing Materials*

There are some nature-based dust suppressants which can be extracted from various parts of plants. But processing of such products is costly affair and not feasible at larger scale application. Brief information is presented in **Table A.4.**

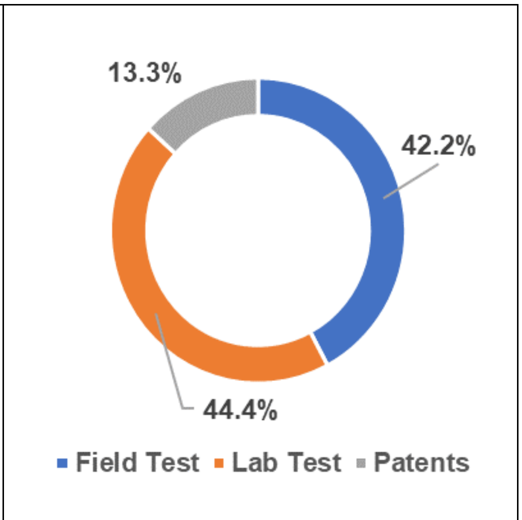
Table A.4: Review of Nature based dust suppressants

Sr. No.	Chemical	Key Property	Native Country Availability	Price (Rs. /Kg) (Imported/Indian)	Disadvantages
1.	Gum Acacia/ Arabica	Moisture, Total ash, Volatile matter, Internal energy	(80%) Sudan, Niger, Nigeria, Chad, Cameroon, Eritrea, Somalia, Ethiopia, Kenya, and Tanzania.	100-150 Imported	• Solid hard material needs first conversion into liquid for mixing into water and then it would be applicable. • Catch Fire in excessive heat, Flash Point ~ 90ºC • Dust can form an explosive mixture in air. • Food product • Expensive to import
2.	Acacia/ Vachellia - Nilotica	Gum Acacia is highly Nutritive, Binding agent in preparation of lozenges, pastilles and compressed tablets	Native from Egypt, Maghreb and Sahel, Mozambique and KwaZulu-Natal (Tropical Africa), India, Sri Lanka, Burma, Indonesia	50-100 (Imported + Indian)	• Solid hard material needs first conversion into liquid for mixing into water and then it would be applicable. • Highly flammable. • Its nutritive and we should consider waste product for dust suppressant
3.	Rubber Latex	Moisture resistance, Resistance to microorganisms, Strong adhesion, Adhesive film is resistant to ageing	Thailand, Indonesia, China, India is the world's 4th largest producer	90-150 (Indian)	• Skid test data not available • At temperatures below 5 °C, the adhesive structure deteriorates.

Country wide studies on the reduction of dust re-suspension due to the use of dust suppressing agents (DSA) on the road in different cities are shown in **Fig. A.1.** The quantity of chemical required on road varies according to the application frequency, ratio of dust suppressant chemical and water, type of road i.e., paved and unpaved road, concrete or black top road. Major test was performed in China (38%) and USA (19%) at lab scale level. In India, two studies were carried out which are explained in next section of this report.



Country wise research on DSA



DSA application scale

Fig. A.1: Participating countries and scale of testing of Dust Suppressing Agents

A.2 Material Safety Data Sheet (MSDS) of common dust suppressants

A Material Safety Data Sheet (MSDS) is a document that provides information about the hazards of a chemical product. It is developed to help people work safely with the product by providing information on its physical and chemical properties, health hazards, fire and explosion hazards, reactivity hazards, and personal protection equipment (PPE) requirements. The MSDS was available only for 12 suppressants as shown in **Table A.5**, it has been majorly classified according to hazards related to dust suppressant use and the long-term effect of the application on humans and its surrounding environment.

Table A.5: Material Safety Data Sheet (MSDS) of various road dust suppressants available in literature review

Sr. No.	Chemical Name and Composition	Hazard Identification	Flammable/ Non-Flammable	Toxicology	Exposure Controls		
					Eye	Skin	Respiratory
1.	CMA ($C_2H_4O_2Ca_x Mg$)	May cause eye irritation	Non-Flammable	Non-Toxic	Eye protection Glass	Protective gloves	Wear a mask while spraying
2.	Magnesium Chloride ($MgCl_2$)	May cause eye irritation	Non-Flammable	Non-Toxic	Chemical safety goggles	Protective gloves	Respiratory protection required

Sr. No.	Chemical Name and Composition	Hazard Identification	Flammable/ Non-Flammable	Toxicology	Exposure Controls		
					Eye	Skin	Respiratory
3.	Calcium Chloride ($CaCl_2$)	May cause severe eye, skin and respiratory tract irritation with possible burns	Non-Flammable	Non-Toxic	Chemical safety goggles	Wear impervious gloves.	Respiratory protection required
4.	Sodium Lignosulphonate ($C_{20}H_{24}Na_2O_{10}S_2$)	Repeated /prolonged exposure to the substance can produce target organs damage	Flammable at high temperature	Non-Toxic	Safety glasses	Protective gloves	-
5.	Sodium dodecyl sulfonate ($NaC_{12}H_{25}SO_4$)	Causes skin irritation, Causes serious eye damage.	Flammable. Dust can form an explosive mixture in air.	Acute Toxicity	Chemical safety goggles	Wear impervious gloves.	Respiratory protection necessary
6.	Soy Protein Isolate ($C_{12}H_{12}N_2O_3$)	Non-Hazardous	N/A	N/A	Safety glasses	N/A	Dust mask if levels exceed 15 mg/m³
7.	Poly Ethylene Glycol ($HO(C_2H_4O)nH$)	Non-Hazardous	Non-Flammable	Non-Toxic	Use safety goggle with side protection	Wear suitable gloves.	Respiratory protection necessary at: Dust formation
8.	Sodium Poly acrylate ($(C_3H_3NaO_2)_n$)	Causes serious eye irritation	Non-Flammable	Acute Toxicity	Safety glasses or goggles are appropriate eye protection	Select glove material impermeable and resistant to the substance	Not required under normal conditions of use
9.	Sodium Carbonate (Na_2CO_3)	Causes serious eye irritation	Non-Flammable	Acute Toxicity	For dusty or misty conditions , wear	Wear impervious gloves when	In cases of inadequate ventilation, wear

Sr. No.	Chemical Name and Composition	Hazard Identification	Flammable/ Non-Flammable	Toxicology	Exposure Controls		
					Eye	Skin	Respiratory
					chemical safety goggles	handling solutions (rubber, neoprene)	respirators
10.	Alkyl Glycoside ($C_nH2_nO_6$)	Serious eye damage/eye irritation	Non-Flammable	Acute toxicity	Wear eye protection	Wear impervious gloves when handling solutions Nitrile rubber	Use only in well-ventilated areas
11.	Glycerol	Not a hazardous substance	Flammable	Low acute toxicity	Wear safety glasses with side shields (or goggles)	Protective gloves	Respiratory protection required for prolong usage
12.	Guar gum ($C_3H_8O_3$)	Not a hazardous substance	Non-Flammable without melting or heating	Non-Toxic	Use equipment for eye protection	Handle with gloves	Respiratory protection is not required

A.3 Evaluation of Efficiency of Selected Dust Suppressants

Considering the findings of the review and discussion in various meetings at CAQM, the study team has done few experiments to evaluate the dust suppressant efficiency in reduction of re-suspension of dust. The experiments were performed in different environmental conditions. The following sub-sections explain the adopted methodology and findings of experiments. The dust suppressant tested in various experiments are Sodium Alginate (SA), MixChem, Calcium Chloride, Magnesium Chloride and Cow Dung Slurry (CDS). The basic steps involved in the dust suppressants experiments are as follows:

i) **Preparation of solutions of dust suppressant:** All the dust suppressants were applied in solution/liquid form which were prepared by mixing a known volume/mass of suppressant/ materials/chemical in known volume of water, which varied for each dust suppressant.

ii) **Spreading of dust on a clean surface:** A known amount of road dust was spread on a designated place of 1 x 1 sq ft (in one experiment, it was taken 1 sq.m). The road dust was collected from the edge of the road and filtered through a sieve of size 750 µm before application of dust suppressant.

iii) **Application of dust suppressant:** A known volume of each dust suppressant solution was spread on the particular experimental surface where dust was spread. One experimental surface for comparison purpose was left without adding any suppressant, as control.

iv) **Application of Turbulence force:** All dust-covered experimental surfaces were exposed to a consistent wind force generated by table fans. The applied wind force was more or less equal to the wind force generated by traffic at the road median and edge, which is being monitored by the study team at ring road i.e., 4.5 m/s.

v) **Collection of dust after application of force:** All the dust left over after the application of wind force was collected and weighed through weighing balance. The efficiency of dust suppressant was calculated by subtracting the weight of leftover dust from the initial weight of dust and divided by the initial weight.

A.3.1 Experiment 1: Under controlled condition

In this experiment, the effectiveness of three different chemical additives as dust suppressants was tested inside the building in an indoor space. The dust suppressant solutions (mixed with water) namely Sodium alginate, Calcium Chloride ($CaCl_2$) and Magnesium Chloride ($MgCl_2$) were tested in this experiment. A volume of 50 mL of each solution was applied over a 1 sq. ft area. Chemicals were applied in a 20% weight by volume ratio. The 50 g of dust sample were spread evenly on the marked area of 1 sq. ft and artificial turbulence in the form of wind with fans at a speed of 4.5 m/s was generated as shown in **Plate A.1**. The findings of experiments in terms of dust leftover and efficiency are given in **Table A.6.**

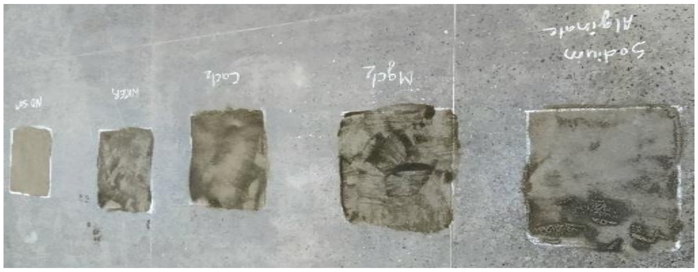
Step No.	Description	Photograph
1	Initial weighting of road dust with particle size less than 710 µm	
2	Spreading of road dust on 1 sq.ft of area for different suppressants	
3	Initial deposition of dust without application of dust suppressant	
4	Condition after application of dust suppressant	
5	Wind turbulence monitoring using Anemometer	

Plate A.1: Photographs showing the experimental setup and testing of different dust suppressants

Table A.6: Experimental details of dust suppressants application

Sr. No.	Parameters	Without Solution	Water	Sodium Alginate Solution	$MgCl_2$ Solution	$CaCl_2$ Solution
1.	Dust Spread (g)	50	50	50	50	50
2.	Dust Suppressant Solution Strength	-	-	20% (w/v)	20% (w/v)	20% (w/v)
3.	Weight of dust retained application of wind force (g)	0	19.6	43.6	30.0	20.8
4.	Wight of dust which became airborne (g)	50	30.4	6.4	20.0	29.2
5.	**Efficiency (%)**	**0**	**39.2**	**87.2**	**60.0**	**41.6**

Table A.6, shows that out of three chemical additives as dust suppressant solutions, sodium alginate was the most effective suppressant chemical additive for dust suppression, as it retained 43.6 g of the dust and had an efficiency of 87.2%. Water and $CaCl_2$ solution were the least effective, as they retained only 19.6 g (39.2%) and 20.8 g (41.6%) of dust respectively. $MgCl_2$ was moderately effective, as it retained 30 g of the dust and had an efficiency of 60%.

Plate A.2, shows dust left after 8 hours of turbulence, these results suggest that sodium alginate is a promising chemical additive for dust suppression, as it can form a gel-like coating on the dust particles and prevent them from being dispersed by the applied force. Water, on the other hand, can only wet the dust particles and make them heavier, but not prevent them from being blown away by the wind force after a certain period. $MgCl_2$ has also created some coating on the dust particles, but not as strong as sodium alginate.

	
No Solution	Water
	
Sodium Alginate	Magnesium Chloride
	
Calcium Chloride	

Plate A.2: Dust left after application of DSA

A.3.2 Experiment 2: Under external wind conditions (Outdoor Environment)

After Experiment 1, the study team conducted another experiment outdoor, on the rooftop of a building with the effect of natural wind, ambient temperature and artificial wind force of 4.5 m/s. In this experiment, the effectiveness of four different dust suppressant solutions was tested namely, Water, Sodium Alginate, Cow dung, and MixChem. The $MgCl_2$ and $CaCl_2$ were eliminated due to their underperformance in the controlled condition with respect to water as the benchmark dust-suppressing agent which is commonly practiced in Delhi NCR. The experimental setup and deposited dust on marked surface area for each dust suppressant is shown in **Plate A.3.**

Condition of dust after sprinkling of dust suppressant solution

Condition of dust after sprinkling of dust suppressant solution

		
Cowdung	MixChem	Sodium alginate

Plate A.3: Photographs showing testing of different DSA in external conditions

50 mL of each dust suppressant solution was applied on a 1 sq. ft marked area. Chemicals were applied in a 20% weight-by-volume ratio over a 50 g dust sample evenly spread on the surface. Artificial turbulence in the form of wind with fans at the speed of 4.5 m/s was generated. The findings of the experiments are summarized in **Table A.7**.

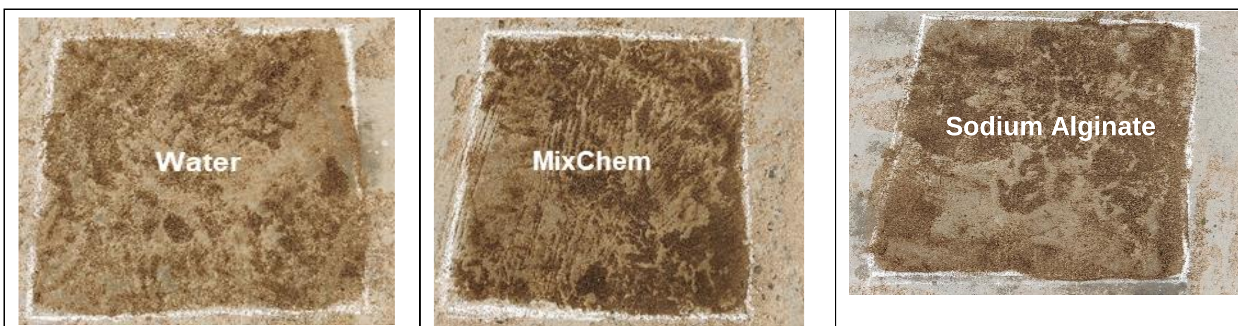
The sodium alginate was found to be the most effective DSA for dust suppression, as it retained 78.40% of the dust that was distributed evenly on the surface. Sodium alginate is a natural polysaccharide that can form a gel-like coating on the dust particles and prevent them from being dispersed by the applied force. Water was the least effective, as it retained only 38.40% of the dust. Cow dung was moderately effective, as it retained 72.40% of the dust. MixChem was slightly effective, as it retained 50.80% of the dust. MixChem is an organic-based surfactant and tackifier that can agglomerate fine particles and hold them together even after the treated material has dried. These results suggest that sodium alginate is a promising dust suppressant for dust suppression, as it can reduce dust emission against various wind forces and vehicular movement.

Table A.7: Efficiency of DSA in external conditions

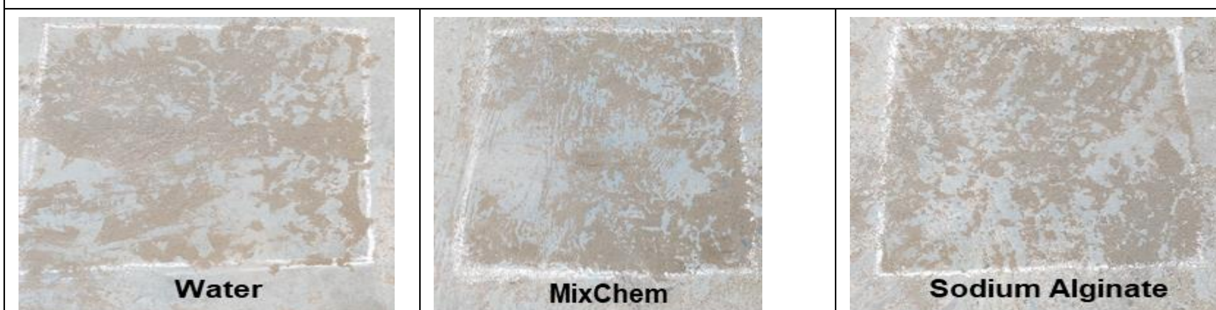
Sr. No.	Parameters	Water	Sodium Alginate	Cow Dung	MixChem
1.	Dust Spread (g)	**50**	**50**	**50**	**50**
2.	Dust Suppressant Solution Strength	100%	20% (w/v)	20% (w/v)	20% (w/v)
3.	Weight of dust retained application of wind force (g)	19.20	39.20	36.20	25.40
4.	Wight of dust which became airborne (g)	30.80	10.80	13.80	24.60
5.	**Efficiency (%)**	**38.40**	**78.40**	**72.40**	**50.80**

A.3.3 Experiment 3: Efficiency of dust suppressant during traffic movement

In the previous two experiments, the efficiency was estimated against the dust re-suspension due to wind erosion/force in Indoor and outdoor environments. However, the situation on the road will be different where one more force also works significantly i.e., wear and tear by Tyre movement, which will disturb the suppressant layer over the road surface. The dust suppressant application was tested during the vehicular movement that creates vibrations and loses the dust particles, thus making them easy for re-suspension. Heavier vehicles exert more force on the road surface, crushing and re-suspending more dust particles. It is very difficult and complex to conduct such an experiment on a running trafficked road due to safety issues as well as other variables. Therefore, team has conducted an experiment to test the efficiency of dust suppressant on the porch of NEERI's building entry gate. In this experimental setup, efficacy of 3 dust suppressants was studied as shown in **Plate A.4**.



After application of Dust suppressant on Day 1



Dust left on Day 2 after vehicular motion

Plate A.4: Photographs showing deposition of dust after sprinkling of dust suppressant solution and dust leftover on 2nd day

The chemicals were applied on a 4 sq.ft area on a road close to the gate of the CSIR NEERI Delhi office and each box area was covered with 200 g of dust (passed through a sieve of particle size of 710 µm). The dust suppressant solutions were applied in a 20% weight by volume concentration and in a 200 mL volume as described in **Table A.8**. The experiment also simulated the effect of vehicle movement on the dust re-suspension after movement of 26 vehicles (7 cars and 19 two-wheelers). The dust suppression efficiency was measured by the amount of dust that remained on the road surface after the treatment.

The sodium alginate had shown the highest resistance against dust re-suspension, with having efficiency of 80.8%, Sodium alginate can form a gel-like layer on the road surface and bind the dust particles together. MixChem relatively showed low dust suppression efficiency of 66.9% and water with least efficiency of 55.1% after 2 days of vehicular movement.

Table A.8: Efficiency of different dust suppressant solution after vehicular movement on road

Sr. No.	Parameters	Description		
1.	Area of application	4 sq. ft		
2.	Dust suppressant Solution Applied	200 mL		
3.	No Vehicle Movement	26 Vehicles (7 Car, 19 2-Wheeler)		
4.	Dust spread	200 g @ 710 µm Sieve		
5.	Dust Suppressant Solution	**Water**	**Sodium Alginate**	**MixChem**
6.	Solution Strength	100%	20% (w/v)	20% (w/v)
7.	Weight of dust retained (g)	110.2	161.6	133.8
8.	**Efficiency (%)**	**55.1**	**80.8**	**66.9**

A.4 NEERI'S earlier study on dust suppressants

NEERI has also worked on application of dust suppressants with two distinct organizations in the past and carried out field investigations with suitability of application on different locations in Delhi NCR. The summary of the findings of these studies are given below:

A.4.1 Application of $MgCl_2$ as Dust Suppressant (EPRI-NEERI-CPCB Study)

Central Pollution Control Board (CPCB) awarded a study to EPRI, Mumbai in 2019 with an advisory role of CSIR-NEERI for methodology and supervision. In this study, EPRI demonstrated the $MgCl_2$ as dust suppressant at three locations in Delhi. These locations were road corridor at Sarai Kalekhan, Dilshad Garden and DDA construction site at Narela. The application was tested during October 28-November 1, 2018, whereas at DDA construction site, it was done during November 20-23, 2018. Summary of the selected site for application of dust suppressant is given in **Table A.9,** which shows site features and activities at selected sites.

Table A.9: Landuse / activities Surrounding the Selected Sites

Sr. No.	Parameters	Sarai Kale Khan Road	Dilshad Garden Road	DDA, Narela Site
1.	Type	Road site	Road site	Building Construction site
2.	Metro station	Not present	Existing (Dilshad Garden Metro Station)	Not present
3.	Metro station Proposed	Hazrat Nizamuddin metro to be connected to Sarai Kale khan Inter-State Bus Terminus (ISBT)	Shahid Nagar Metro station	Not proposed
4.	Flyover proposed	Yes (ongoing construction of flyover)	Yes (ongoing construction of flyover)	Not present
5.	Paved Road	Partial	Partial	No
6.	Un-paved road	Partial	Partial	Yes
7.	Vehicular movement	Continuous vehicular movement	Continuous vehicular movement	For transportation of materials for construction activities
8.	Probable Sources of dust emission	Construction of flyover& heaps of uncovered	Construction of Shahid Nagar metro and flyover and unscientific & uncovered method for storage of construction materials	Construction activity, unscientific & uncovered demolished materials along with construction raw materials

Application Rate: In this study 1,00, 000 (1 Lakh) m^2 or 10 Hectare of area was considered for 3 different sites, before applying it was well mixed with water. The solution of 10% was spread with rate of 2 litres per sq.m.

The dust suppressant was applied through a tanker, twice a day for three consecutive days at each location and dust levels were monitored each time before the application of dust suppressant, and then after 10 minutes, 1 hr, 2 hrs, 3 hrs and 6 hrs of dust suppressant application. Dust levels were monitored using handheld dust monitor "DUST TRACK", which monitors PM_{10} and $PM_{2.5}$ simultaneously. Sampling was carried out at 4 locations of 1 km road stretch and monitoring was carried out at each location for 15 min. The dust suppressant study indicates that it has significantly reduced the PM_{10} concentration at all three sites up to 60% immediately after 10 minutes of application, and the effect was seen up to 6 hrs (with reduction to about 40%).

More or less similar pattern was observed in case of $PM_{2.5}$ levels. **Table A.10** gives detail of overall efficiency of dust suppressant for different interval of time in a day after application.

Table A.10: Overall efficiency of dust suppressant

Session	Time Period (after spraying dust suppressant)	PM_{10} reduction (%)	$PM_{2.5}$ reduction (%)	Overall Efficiency (% reduction)
Morning	10 min	59.01	62.37	61.13
	1 hour	56.11	53.60	54.64
	2 hours	50.38	48.95	49.28
	3 hours	43.84	42.42	42.96
	6 hours	40.52	36.79	37.88
Evening	10 min	59.60	59.01	59.39
	1 hour	55.82	51.09	53.07
	2 hours	48.52	43.16	45.30
	3 hours	42.39	39.03	39.99
	6 hours	39.26	33.48	34.81

A.4.2 Application of Sodium Alginate as Dust Suppressant (NEERI-CRRI Study)

In another study jointly conducted by CSIR-NEERI Delhi Zonal Centre and CSIR-CRRI. Delhi in 2018, a dust suppressant made up of sodium alginate was tested. The study has been conducted in two parts by CSIR-NEERI, Delhi Zonal Centre and CSIR-CRRI for testing the efficacy of dust suppressant by considering various aspects to assess its applicability listed below.

1. Evaluation of efficiency of dust suppressant for control of road dust emissions on a selected road in CSIR-CRRI campus, New Delhi (test road) and Urban Road near Nitto Denko Office, Manesar, Gurugram
2. Chemical characterization of the dust suppressant
3. Impact of Application of DSA on physical properties of dust
4. Evaluation of frictional properties of pavement after the application of road dust suppressant.

A.4.2.1 Assessment of efficacy of Dust Suppressant Agent under Different Conditions

Sodium alginate dust suppressant has been tested for its efficacy under different experimental set-ups and conditions at CSIR-NEERI, DZC, CSIR-CRRI and Nitto Denko Pvt. Ltd. **Table A.11** describes the details of the experiments performed at different locations.

Table A.11: Details of experimental setup

Sr. No.	Study Area	Details of Experiment	Composition of Dust Used	Source of Turbulence
1.	CSIR-NEERI Campus, Delhi	Carried out in a Closed Room under Controlled Conditions	Road Dust	Table fan operated at a speed of ~5 m/s
2.	CSIR-CRRI Campus, Delhi	Carried out at three selected road sections within campus	50% Road Dust 50% Fly Ash	Vehicle movement (4 wheelers)
3.	Nitto Denko Campus, Delhi	Carried out at two road sections, one within campus and other outside campus	Soil from nearby field	Vehicle Movement Within Campus: 4 Wheelers Outside Campus: Different Vehicle Types

a. CSIR-NEERI Campus (Delhi)

Starting from the first experimental setup, the preliminary experiment was set up in a closed room under controlled conditions at CSIR-NEERI, campus. The experiments were carried out under different dosages and for different durations to evaluate its efficacy in controlling road dust emissions. **Table A.12** shows, experiments were carried out in two sets in a closed room (under controlled conditions) to understand the efficiency of the developed dust suppressant with different dosages (1 L/m^2 and 0.5 L/m^2, 20% v/v) applied on a known quantity of dust i.e., 1 kg spread over an area of 1 m^2. The dust used in the present study was the dust collected by brooming and sweeping from the roads of Naraina area, sieved to 5 mm size.

Table A.12: Details of the closed room experiments carried out under controlled conditions

Sr. No.	Selected Area	Quantity of Dust Used	Dosage		Table Fan Speed
			Dust Suppressant	Water	
1.	1 m^2	1 kg	1 L/m^2 (20% v/v)	1 L/m^2	~5 m/s
2.	1 m^2	1 kg	0.5 L/ m^2 (20%v/v)	0.5 L/m^2	~5 m/s

The experiments were repeated under similar conditions, using water as a dust controlling agent in place of a dust suppressant to draw a comparison between the two different methods to control road dust re-suspension considering the cost-effective nature and dust controlling efficiency. Table fan at full speed (~5 m/s) was used to generate turbulence allowing dust to re-suspend. Anemometer was used to measure the speed of the fan. The background concentrations were also monitored for PM_{10} and $PM_{2.5}$ in the room (when no controlling agent applied).

Table A.13 describes the 15-minute average concentrations of PM inside the closed room when the selected dust spread area was treated with 1 L/m^2 (20% v/v) solution of Sodium Alginate dust suppressant. It is observed that on the application of dust suppressant (Day 0 – day when DSA applied), the concentrations decreased substantially to 117 µg/m^3 for PM_{10}: and 82 µg/m^3 for $PM_{2.5}$. The reduction in the concentrations is found to be 74% and 58% respectively with respect to background average concentrations (i.e. 443 µg/m^3, and 194 µg/m^3 respectively). PM measurements were taken daily for up to 5 days, without altering any condition of the room and keeping the table fan speed at ~5 m/s. The concentrations were found to decrease significantly up to the third day of application.

Table A.13: PM concentration reduction on dust suppressant application at dose 1 L/m^2

Day	15 min. Average PM Concentrations (μg/m^3)		Reduction (%)	
	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$
Before Application of Dust Suppressant				
Day 0	443	194	--	--
After Application of Dust Suppressant				
Day 0	117	82	74	58
Day 1	73	56	84	71
Day 2	69	42	85	78
Day 3	43	30	90	85
Day 4	88	65	80	66
Day 5	116	69	74	64

The PM concentrations reduced substantially up to the third day of application of dust suppressant agent at a dose of 1 L/m^2. It is observed that the PM_{10} concentrations reduced by 74% - 90% with respect to background concentrations, and $PM_{2.5}$ by 58% - 85%, respectively.

b. Pilot Study on a Road Corridor at CSIR-CRRI Campus

This section discusses the application of Sodium Alginate dust suppressant on the test road at CSIR-CRRI, New Delhi. The experiments were performed simultaneously on a selected road of the CRRI campus and the same set-up was used with a sprinkling of water in order to draw a comparison between the two. **Plate A.5** shows the road stretches of sections 1 & 2.

a. Road Section 1

b. Road Section 2

Plate A.5: Photograph showing the selected road corridor for the study at CSIR-CRRI campus

The pilot study was carried out at three selected road corridors of CRRI Campus from 5-8 June 2018. The dust used in the present study was a mixture of re-suspended road dust (50%) and fly ash (50%) to make it finer so that the effectivity of the suppressant can be evaluated on fine particulate matter also.

Further, the dust was spread on all three selected sections of the road in equal proportion i.e. 0.5 kg/m^2. The selected road sections were subdivided into small sections of 3 x 3.5 m^2 area and dust of known quantity was spread on each section to make uniform spread of dust on the whole stretch of the road. Total 135 kg of dust was spread over an area of 270 m^2. The untreated section-3 does not witness any application of dust suppressant or water while the other selected sections 1 and 2 were treated with dust suppressant and water sprinkling, as shown in **Plate A.6.** The dust suppressant and water were spread at the rate of 0.45 L/m^2. The concentration of dust suppressant was kept 20 % v/v like chamber experiments.


a. Application of Dust on Selected Road Sections


b. Application of Dust Suppressant on Selected Road Section

Plate A.6: Photographs showing the application of dust and dust-suppressant at the selected road corridor

In order to simulate the condition of road dust re-suspension and friction of Tyre movement, a 4-wheeler (car) was repeatedly moved on all the sections of the road. The PM concentrations were monitored by GRIMM Aerosol Dust Monitor placed at a distance 1 m away from the selected road corridor in the downwind side.

The background average pollutant concentrations have been observed under natural conditions, the background concentrations for PM_{10} lie in the range of 167-303 µg/m^3 and $PM_{2.5}$ in the range of 66-107 µg/m^3 respectively. **Table A.14** represents the 15-minute average concentrations of PM on selected road sections during the application of dust suppressant (20% v/v) and a sprinkling of water. The average, PM_{10} and $PM_{2.5}$ concentrations were measured to be 2491 µg/m^3 and 357 µg/m^3 respectively after application of dust suppressant on Day 1 after movement of approx. 32 cars, however, these values for water sprinkling were found to be 5251 µg/m^3 and 308 µg/m^3 respectively.

Table A.14: PM concentration reduction on the application of dust suppressants at CRRI

Day	15 min. Average PM Concentrations (µg/m^3)		Reduction (%)		Vehicle Movement	Average Vehicular Speed (km/h)
	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$		
Before Application of Dust Suppressant						
Day 0	12460	1725	--	--	80	27-32
After Application of Dust Suppressant						
Day 0	2491	357	80	79	80	27-32
Day 1	433	102	97	94	83	27-32
Day 2	214	78	98	95	91	27-32
Day 3	595	131	95	92	79	27-32

Reduction in PM_{10} and PM $_{2.5}$ concentration were found to be 80% and 79% respectively, when dust suppressant was applied on dusty roads. On a daily basis, 80-90 cars crossed both the road sections with a speed of 27-32 km/hr. The PM monitoring results indicate a sharp decrease in concentrations till the second day and increased on the third day of application of dust suppressant.

c. Pilot Study on a Road Corridor at Nitto Denko Campus

This section describes the application of dust suppressant on re-suspension of road dust at selected road corridors within and outside the Nitto Denko Pvt. Ltd. Campus. The experiments were carried out at two different road corridors, of which one was within the campus (Site A) and the second was the main road in front of the Nitto Denko campus (Site B). Both the roads were treated with dust suppressant; however, dust was spread only at Site A, inside the campus. The pilot study was conducted at two selected road corridors from 1-6 November 2018. The dust suppressant was spread at the rate of 0.45 L/m^2 at road section A. The concentration of dust suppressant was kept at 20 % v/v like in previous experiments.

The PM concentrations were monitored using GRIMM Aerosol Dust Monitor placed at a distance of 1 m from the selected road corridor. Background concentrations were measured daily at selected road sections when there was no vehicle movement.

The PM monitoring is carried out for seven days at Sites A and B under two different conditions i.e. without vehicle movement (Baseline Concentration) and with vehicle movement during the study period.

SITE A: Table A.15 describes the comparison in PM concentrations during vehicle movement with respect to baseline levels at Site A on the same day. The baseline PM concentration of PM_{10} (257 µg/m^3) was monitored less when compared with the concentration measured during vehicle movement: 467 µg/m^3). It is observed that the movement of vehicles generated PM due to the re-suspension of road dust.

Table A.15: Comparison in concentrations of baseline and during vehicle movement at Site A

Day	Conc. without Vehicle Movement (µg/m^3)	Conc. during Vehicle Movement (µg/m^3)	Change in Conc.	No. of Vehicle Rounds	Remarks
Before Application of Dust Suppressant					Intermittent movement of LCVs and trucks on test road Dusty and Windy Conditions Parking adjacent tothe test road Loading/ UnloadingArea in the vicinity
Day 0	257	467	81%	98	
After Application of Dust Suppressant					
Day 0	685	587	-14%	88	
Day 1	849	813	-4%	72	
Day 2	612	606	-1%	79	
Day 3	267	299	12%	87	
Day 4	160	131	-18%	84	
Day 5	253	279	10%	54	
Monitoring Time	5-10 min	35-40 min	--	35-40 min	

This indicates that the dust suppressant was effective for up to five days, and reduced the PM concentrations by 4-18%. However, its efficiency as a suppressant of dust was reduced after 4th day of its application. It was also observed that the high fluctuation in the baseline concentration affected the experimental results and suggested for more experimental study.

SITE B: Table A.16 describes the comparison in PM concentrations measured during vehicle movement with respect to the baseline level at Site B. The baseline PM concentration of PM_{10} (270 µg/m^3) was monitored less when compared with vehicle movement: 323 µg/m^3). It was observed that the movement of vehicles generate PM from the re-suspension of road dust.

Table A.16: Comparison in concentrations of baseline and during vehicle movement at Site B

Day	Conc. without Vehicle Movement (µg/m³)	Conc. during Vehicle Movement (µg/m³)	Change in Conc.	No. of Vehicle Rounds	Remarks
Before Application of Dust Suppressant					The test road was relatively a clean road Dust was majorly present at the edges Dominance of slow-moving vehicles
Day 0	270	323	20%	80	
After Application of Dust Suppressant					
Day 1	184	210	14%	79	
Day 2	375	325	-13%	76	
Day 3	144	150	4%	83	
Day 4	365	393	7%	76	
Day 5	236	217	-8%	84	
Monitoring Time	5 min	40 min	--	40 min	

It was also observed that the high fluctuation in the baseline concentration affected the experimental results.

A.5 Standard Operating Procedure for Application of Dust Suppressant

This section of the report presents application of dust suppressant on road for reduction of dust re-suspension. As discussed in section 3.0 above, it is essential to understand the road condition, source of dust on road and then selection of appropriate control options. The following sections of the report will discuss where and when to apply dust suppressants, as well as how and who will apply it along with its cost and monitoring with implementation.

1. **Selection of Road/ Status of road condition**: To assess the suitability of a road for dust suppression, it is crucial to understand its structure and sensitive areas of dust re-suspension. Avoid applying dust suppressant on wrecked or broken roads. Indian road structures, such as road edges, shoulders, and medians, are highly affected by turbulence from vehicle movement and natural wind forces. Therefore, it is suggested to use the dust suppressant along the road edge, median soil and any other open loose soil along the

road. On the paved road surface, it is suggested to first explore the option of stopping the dust generation at the road surface followed by lifting of dust from the road.

2. **Preparation of dust suppressant:** Mixing the chemical thoroughly with water and filtration is essential for removal of clogging particles to maintain homogeneity. Store the mixture in a cool place and choose appropriate nozzle for spraying the dust suppressant. Rate of application will be 0.5-1 L/m^2 depending upon the properties of dust holding capacity of suppressant.

3. **Method of application:** There are two possible ways of application of dust suppressant mentioned below:
   a) **Manual sprinkling:** Dust suppressant can be applied manually by carrying as back pack in bottles or on cart wheels using sprayer containers for addressing small localized dust re-suspension issues. The nozzle size should be appropriate to avoid the flooding situation/ overflow.
   b) **Sprinkling through Tanker:** This method can cover large areas quickly, ideal for highways and expressways with high dust re-suspension issues. Maintain optimal flow rate and discharge for homogeneity, and ensure sprayer nozzles have wider coverage. Check for nozzle choking and ensure consistency.

4. **Weather Conditions**: Dust suppressant application should be avoided during rainy days and flooded conditions. The best time for application is between March and before the monsoon season for warm weather locations. Frequency can be increased upto 4 days in winters, windy and in dry conditions. Implementing agencies should monitor Indian Metrological Department (IMD) weather forecasting data and avoid application if rain is expected. Due to heavy load of traffic during the day time, it is not feasible to apply during mid-day, so early morning hours will be suitable time for application of dust suppressant.

5. **Monitoring implementation:** Monitoring application rates is crucial for ensuring adequate coverage without product pooling or runoff. Dust suppressant should not exceed the minimum amount needed, and not applied during rain or forecasted rain. Improper application could lead to non-compliance or enforcement action. Concentration of dust suppressant in water solutions may vary, but the rate of application per unit area should remain consistent.

6. **Governance Model for Implementation**: There is a need to develop a governance model for implementation and sustainability of DSA for its application at larger scale. For example, Cow dung slurry is easily available in rural areas of Punjab, Haryana, and Uttar Pradesh, and can be obtained from gaushalas, dairies, or village panchayats. The application of cow dung slurry can help to stabilize the unpaved surface and support vegetation growth. It is eco-friendly, biodegradable, and does not cause secondary contamination. The application rate of the suppressant will depend on the specific product.

A.6. Cost Assessment of Dust Suppressant Application

The application of dust suppressant to suppress the re-suspension of road dust involves expenditure on manpower cost, water tanker cost and dust suppressant material cost. The manpower and water tanker costs are common for all types of dust suppressants whereas only dust suppressant material costs vary. The tentative cost for the application of cow dung slurry is estimated for an area of 20,000 sq. m. (i.e., a road length of 10 km with the spread of 1 m on the road edge on each side of the road. 10,000 m x 2 m = 20,000 m^2).

The Cow dung slurry requirement for 20,000 sq.m area of road stretch would be 10,000 litres (@ 0.5 L/m^2: 20,000 m^2 * 0.5 L/m^2 = 10000 Litres). The estimated cost for preparation and application of 10,000 litres cow dung slurry of a 10% w/v solution is given in Table below:

Sr. No.	Description	Cost (in Rs)
1.	Cow dung requirement for 10,000 litres of solution for 10% w/v will be 1000 Kg. Cost for 1 kg of cow dung will be ~Rs. 2 {Under scheme Godhan Nyay Yojana} Total Cost for Cow dung = 2*1000 = Rs. 2000	2000
2.	Requirement of water for 10000 ltr 10% w/v Slurry = 9000 ltr Cost of water tanker having capacity of 5000 Litres = 1080 by Delhi Schedule of Rates 2020 (CPWD) Total Cost for 2 tankers = Rs. 2160	2160
3.	Lump sum tentative cost for 10000 litres of spraying tanker. [As Per By [DELHI SCHEDULE OF RATES 2020 (CPWD)]	3000
4.	Manpower Cost for 2 Numbers (1 for operating spray nozzle and 1 helper for traffic management). Cost of one labour for per day (8 hrs) will be Rs.700	1400
Tentative Total Cost		**Rs. 8560 (~8600)**

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