Report on

Source Identification, Apportionment and Emission Inventory with respect to PM_{10} at Thoothukudi City, Tamil Nadu

Submitted to

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Submitted by

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

Particulate matter (PM_{10}) pollutant for Thoothukudi , non-attainment city in Tamil Nadu was studied. The study comprises of collection and compilation of secondary and primary data on PM_{10}, emission inventory, source apportionment study, and future projection and emission reduction targets related to Thoothukudi city. The assessment of PM_{10} was carried out existing three ambient air quality monitoring stations and five more new locations. The dust samples collected from commercial, industrial and highway were examined using SEM-EDX (Energy dispersive X-ray). The study results revealed that the level of PM_{10} concentration during this study at Thoothukudi city and from the past monitored data shows that it is mostly above the standard limit. The major findings of the study are

- Source apportionment study reveals that the main contribution of PM_{10} is from the mineral dust containing silica due to re-suspension of road dust
- The water-soluble organic matter and elemental carbon is present in all the stations indicate the other main source is combustion of fuel emissions from vehicles fuel and biomass

The following recommendations are suggested to control the particulate matter emission for Thoothukudi city.

- Vacuum cleaning of roads ,wall to wall paving of roads to control road dust
- For vehicular emission control, public transport should be increased with good transport management practises
- In highways and roads, tree plantation should be provided on both sides of the roads. Small herb plantations to be planted in the middle of the roads
- Use of biomass instead of high coal ash in power plant and similar industries. Open burning of agri.residues to be avoided and composting to be practiced
- Industrial emission to be monitored for the stringent compliance through continuous monitoring.

I INTRODUCTION

1. BACKGROUND

The air quality at Thoothukudi City has been monitored over years by Tamil Nadu Pollution Control Board (TNPCB). The main air pollutants such as NO_x, SO_2 and Particulate Matter (10 & 2.5-micron size) are being recorded. This city is recognized as one of the Industrial Hub of South India. The increasing economy and rapid increase of population of the urban areas increases the stress on environment. The life standards of all households have increased and as a result, the motorized vehicle either scooter or car access increased drastically. The air pollutants are also showing an increase.

Hence, it is the need of the hour to determine the policy to be adopted specific to this study which can be implemented by the Government at a comfortable pace without damaging the environment. This study comprises only on the PM_{10} air pollution according to the Hon'ble National Green Tribunal (NGT) order 2018 (no.681/2018), which stated that CPCB has identified Thoothukudi city as non-attainment city for pollutant PM_{10} parameter exceeding the prescribed annual norms. Hence the contribution of the various sources to PM_{10} so as to drawn an effective policy for a complete and sustainable growth of the country. This study will also aid in course of the transport sector so as to support the auto fuel policy by the government. Hence the contribution of the various sources to the pollution levels has to be determined so that sensitive sources of pollution can be determined and further necessary action can be taken.

In order to achieve this, a detailed analysis of the composition of the particulate matter such as elements, ions and carbon content has to be determined. Source apportionment study through receptor modelling can be achieved through Factor analysis. This result will helpful in validating the source-based emission inventory for the Thoothukudi city. Projection of the vehicular source through emission factor will help in determine the current and future projection of the air pollution from transport sector.

1.1 GENERAL DESCRIPTION OF THOOTHUKUDI CITY

1.1.1 CLIMATE:

Thoothukudi city possess a tropical climate situated in the Coastal area with the Gulf of Mannar on the eastern side about 125 km (78 mi). Hence the weather is usually hot and humid. The annual mean minimum and maximum temperature are 23°C and 29°C respectively. The major seasons are Winter (Jan-Feb), Summer (Mar-Apr-May), Southwest Monsoon (Jun-Jul-Aug-Sept) and Northeast Monsoon (Oct-Nov-Dec). Summer characterized by heavy humid with peaks at 39°C. The projected of maximum temperature over Thoothukudi for the periods 2010-2040 (2020s), 2040-2070 (2050s) and 2070- 2100 (2080s) with reference to the baseline (1970- 2000) indicate an increase of 1.0°C, 1.9°C and 2.8°C respectively.

The city receives rainfall primarily from Northeast Monsoon with more than 70% and the city is also categorized as very low rainfall regions. The average annual rainfall over the district varies from about 570 mm to 740 mm. The projected rainfall over Thoothukudi for the periods 2010- 2040 (2020s), 2040-2070 (2050s) and 2070-2100 (2080s) with reference to the baseline (1970-2000) indicate an increase of 2.0%, 8.0% and 10.0% respectively. This is due to its orographic nature as the precipitable clouds towards Thoothukudi regions is heavily immobilized by the Sri Lankan Land. It is also to be noted that the rainfall attributes to the inverse relation for the suspended air pollutants.

1.1.2. DEMOGRAPHIC INFORMATION

Thoothukudi is a Municipal Corporation and also a port and an industrial city in the Tuticorin (also known as Thoothukudi) District in the Indian State of Tamil Nadu. It is geographically located nearby the Gulf of Mannar, at a latitude of 8°48′N and a longitude of 78°11′E and about 4 m above the sea level. The city is covering an area of 353.07 km^2 and had a population of 237,830 in 2011. The urban agglomeration had a population of

410,760 as of 2011. Fig.1 shows the landuse land cover of Taluk of which Thoothukudi City covers and Fig. 2 shows the transport connectivity map.

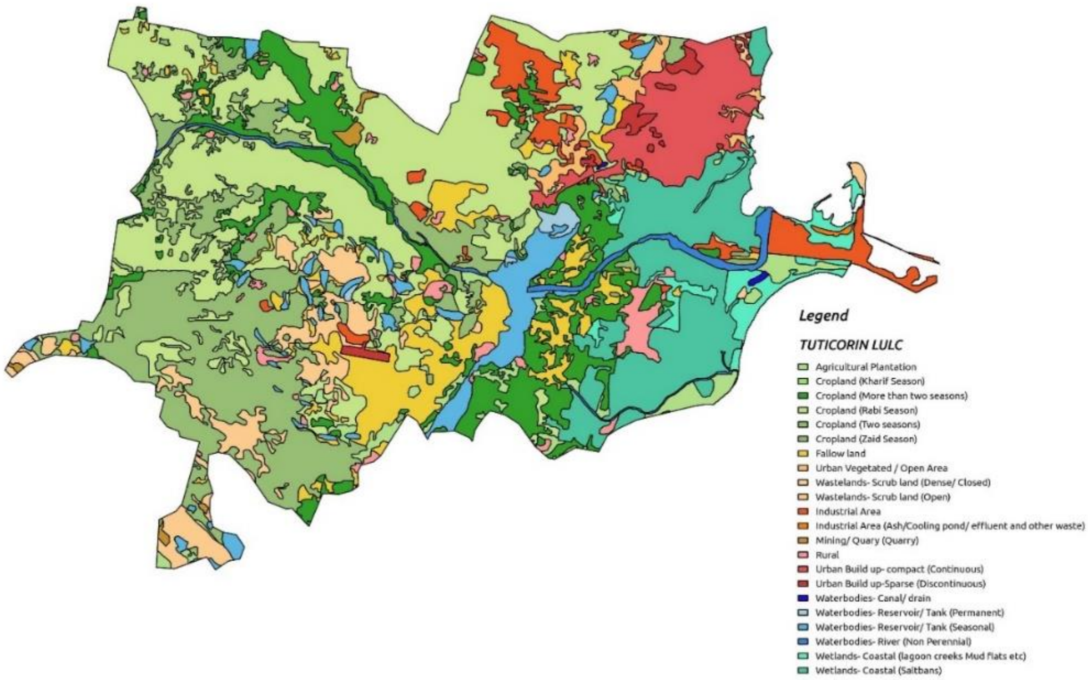


Figure 1 Thoothukudi City - Land use Landcover Map

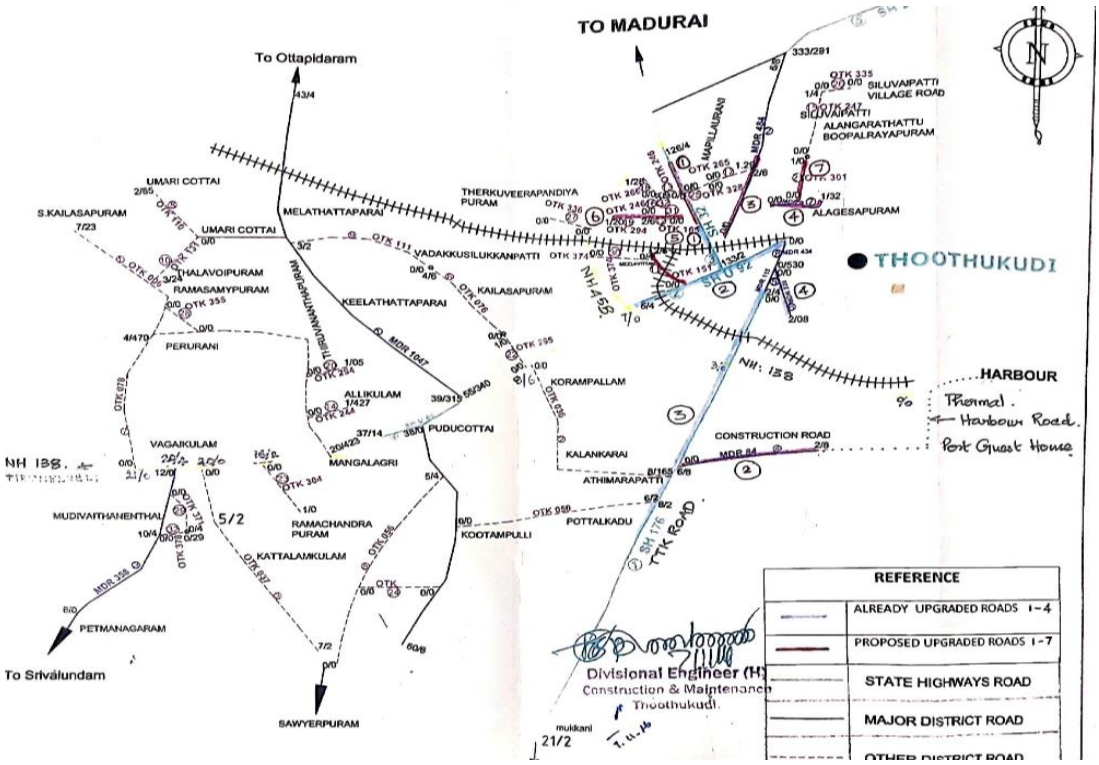


Figure 2 Thoothukudi City Map

1.3 MAJOR SOURCE OF AIR POLLUTION AT THOOTHUKUDI CITY

The different sources of air pollution at Thoothukudi City are classified under the following categories Transport, Industries, Domestic (Residential/Commercial) and other sources.

1.3.1 TRANSPORT

The major modes of transport namely Air, Sea, Road and Rail are significant at Thoothukudi. The city has one of the oldest railway station. The air quality from transport sector comprises from two factors Road Side Suspended Dust and Vehicle Fuel Combustion. Most of the railways are driven from electric engine and except for coal transport, it is not directly contributing to the air pollution in the city. Also, the rail network is not effective as compared to road. The city buses along with private buses are mostly used for common public transportation. Lorries/trucks are used for transporting goods in and around city.

1.3.1.1 ROAD DUST

Thoothukudi city is well connected by road. The Major Highways are, Thoothukudi – Madurai – Trichy – (NH 45-B), Thoothukudi – Palayankottai (NH 7-A). Thoothukudi – Palayakayal – Thiruchendur (State Highway) and Thoothukudi – Ramanathapuram - Chennai (ECR). The road transport majorly influences the air quality of Thoothukudi city mainly road dust.

1.3.1.2 VEHICULAR EMISSION

Large number of privately owned 2 wheelers and four wheelers are used majorly in the city. Lorries or trucks are used for transporting goods within the city. The total number registered vehicles as on 31.3.2018 in the Thoothukudi city with state transport authorities is 7,66.793 (Table 1).

Table 1 Vehicular details of Thoothukudi City

Details of vehicles	Total number
Number of Private Vehicles (Car/SUV/MUV)	59,350
Number of Private Vehicles (Two wheelers)	6,75,113
Number of Commercial Vehicles	26,661
Number of Auto rickshaws	5669
Total Number of vehicles registered at Thoothukudi as on 31.3.2018	7,66,793

1.3.2 INDUSTRIES

There are 940 Industries functioning in this district as shown in (Table 2). The small-scale industries accounts for large numbers (852 nos) when compare to large and medium scale industries. The high polluting industries contributes for 31%, primarily percentile contribution of medium polluting industries (52%) are higher.

Table 2 Industries Details of Thoothukudi

City	Large (in Nos)			Medium (in Nos)			Small (in Nos)		
	Red	Orange	Green	Red	Orange	Green	Red	Orange	Green
Thoothukudi	42	19	5	5	17	0	248	462	142
									Total - 940

1.3.3 DOMESTIC SOURCES

The rate of urbanization is increasing rapidly at Thoothukudi city. The residential population mainly relies on LPG and small-scale units (*viz.,* bakeries) on wood/coal (open burning) for cooking. Construction activities generates dust particles like sand, soil etc., also contributes for the air pollution.

1.3.4 OTHER SOURCES

The activities like open burning of municipal solid waste/ agricultural residues on road side is also source of air pollution in the city.

1.4 NEED FOR THE STUDY:

1.4.1 STATUS OF AIR QUALITY AT THOOTHUKUDI CITY

The major source of air pollution at Thoothukudi city is from road dust, vehicular emission, domestic fuel burning, open waste burning, construction activities, Industrial Emissions etc. Tamil Nadu Pollution Control Board (TNPCB) is regularly monitoring the air quality of the city through three manually operated Ambient air quality monitoring stations functioning under National Ambient Air Quality Monitoring (NAAQM) Project funded by Central Pollution Control Board (CPCB) under the Ministry of Environment, Forest and Climate Change (MoEF&CC), Govt. of India. One number of Continuous Ambient Air Quality Monitoring Station (CAAQM) is also functioning in Thoothukudi city.

The results of the monitoring stations indicated that particulate matter of 10-micron size (PM_{10}) as main source of air pollutant which is higher than the prescribed limit. Hence it is identified as one of the Non-attainment cities of PM_{10}. In this regard, CPCB has instructed the TNPCB to chart out the Action Plan for controlling Respirable Dust Matter (PM_{10}). In this connection, the TNPCB has requested the Centre for Climate Change and Adaptation Research (CCC&AR), Anna University to carry out the particulate matter source apportionment study. The study comprises of collection and compilation of secondary and primary data on particulate matter (PM_{10}), emission inventory, source apportionment study, future projection and interim emission reduction targets related to Thoothukudi city.

Expert team from CCC&AR, Anna University and TNPCB has visited the entire Thoothukudi city on March 16-17, 2019 for assessment of existing ambient air quality monitoring stations and to identify new locations for PM sampling. The air pollution due to Particulate Matter is caused due to the re-suspension of road dust, emission from vehicles, D.G.sets, construction activities, burning of domestic fossil fuels, open burning of solid wastes/ agricultural residues and transportation of construction materials such as sand, soil etc., without cover. At Thoothukudi city, the potential sources of PM_{10} are road dust, vehicular emission, Industries, open biomass burning especially in night time bakeries etc., as shown in the photographs given in the Annexure I.

1.5 OBJECTIVES AND SCOPE OF THE CURRENT STUDY

The Current Study involves

I. Emission Inventory estimation and determine the emission load of PM_{10} pollutants at sites such as residential, commercial and industrial
II. Future Projection of PM_{10} load yearly trend from Vehicular fuel combustion
III. Chemical Speciation of PM_{10} to determine the contents of elements, ions, carbon. Estimating the source contribution through Factor Analysis
IV. Formulation of Action Policy to control the air quality with respect to PM_{10}

2 METHODOLOGY

The study comprises of source identification, apportionment and inventory at Thoothukudi city. The methodology outline of the study is shown in the Fig.3 It includes identification of potential sources with receptors, collection of primary data and Secondary data.

Emission inventory carried out based on the secondary data collection with the PM_{10}. An emissions inventory is a database that lists, by source, the amount of air pollutants discharged into the atmosphere from the community for a given time period. For listing the sources of air pollution, sources classified as Point sources (industries, fuel terminal, etc.), Area sources (road construction, electric generators, fuels, etc.) and Line sources (on-road an off-road mobile source). The emission factor for seasonal and year load and the future projection of the inventories were identified based on the source trend.

The samples of PM_{10} were collected from existing and new locations as given in Table.3. The PM_{10} and $PM_{2.5}$ sampling was collected using high volume sampler through glass fiber filter and teflon filter paper, respectively. The sampling period of PM_{10} and $PM_{2.5}$ was taken for 24 hrs. The concentration of the PM_{10} and $PM_{2.5}$ were calculated based on the gravimetric analysis. The chemical analysis was carried out in the collected samples for Ions (such as Cl^-, NO_3^-, SO_4^{2-} Na^+, NH_4^+, K^+, Ca^{2+} and Mg^{2+}) using ion chromatography after extraction with water under sonication for 4 hrs and Elements/ Heavy metals by using ICP-OES after extraction with Nitric acid under sonication for 4 hrs. The dust samples collected from commercial, industrial and highway were examined using ED-XRF (Energy dispersive X-ray).

The receptor modelling based on the chemical speciation results and major sources of PM_{10} were identified. The receptor Modelling carried out by Factor analysis (R Programming) for quality and quantification of major sources respectively. Factor Analysis is a statistical approach which allows us to determine the important factors which can explain the variations in the experimental data set. Thus, the variations in a large set of data is explained using a small set of factors. The factors are allowed to qualitatively determine the sources contributing to a particular site. Based on the analysis, a detailed Control Strategy of PM_{10} are recommended related to Thoothukudi city.

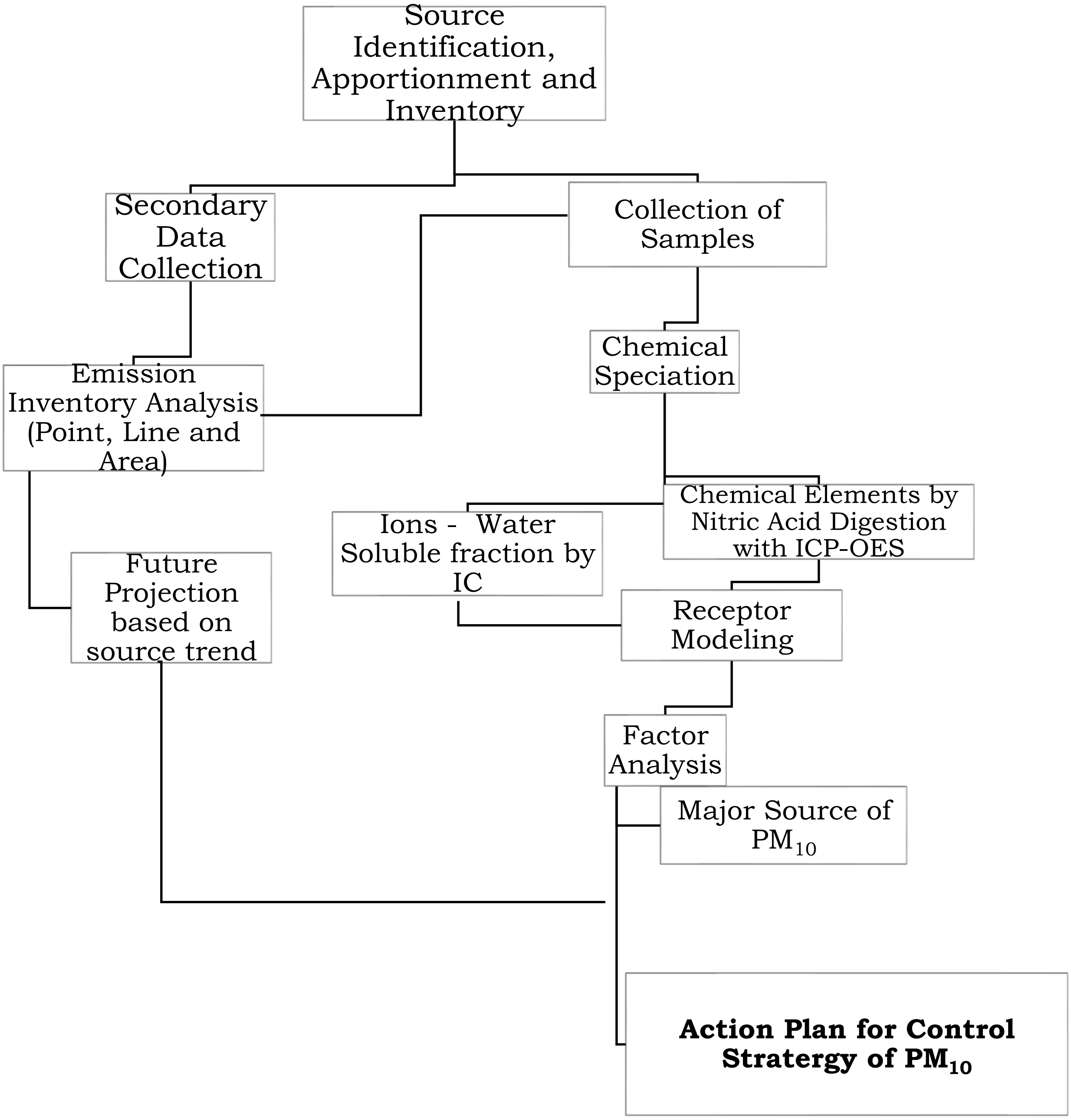


Figure 3 Methodology Outline

At Thoothukudi city, the ambient air quality monitoring stations were conducted in three existing sites. Additional sites were required to monitor the air quality of the city as a quality test of the existing locations. The details of the selected air quality monitoring stations for the study are explained as follows which was done for 2 days (48 hrs) during March 29th – 31st 2019.

2.1 MONITORING SITES

The details of the selected eight air quality monitoring stations for sampling at Thoothukudi city is depicted in Fig 4 and given in Table.3 and and photographs of sites shown in Annexure-II. The PM_{10} was monitored at eight locations residential (3), industrial (3), and residential/commercial (2) locations. The details of the selected monitoring locations, their air quality measurement and analysis are presented in the following section.

Figure 4 Sampling Locations during the study period

Table 3 Description of sampling location

S. No	Sampling Location	Description of the site (Land use type)	long	lat
1	SIPCOT-239	Industrial	78.085264	8.806477
2	AVM Jewelry-366	Residential cum Commercial	79.153330	8.804727
3	RAJA AGENCY-240	Industrial cum Highway (Harbour bypass)	78.151820	8.759323
4	Thermal Nagar CAMP 1 - N_240	Industrial cum Highway (Harbour bypass)	78.147134	8.757899
5	WGC Road - N_366	Commercial	78.150897	8.804878
6	Celseeni Colony - N1	Residential	78.135645	8.782529
7	Raju Nagar - N2	Residential	78.117078	8.796559
8	Meelavittan - N3	Residential	78.103780	8.815701
9	Meelavittan - CAAQM	Residential (Near to SIPCOT)	78.099096	8.816554

2.2 DESCRIPTION OF LOCATIONS

The description of the sites in the present study is described as follows.

2.2.1 TNPCB OFFICE, SIPCOT COMPLEX (INDUSTRIAL AREA)

This monitoring station covers Air Pollution from industries located in and around SIPCOT complex, South East of M/s.Vedanta Limited, Copper Smelter unit and M/s.V.V. Titanium Pigments (P) Ltd.,.

2.2.2. AVM JEWELRY BUILDING (COMMERCIAL AREA)

Station is located in North Cotton road, adjoining West Cotton road, which is main road of Thoothukudi City. This station covers commercial activities, which includes residential area. This monitoring station is functioning two days in a week. This monitoring station is nearer to seashore area (500M from sea) and railway station is also very near.

2.2.3 RAJA AGENCY BUILDING (HIGHWAY ROAD AREA)

Located in Harbour Express Highway Road leading to Thoothukudi Port Trust. Thoothukudi Thermal Power Plant is located 1KM East side of this station. This monitoring station covers air pollution from Thoothukudi Thermal Power Plant and Transport activities in the Harbour Road. This Monitoring Station is functioning two days in a week

2.2.4 THERMAL NAGAR CAMP

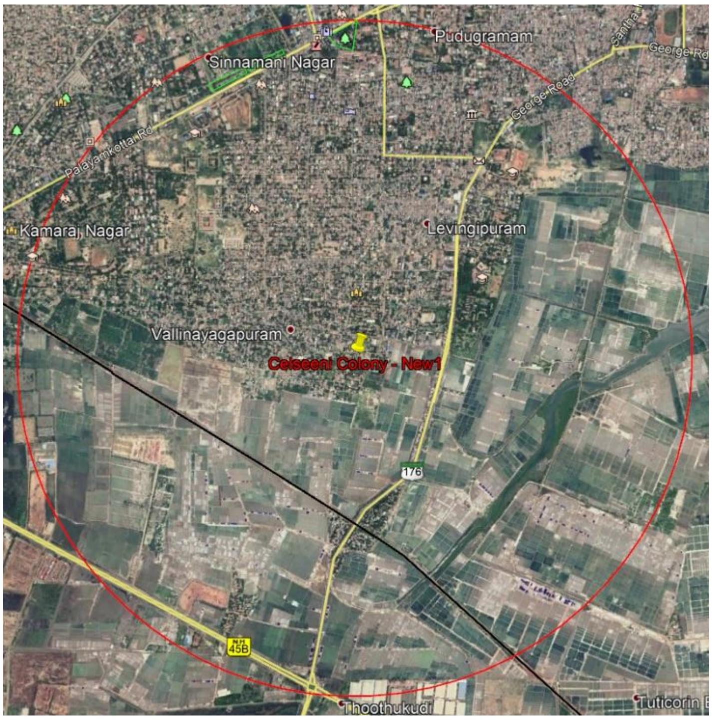
The sampling location 4 at Thermal Nagar CAMP 1 - N_240 is an industrial and highway zone in harbour bypass road. It is located inside the Thermal Colony at the Auditorium in VOC Road (Annexure II). This location has been chosen for the existing monitoring sites in addition to Raja Agency Building

2.2.5 WGC ROAD - N_366

The sampling location 5 at WGC Road - N_366 is a commercial zone in West great cotton road. It is located near to the BSNL office and opposite to Thangamayil Jewellery at Thoothukudi HO (Annexure II). This location identified as additional location of AVM Jewellery Building, commercial & Residential area

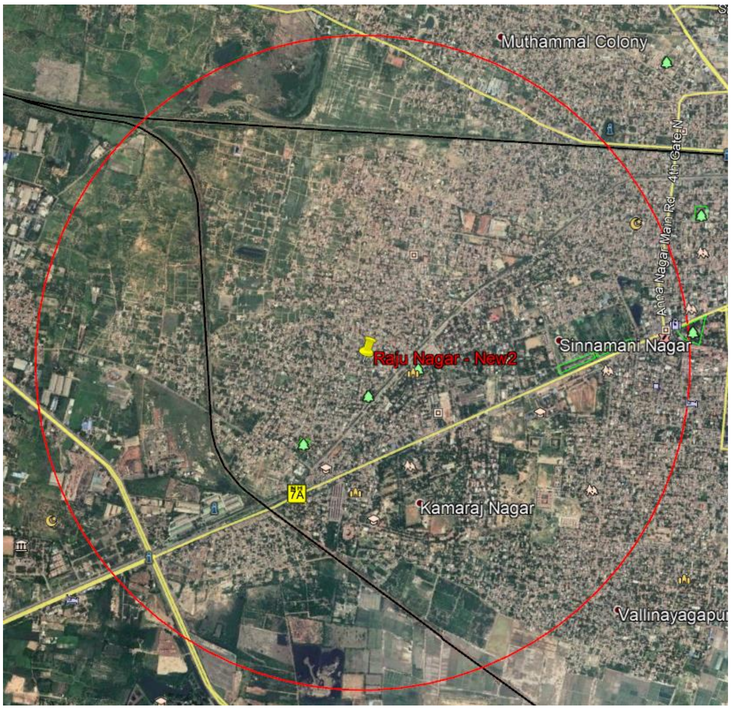
2.2.6 CELSEENI COLONY

The sampling location 6 at Celseeni Colony - N1 is a residential zone in Celseeni colony. It is located at residential area; hence less activity is observed. The movement of vehicles are lower when compared to the other sites (Annexure II). The roads are sandy and properly closed and shows calm activity.



2.2.7 RAJU NAGAR - N2

The sampling location 7 at Raju Nagar - N2 is a residential zone in Raju nagar. It is located at residential area near to the salt pans in Raju Nagar. Movement of vehicles are very less and low activity is observed (Annexure II).



2.2.8 MEELAVITTAN - N3

The sampling location 8 at Meelavittan - N3 is a residential zone. It is located near the SIPCOT area (Annexure II).

2.2.9 CAAQM

This Continuous Monitoring Site is located in Meelavittan Village which is a residential zone. It is located near the meelavittan railway station (Annexure II).

3.MONITORING RESULTS OF PM_{10}

The results of the air quality data for PM_{10} monitored at all locations for two days during 29.03.2019 to 31.03.2019 are given in Table.4 & Fig.5.

Table 4 PM_{10} values at Thoothukudi city

S. No	Station Code	Date of Sampling	Station Type	PM_{10} (µg/m³)
1	SIPCOT-239	3/29/2019	Industrial	174
		3/30/2019		141
2	AVM Jewelry-366	3/29/2019	Residential cum Commercial	110
		3/30/2019		152
3	RAJA AGENCY-240	3/29/2019	Industrial cum Highway (Harbour bypass)	126
		3/30/2019		116
4	Thermal Nagar CAMP 1 - N_240	3/29/2019	Industrial cum Highway (Harbour bypass)	132
		3/30/2019		112
5	WGC Road - N_366	3/29/2019	Commercial	73
		3/30/2019		84
6	Celseeni Colony - N1	3/29/2019	Residential	61
		3/30/2019		40
7	Raju Nagar - N2	3/29/2019	Residential	101
8	Meelavittan - N3	3/30/2019	Residential	100
Standard Values for 24 hours average				**100**

The results reveal that the 24 h value for PM_{10} for eight monitoring location were in range of 40 to 174 µg/m³. It is exceeding the standard limits of 100 µg/m³ in all the sites except the residential/commercial area (Celseeni colony and WGC Road-N-366). The PM_{10} annual average limit of 60 µg/m³ are exceeding in all sites except the residential area of Celseeni colony. The higher

PM_{10} values was observed at SIPCOT, AVM Jewellery, Raja Agencies and Thermal Nagar which is mainly due to the road dust, vehicular emission and industrial emission.

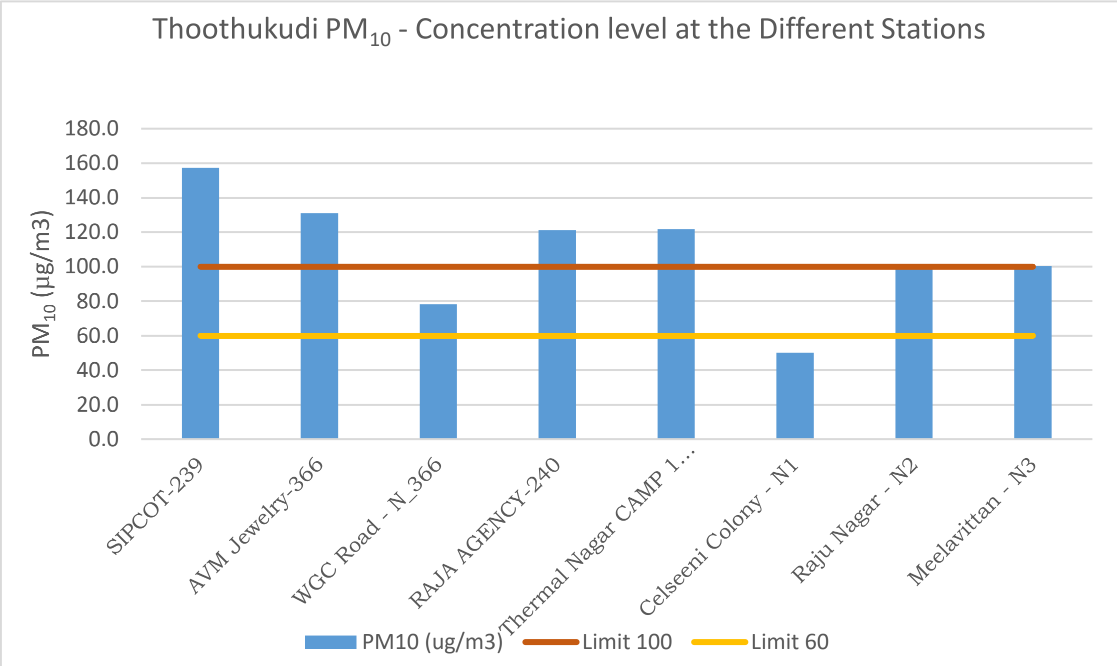
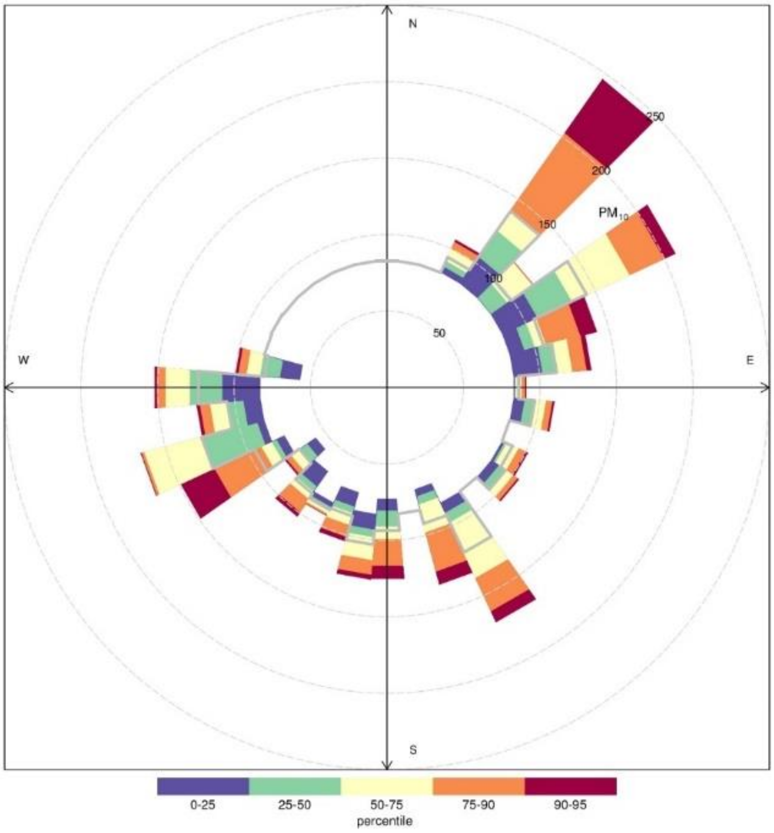


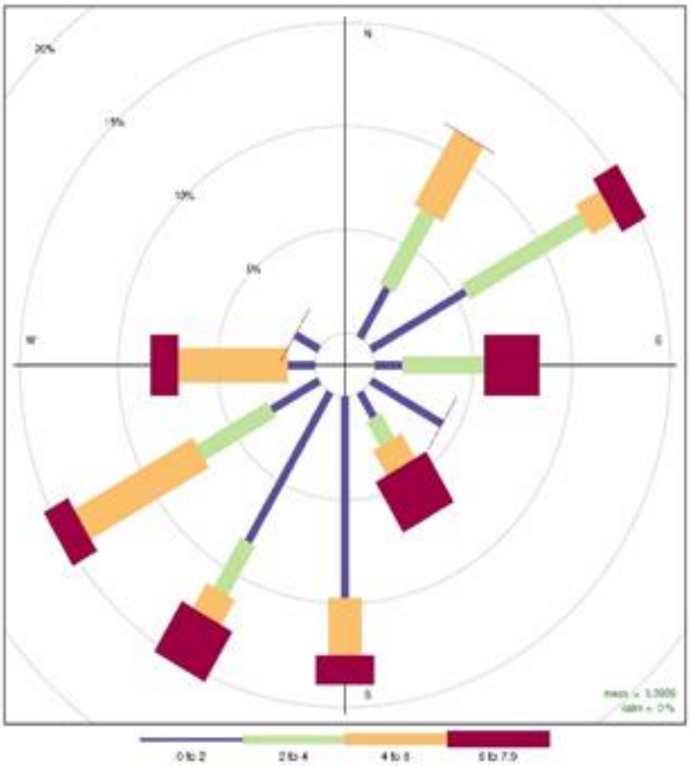
Figure 5 PM_{10} concentration at different sites

3.1 PM_{10} CONCENTRATION WITH RESPECT TO WIND SPEED AND WIND DIRECTION

The wind pattern analysed during the sampling period (29.03.2019 to 31.03.2019) shows the percentile-based wind speed with respective to PM_{10} concentration. The wind direction during night time and early morning shows southwest to Northeast direction and during day time wind pattern is changed to from northeast to southwest (Fig.6.a).



a) Wind speed with respective to PM_{10}



b) Windrose plot

Figure 6 Wind pattern analysis and PM_{10}

The same has been observed in south east wind pattern with less concentration. The wind speed is higher in south west direction and night time shows a low wind speed in North east (Fig.6 b).

3.2 SPATIAL DISTRIBUTION OF PM_{10} CONCENTRATION AT THOOTHUKUDI CITY

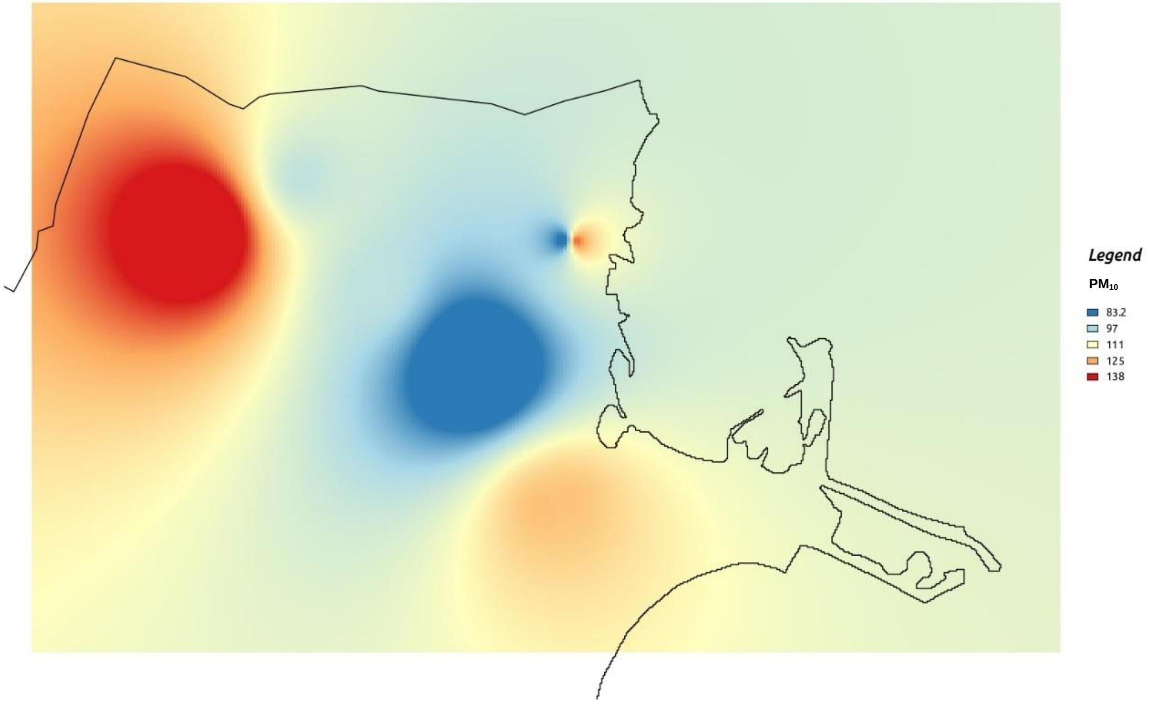


Figure 7 Thoothukudi PM_{10} Spatial distribution

The spatial distribution shows the values of PM_{10} at Thoothukudi city observed based on nine sites (including CAAQM) (Fig.7). The residential and commercial areas show lower PM_{10} values (83 – 97 µg/m^3). The salt pan, highway areas and thermal power plants showed a medium value (111 -125 µg/m^3). The industrial area indicated a higher value of PM_{10} (138 µg/m^3).

The hourly PM_{10} concentration from the continuous monitoring station during the study is shown in Figure.8. The hourly variation was taken, with this plot indicates that PM_{10} concentration was higher at 8.pm. The weekly, PM_{10} concentration is higher on Friday than Saturday and Sunday. The concentration of PM_{10} is above 100 µg/m^3 on Friday, Saturday and Sunday.

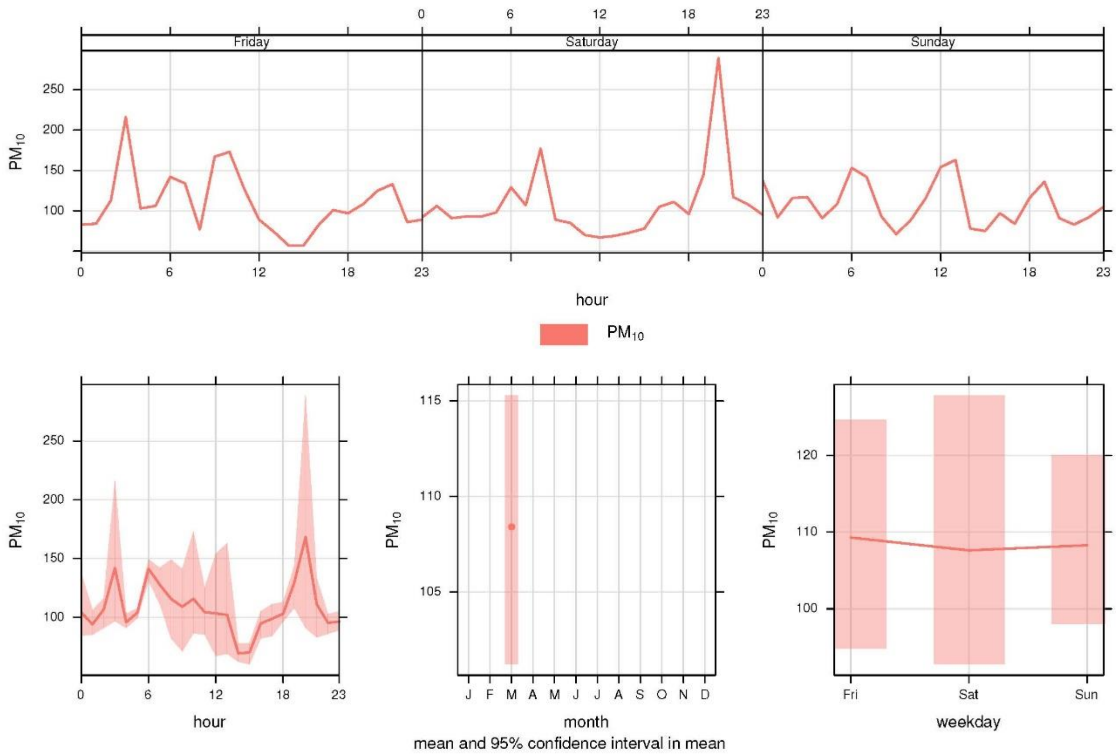


Figure 8 Time variation of PM_{10} at CAAQM Station

The observed yearly average of PM_{10} value for three monitoring station under NAMP at Thoothukudi City for the period 2011-2018 is presented in Table.5. The annual average limit for PM_{10} of 60 µg/m^3 is exceeding mostly in all the monitoring stations (Fig.9). The concentration of the PM_{10} pertains to annual average for the period 2011-18 at SIPCOT, AVM and Raja Agencies values varied from 74-162, 53-124 and 102-240 µg/m^3 respectively.

Table 5 Annual average of PM_{10} values at Thoothukudi city

Year	Raja Agencies	AVM Buildings	SIPCOT
2011	178	53	88
2012	132	81	112
2013	115	92	100
2014	102	67	74
2015	105	67	84
2016	190	91	118
2017	240	124	162
2018	109	93	92
All the values are in µg/m³			

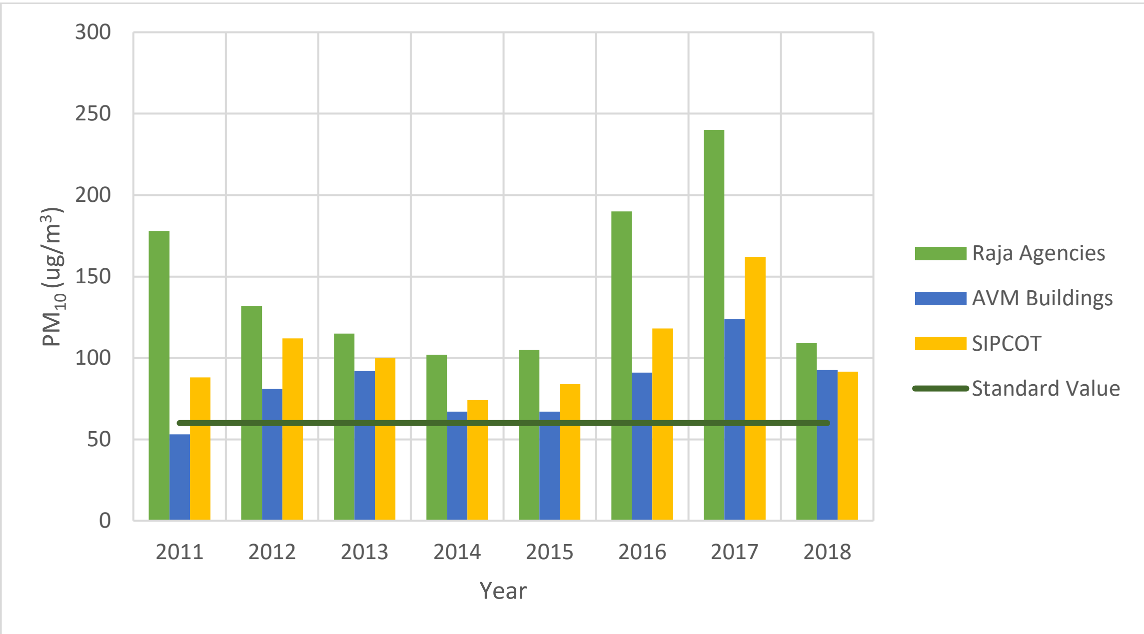


Figure 9 Observed yearly average of PM_{10} values at Thoothukudi AAQM Stations

The observed monthly average of PM_{10} Value for three monitoring station under NAMP at Thoothukudi City for the period Apr 2017- Feb 2019 is shown in the Fig 10. The secondary data collected also reveals the PM_{10} annual average value exceeded permissible limit of 60 µg/m^3.

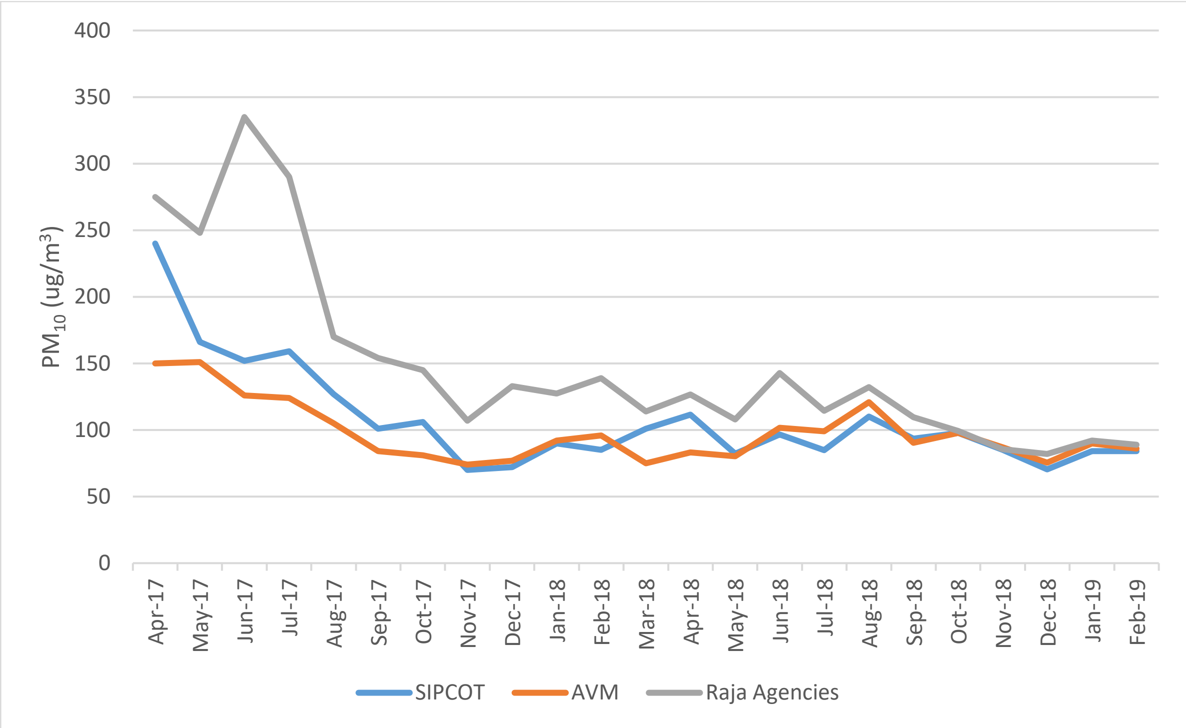


Figure 10 Monthly observed average PM_{10} Concentration at Thoothukudi AAQM Stations

The wind rose diagram depicted in Fig 11 indicates the predominant wind direction is from northwest to southeast with the average wind velocity of 3.8 m/s for the year 2018.

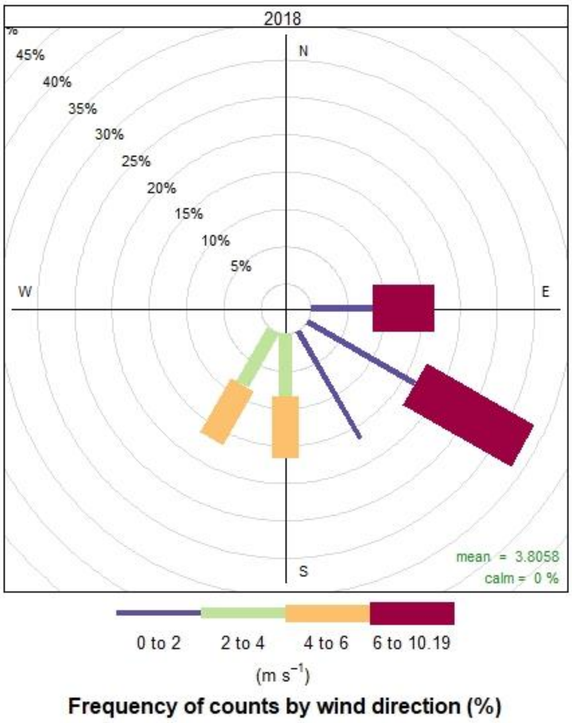


Figure 11 Wind rose Plot for the year 2018

The categorization of PM_{10} based on its value as per National clean Air programme is furnished in Table 6.

Table 6 Categories of PM_{10} Concentration

Category	Description
Severe + or Emergency	Ambient PM_{10} concentration values of 500 µg/m3 respectively persist for 48 hours or more
Severe	Ambient PM_{10} concentration value is between 430 µg/m3 respectively
Very Poor	Ambient PM_{10} concentration value is between 351- 430 µg/m^3
Moderate to poor	Ambient PM_{10} concentration value is between 101- 350 µg/m^3

Based on the observed PM_{10} concentration (Fig 10), the Thoothukudi city falls under severe (Raja Agencies), very poor (SIPCOT and Raja Agencies) and moderate to poor (all three stations).

3.3 $PM_{2.5}$ VALUES AT DIFFERENT MONITORING STATION

During the present study, $PM_{2.5}$ value was also monitored at five locations. $PM_{2.5}$ values were in the range of 4 to 46 µg/m^3. The higher $PM_{2.5}$ values were observed in AVM Jewellery, Raja Agencies and Thermal Nagar which is mainly due to the road dust and vehicular emission from the highways (Fig.12). Similar to the PM_{10} trend, the $PM_{2.5}$ trend is lower in residential/ commercial area (WGC Road). However, $PM_{2.5}$ values were within the standard limit (60 µg/m^3) in all location during 24 h period.

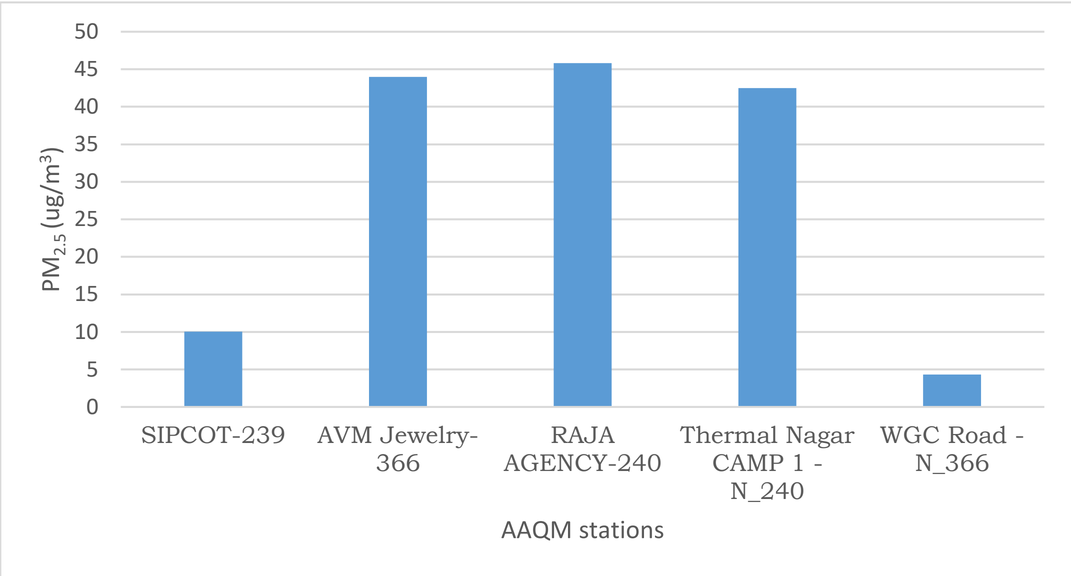


Figure 12 $PM_{2.5}$ concentration at Thoothukudi city

4. CHARACTERIZATION OF DUST SAMPLE

The dust samples collected were analysed using Ion Chromatograph after water extraction for soluble cations and anions (Table 7 & 8). Similarly, the dust sample were also extracted with nitric acid for elemental and heavy metals using ICP-OES (Table.9).

The sulphate, sodium, chloride, calcium, nitrate and potassium were the major ions present as water soluble compounds in PM_{10} dust samples. Other anions like phosphate, nitrite and cations like ammonia were below the detection limits. In anions, the concentration of sulphate ion was higher than those of nitrate and chloride. A maximum concentration of sulphate (20.3 $\mu g/m^3$) was observed.

Nitrate is present in all the samples. It was higher in the monitored locations near highways (SIPCOT-239; Thermal Nagar CAMP 1- N_240) and commercial area (AVM Jewellery-366), where the movements of vehicular are more. The nitrate sources include on-road gasoline-powered vehicles, diesel engines, natural gas and coal combustion. In cations, the concentration of sodium is higher than the potassium and calcium. The sodium concentration is maximum in the Celseeni Colony - N1 (residential area near to the salt pans) than other samples. The contribution of higher concentrations of sodium might be due to salt pans in the Celseeni colony. The presence of calcium and magnesium shows the emission from the alkaline source like cement. Potassium is present in all the samples authenticates the burning of biomass content contributing to the dust.

Table 7 Concentration of anions in the dust samples

S.No	Sampling Location	Description of the site (Land use type)	Total PM_{10} (µg/m^3)	Fluoride (F^-) (µg/m^3)	Chloride (Cl^-) (µg/m^3)	Sulphate (SO_4^{2-}) (µg/m^3)	Nitrate (NO_3^-) (µg/m^3)
1	SIPCOT-239	Industrial	174	0.56	13.68	20.32	2.95
2	AVM Jewelry-366	Residential cum Commercial	110	0.14	5.03	12.3	2.5
3	Raja Agency - 240	Industrial cum Highway (Harbour bypass)	126	0.21	5.55	6.20	1.01
4	Thermal Nagar CAMP 1 - N_240	Industrial cum Highway (Harbour bypass)	132	0.43	7.39	12.53	2.23
5	WGC Road - N_366	Commercial	93	0.32	7.53	14.11	0.08
6	Celseeni Colony - N1	Residential	89	0.37	5.24	16.12	0.63
7	Raju Nagar - N2	Residential	101	0.58	7.14	19.44	1.78
8	Meelavittan - N3	Residential	100	0.59	7.44	20.04	0.42

Table 8 Concentration of cations in the dust samples

S.No	Sampling Location	Description of the site (Land use type)	Total PM_{10} (µg/m³)	Sodium (Na^+) (µg/m³)	Potassium (K^+) (µg/m³)	Magnesium (Mg^{2+}) (µg/m³)	Calcium (Ca^{2+}) (µg/m³)
1	SIPCOT-239	Industrial	174	24.39	8.07	0.66	9.34
2	AVM Jewelry-366	Residential cum Commercial	110	20.76	2.58	0.33	3.35
3	Raja Agency-240	Industrial cum Highway (Harbour bypass)	126	21.52	2.88	0.27	3.78
4	Thermal Nagar CAMP 1 - N_240	Industrial cum Highway (Harbour bypass)	132	26.03	2.80	0.34	2.65
5	WGC Road - N_366	Commercial	93	29.34	6.96	0.73	4.01
6	Celseeni Colony - N1	Residential	89	24.46	3.16	0.39	2.46
7	Raju Nagar - N2	Residential	101	24.72	3.54	0.53	3.79
8	Meelavittan - N3	Residential	100	28.78	3.72	0.62	3.43

Table 9 Concentration of metals in the dust samples

S. No.	Sampling Location	Description of the site (Land use type)	Total PM_{10} (µg/m³)	Sodium (Na) µg/m³	Calcium (Ca) µg/m³	Magnesium (Mg) µg/m³	Iron (Fe) µg/m³	Copper (Cu) µg/m³	Zinc (Zn) µg/m³	Lead (Pb) µg/m³	Cadmium (Cd) µg/m³	Chromium (Cr) µg/m³
1	SIPCOT-239	Industrial	174	25.29	15.84	2.40	1.90	0.08	0.83	0.02	BDL	0.006
2	AVM Jewelry-366	Residential cum Commercial	110	25.67	8.76	2.12	0.74	0.03	0.27	0.01	0.005	0.004
3	RAJA AGENCY-240	Industrial cum Highway (Harbour bypass)	126	24.85	9.21	2.23	1.03	0.05	0.25	0.01	BDL	0.004
4	Thermal Nagar CAMP 1 - N_240	Industrial cum Highway (Harbour bypass)	132	29.24	10.59	2.50	1.20	0.15	0.27	0.06	BDL	0.009
5	WGC Road - N_366	Commercial	93	27.42	7.82	2.19	0.71	0.07	0.18	0.01	BDL	0.008
6	Celseeni Colony - N1	Residential	89	22.02	5.47	1.71	0.49	0.03	0.05	0.06	BDL	0.005
7	Raju Nagar - N2	Residential	101	24.55	9.75	2.02	0.94	0.16	0.29	0.07	BDL	0.006
8	Meelavittan - N3	Residential	100	28.64	9.16	2.33	0.75	0.11	0.23	0.04	BDL	0.006

* BDL-Below detectable limit

The metals analysed using ICP reveals in all the dust samples arsenic level was below the detectable limits.

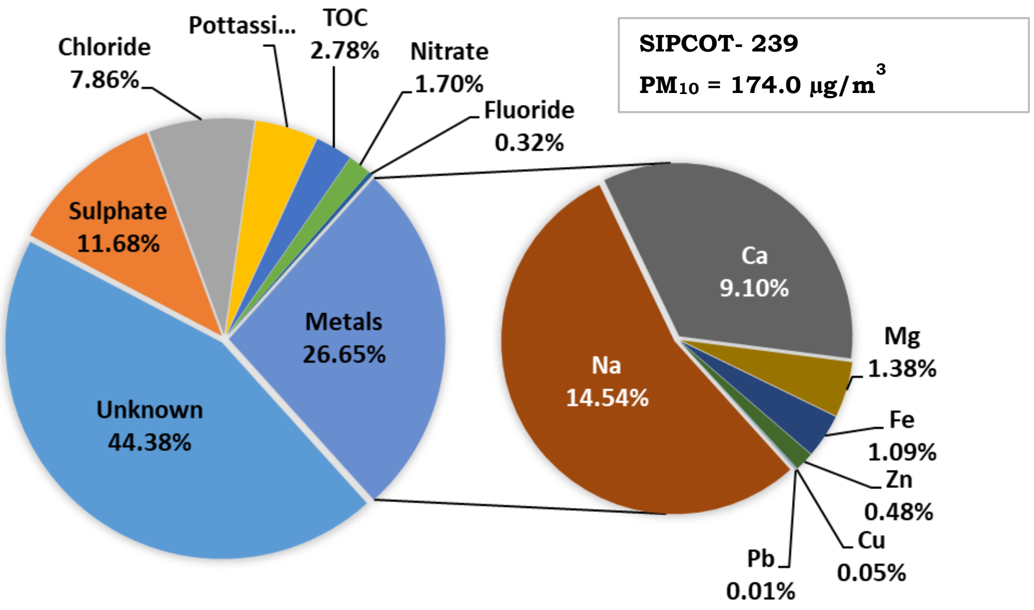
Acid and water-soluble sodium values were closer indicating all sodium compound present as a water-soluble form. Calcium was very low in the water soluble compared to acid soluble portion, which indicates that it is a sparingly water-soluble compound like calcium oxide.

The concentration of water-soluble organic portion – Total Organic Carbon (TOC) is given in Table. 10. It shows that the dissolved organic Carbon present in all the samples which indicates the PM_{10} dust source from the vehicular emission and burning of fuels. Meelavittan shows the higher TOC content than the SIPCOT industries may be due to wind dispersion. In all the samples, the pH values were in alkaline range indicating the dust samples are composed of alkaline materials like calcium and magnesium oxides.

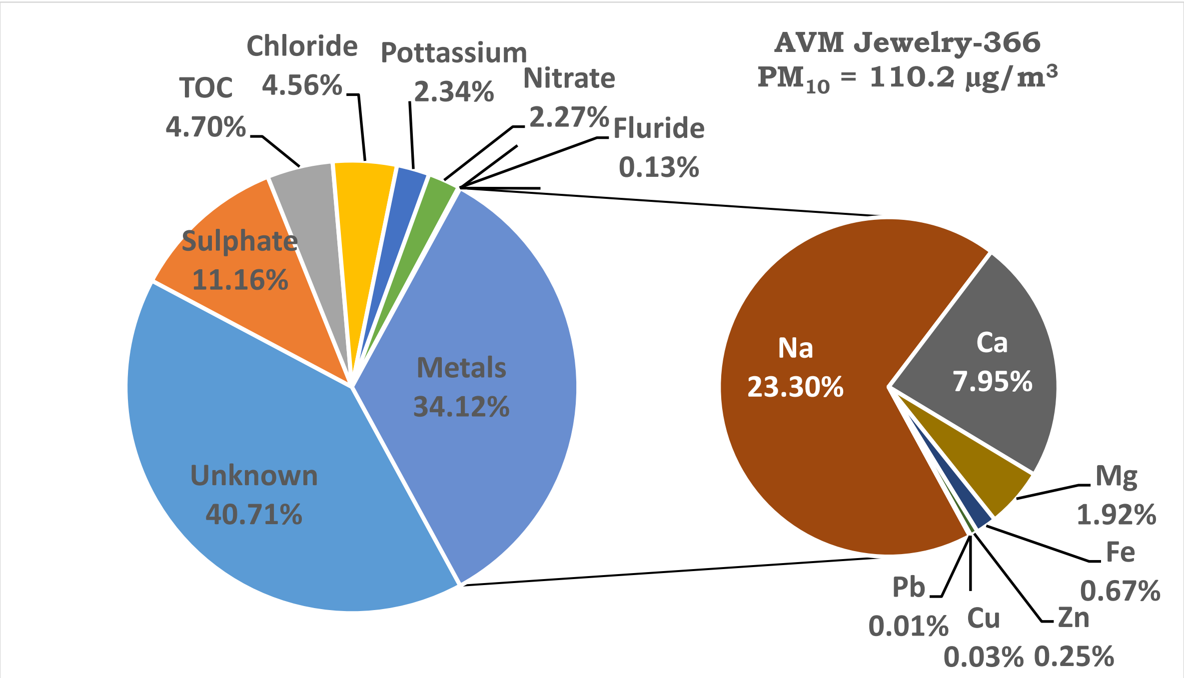
Table 10 Concentration of TOC

S.No.	Sampling Location	Description of the site (Land use type)	Dissolved TOC (µg/m³)	pH	EC (µS/cm)
1	SIPCOT-239	Industrial	4.84	7.53	984
2	AVM Jewelry-366	Residential cum Commercial	5.18	8.30	713
3	RAJA AGENCY-240	Industrial cum Highway (Harbour bypass)	4.68	8.85	588
4	Thermal Nagar CAMP 1 - N_240	Industrial cum Highway (Harbour bypass)	6.07	8.21	802
5	WGC Road - N_366	Commercial	3.84	9.20	709
6	Celseeni Colony - N1	Residential	6.85	8.77	859
7	Raju Nagar - N2	Residential	6.43	8.60	825
8	Meelavittan - N3	Residential	7.04	8.68	886

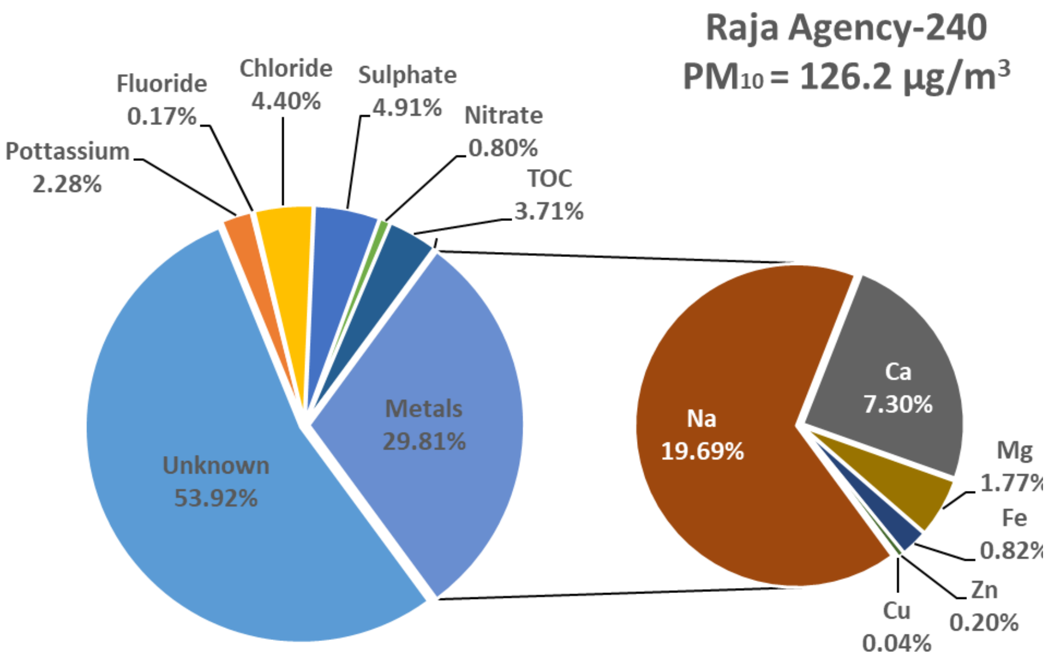
Figure. 13 shows the overall speciation of metals and ions present in all the eight sites in percentile portion.



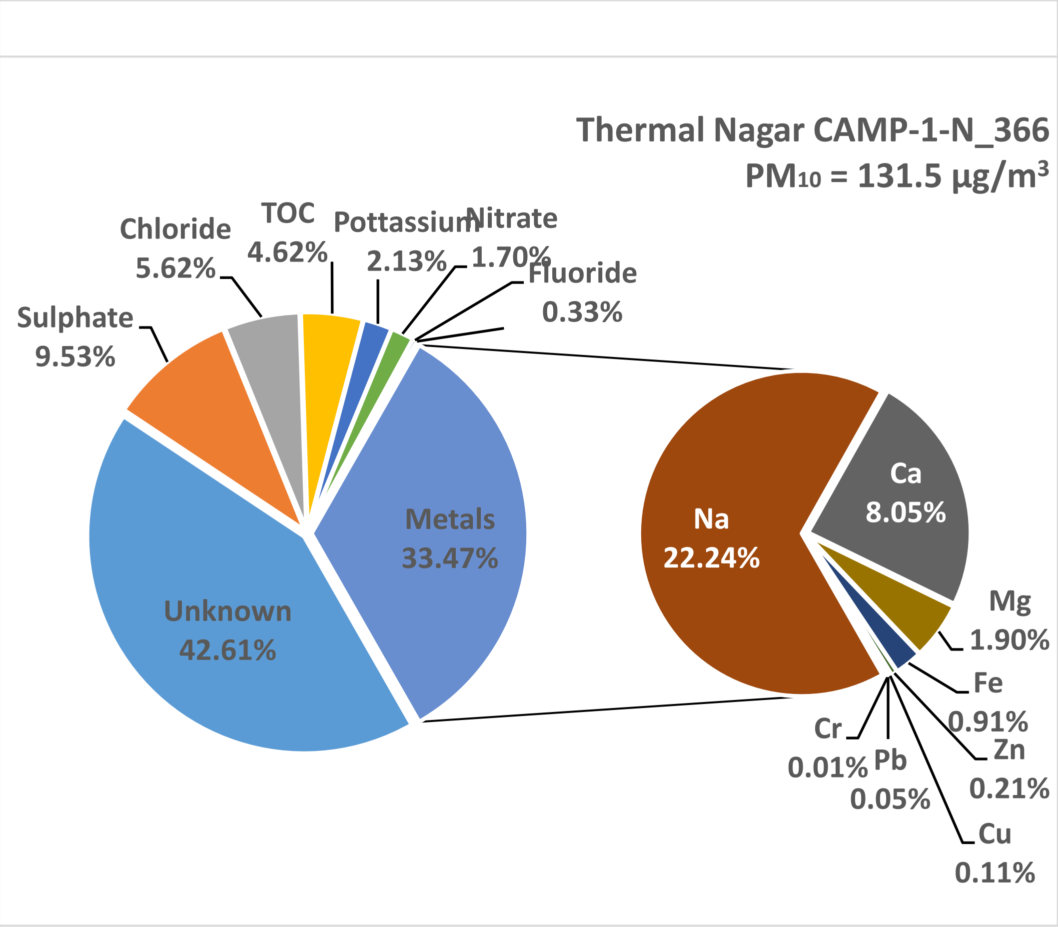
a) SIPCOT (Industrial)



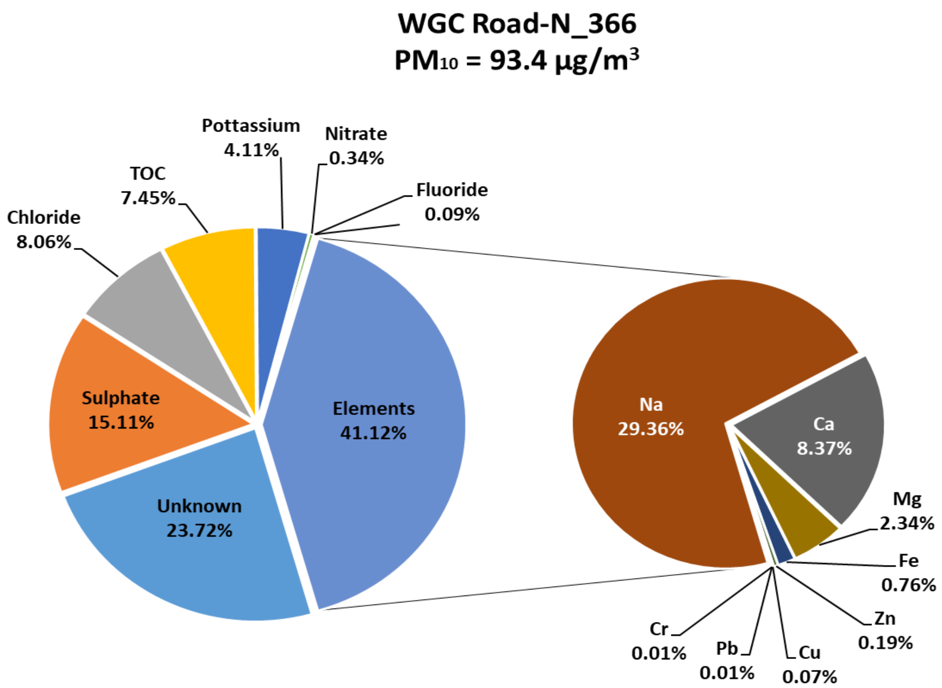
b) AVM Industrial (Residential/Commercial)



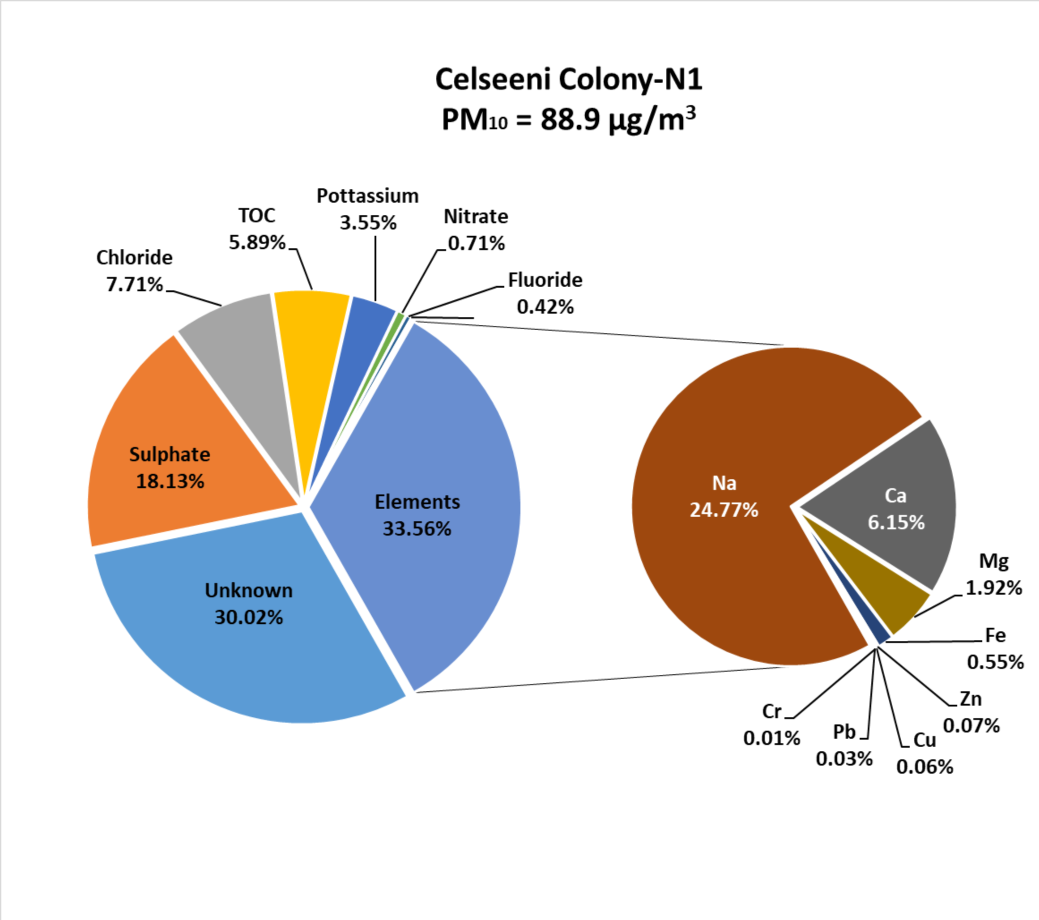
c) **Raja Agency (Industrial/ Highway)**



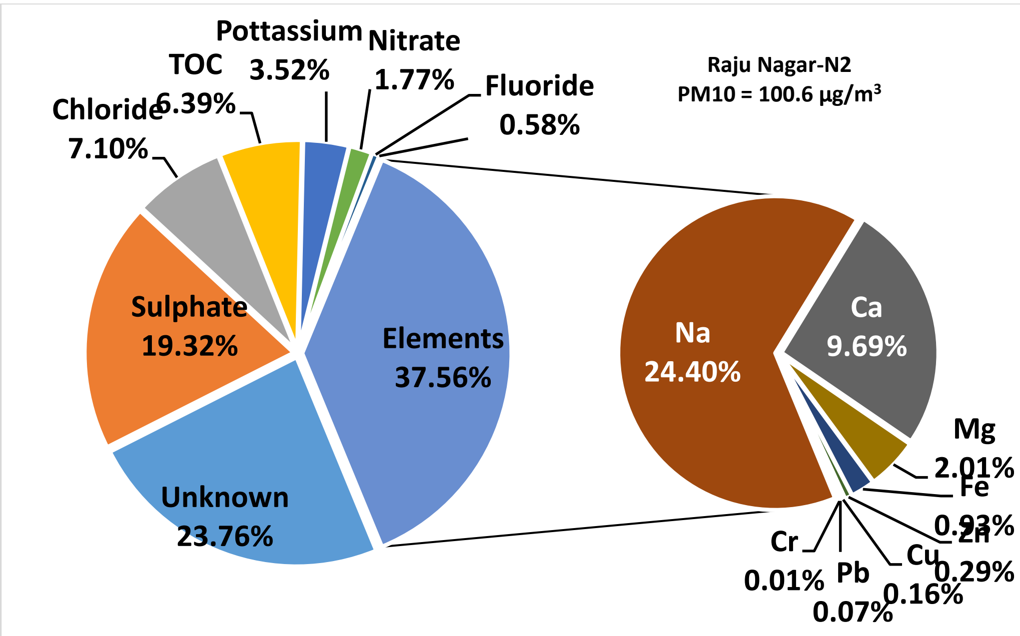
d) **Thermal Nagar (Industrial/ Highway)**



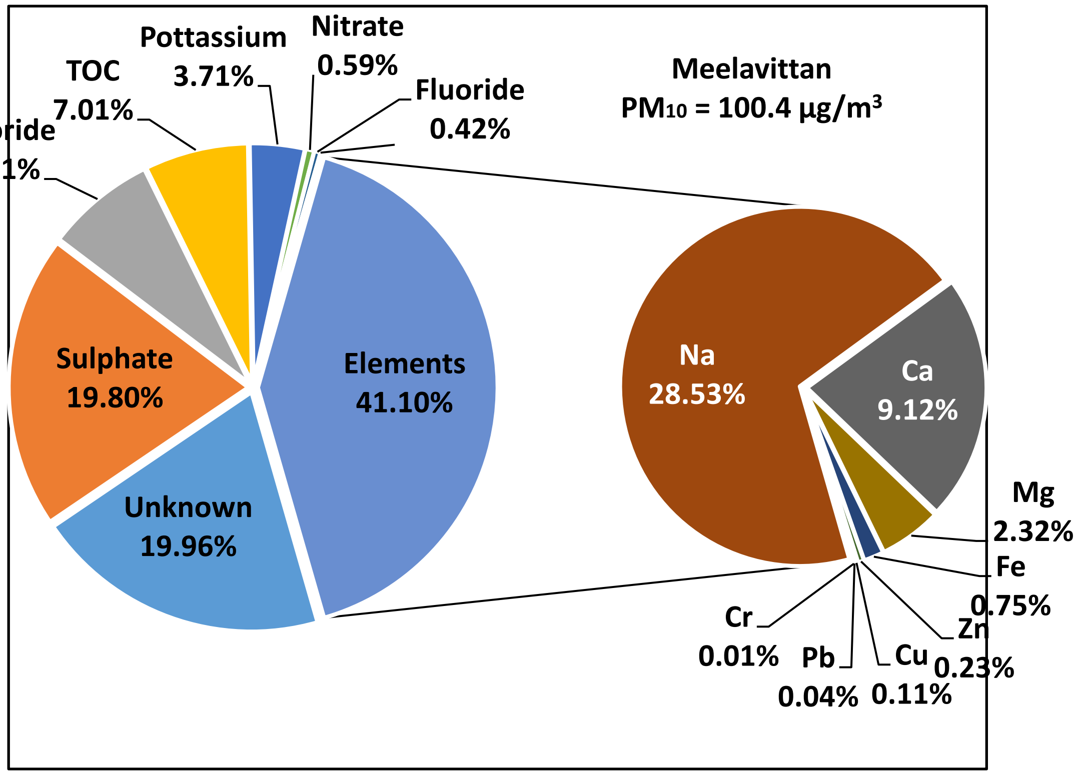
e) WGC Road (Commercial/Residential)



f) Celseeni colony (Residential)



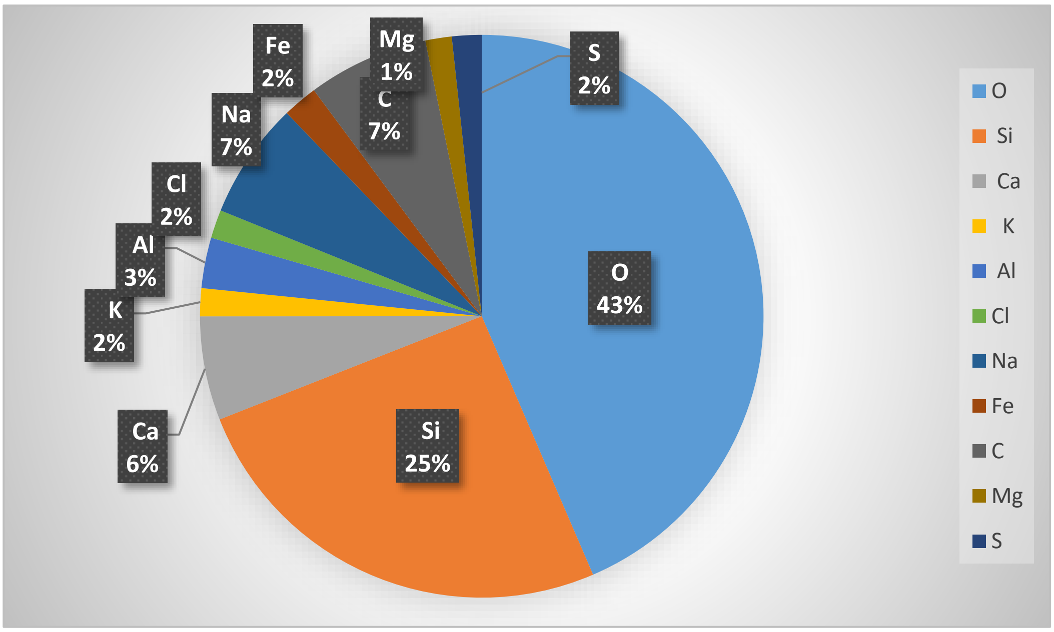
g) Raju Nagar (Residential)



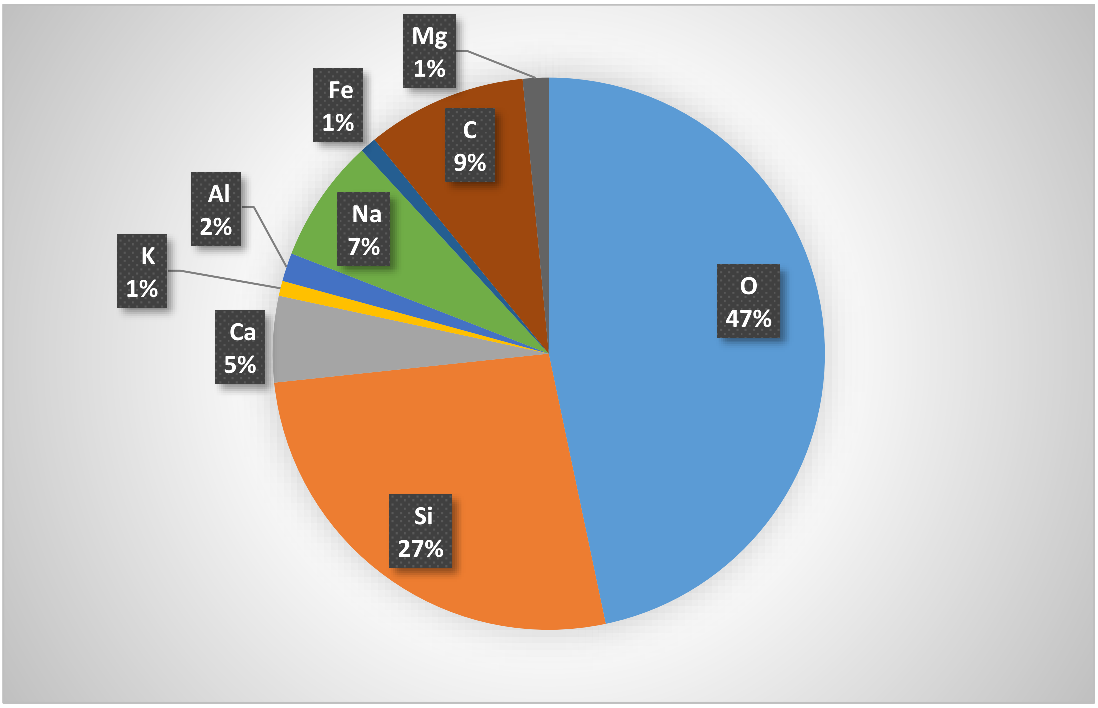
h) Meelavittan (Residential)

Figure 13 Distribution of species on PM_{10} at monitoring sites

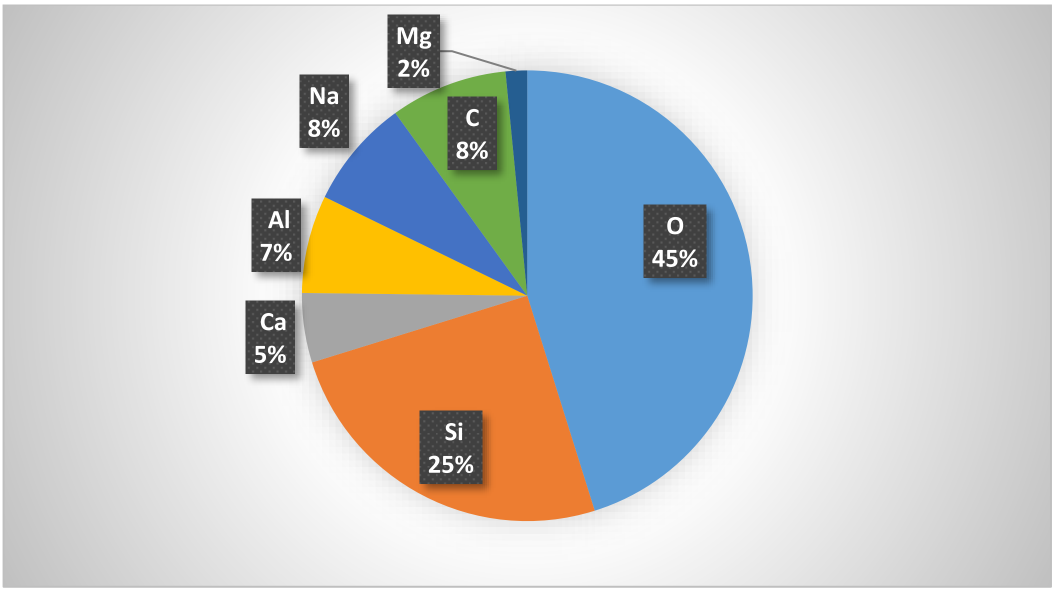
From the three-monitoring stations, EDX results representing commercial, industrial and highway is shown in Figure.14 a, b & c. It shows that Si content is higher in all the three sample which indicating sand dust is the main contribution of PM_{10}. The carbon also presents in all samples indicating the contribution from burning of fuel (vehicle and biomass).



a) Industrial (SIPCOT)



b) Residential/Commercial (AVM Jewellery)



c) Highway (Raja Agencies)

Figure 14 EDX analysis for three monitoring station

From the observation of primary data PM_{10} dust shows the main contribution are from road dust, vehicular emission, industrial emission and biomass burning.

5.RECEPTOR MODELLING

This methodology is a statistical technique which examines the variations in the data measured at a site. It then estimates the number of factors which can explain the variations in the data set measured. This number of factors is usually less than the number of variables measured. The different variables are grouped together so that the variables which occur in a factor can be thought of as a group which can explain the variations observed in the monitored data. The factors that are identified using this method are non-unique. In order to render the factors unique, we use an additional condition that the factors must be able to explain the variations observed in the raw data to a maximum extent. This is called the principal of varimax rotation.

Thus Factor analysis could be used for any of the following purposes:

- To reduce a large number of variables to a smaller number of factors
- To establish that multiple tests measure the same factor, thereby giving justification for administering fewer tests
- To validate a scale or index by demonstrating that its constituent items load on the same factor, and to drop proposed scale items which cross-load on more than one factor
- To select a subset of variables from a larger set, based on which original variables have the highest correlations with the principal component factors
- To create a set of factors to be treated as uncorrelated variables as one approach to handling multicollinearity in such procedures as multiple regression
- To identify clusters of cases and/or outliers.

The factor loadings are the correlation coefficients between the variables (rows) and factors (columns). The squared factor loading is the percent of variance in that indicator variable explained by the factor. To get the percent of variance in all the variables accounted for by each factor, add the sum of the squared factor loadings for that factor (column) and divide by the number of variables. This is the same as dividing the factor's eigenvalue by the number of variables.

The sum of the squared factor loadings for all factors for a given variable (row) is the variance in that variable accounted for by all the factors, and this is called the communality. The ratio of the squared factor loadings for a given variable (row in the factor matrix) shows the relative importance of the different factors in explaining the variance of the given variable. Factor loadings are the basis for imputing a label to the different factors.

Factor scores are the scores of each case (row) on each factor (column). To compute the factor score for a given case for a given factor, one takes the case's standardized score on each variable, multiplies by the corresponding factor loading of the variable for the given factor, and sums these products. Computing factor scores allows one to look for factor outliers. Also, factor scores may be used as variables in subsequent modeling.

Rotation serves to make the output more understandable and is usually necessary to facilitate the interpretation of factors. Varimax rotation is an orthogonal rotation of the factor axes to maximize the variance of the squared loadings of a factor (column) on all the variables (rows) in a factor matrix, which has the effect of differentiating the original variables by extracted factor. Each factor will tend to have either large or small loadings of any particular variable. A varimax solution yields results which make it as easy as possible to identify each variable with a single factor. This is the most common rotation option.

Interpretation of Factor Loadings

Loadings show how data values vary when you move along a factor. Loadings can have negative or positive values so can scores. Factors build a link between samples and variables by means of scores and loadings.

- If a variable has a very small loading, whatever the sign of that loading, it should not be used for interpretation, because that variable is badly accounted by the factor
- If a variable has a positive loading, it means that all samples with positive scores have higher than average values for that variable. All samples with negative scores have lower than average values for that variable
- If a variable has a negative loading, it means just the opposite. All samples with positive scores have lower than average values for that variable. All samples with negative scores have higher than average values for that variable
- The higher the positive score of a sample, the larger its values for variables with positive loadings and vice versa
- The more negative the score of a sample, the smaller its values for variables with positive loadings and vice versa
- The larger the loading of a variable, the quicker sample values will increase with their scores

To summarize, if the score of a sample and the loading of a variable on a particular factor have the same sign, the sample has higher than average value for that variable and vice-versa. The larger the scores and loadings, the stronger that relation.

Table.11 shows that the PM_{10} pollutants and factors are as follows

- Factor 1: Soil dust/Road Paved Dust,
- Factor 2: Vehicular Emission/Biomass Combustion,
- Factor 3: Industries/other source

Table 11 Factor Analysis Scores

Pollutant	Factor 1	Factor 2	Factor 3
Unknown*	3.694	0.242	0.226
Fe	-0.203	-0.587	-0.141
Cu	-0.251	-0.644	-0.307
Zn	-0.230	-0.643	-0.202
Pb	-0.250	-0.653	-0.313
Cd	-0.247	-0.660	-0.321
Cr	-0.248	-0.660	-0.320
Mg	-0.225	-0.396	-0.427
Ca	-0.007	0.325	0.794
Na	-0.178	2.719	-2.147
K	-0.197	-0.232	0.581
F^-	-0.265	-0.586	-0.229
Cl^-	-0.141	0.149	1.126
SO_4^{2-}	-0.771	1.977	2.172
NO_3^-	-0.128	-0.593	-0.038
TOC	-0.353	0.243	-0.454
Sum of Squares	3.967	3.944	0.029
Proportion Var	0.496	0.493	0.004
Cumulative Var	0.496	0.989	0.993

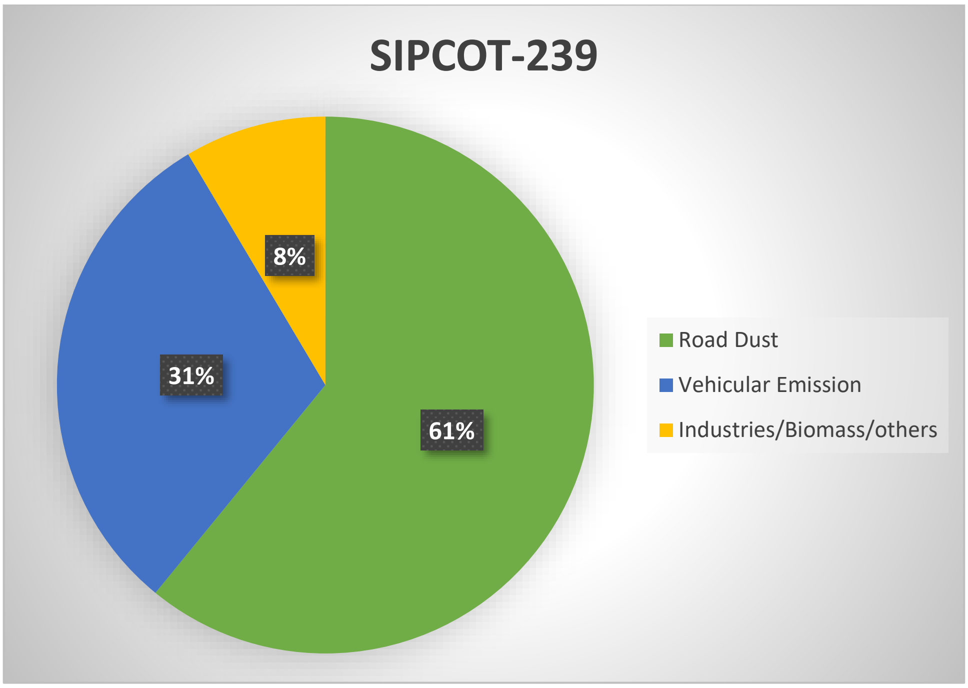
* Unknown includes Si and others

Table.12 shows the different factors contributing to the PM_{10} dust in various monitoring sites. Fig.15 (a-h) depicts the percentage of various source contribution.

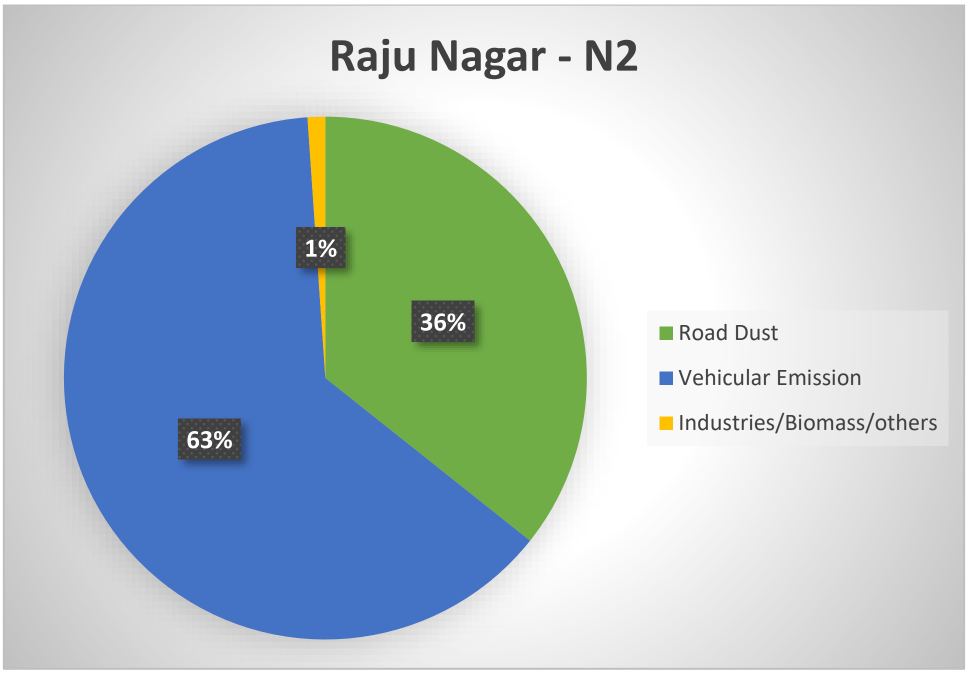
Table 12 Factor Loading to Monitoring Site

Location	Factor 1	Factor 2	Factor 3
SIPCOT	0.885	0.444	0.124
AVM	0.81	0.583	0.023
RAJA	0.922	0.38	0.016
Thermal Nagar	0.841	0.538	0.011
WGC Road	0.482	0.856	0.017
Celseeni Colony	0.61	0.785	0.011
Raju Nagar	0.49	0.868	0.015
Meelavittan	0.355	0.933	0.111

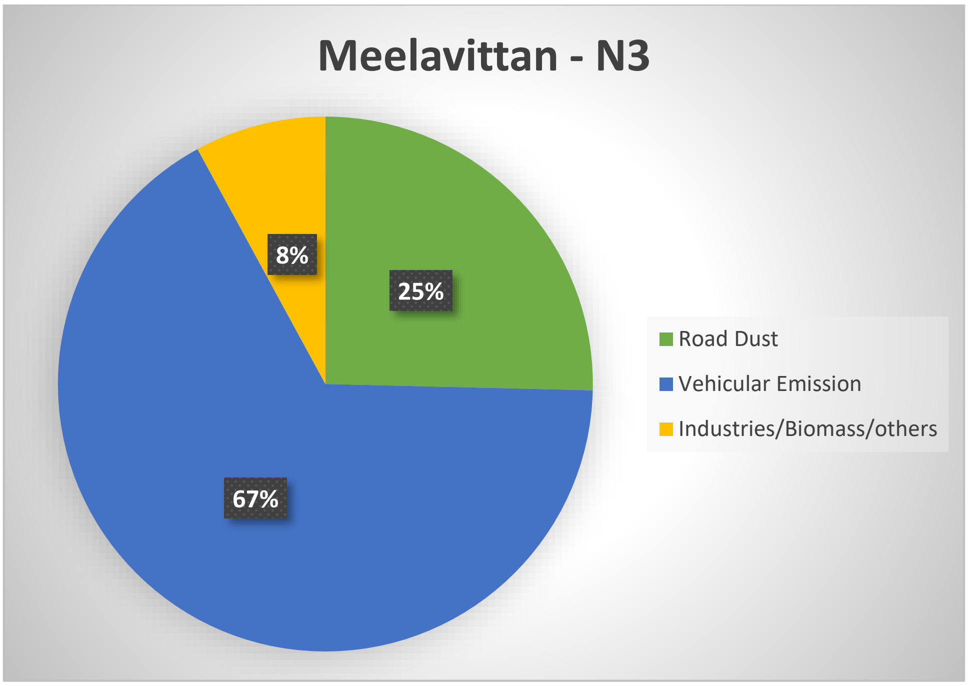
*Factor 1: Soil dust/Road Paved Dust, Factor 2: Vehicular Emission/Biomass Combustion, Factor 3: Industries/other source


SIPCOT-239
8%
31%
61%
Road Dust
Vehicular Emission
Industries/Biomass/others

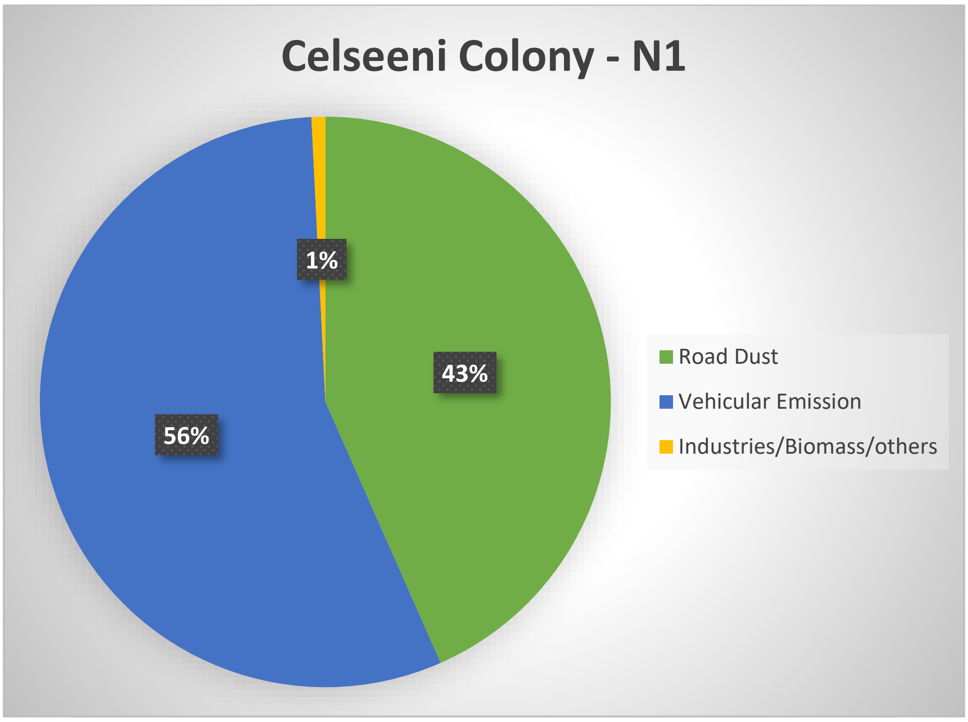
a)


Raju Nagar - N2
1%
36%
63%
Road Dust
Vehicular Emission
Industries/Biomass/others

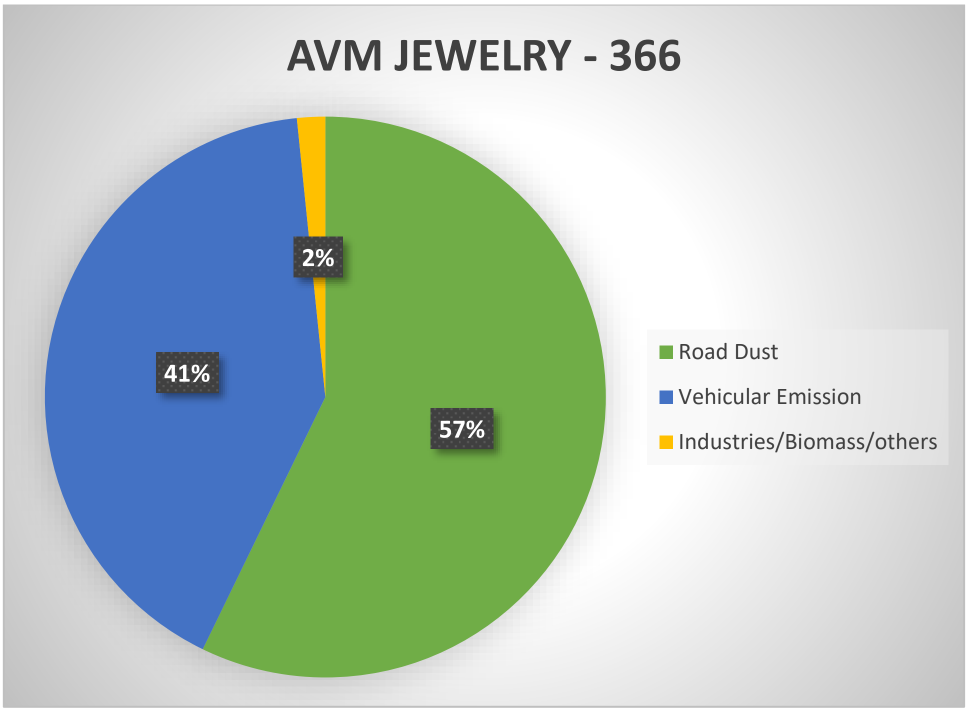
b)


Meelavittan - N3
8%
25%
67%
Road Dust
Vehicular Emission
Industries/Biomass/others

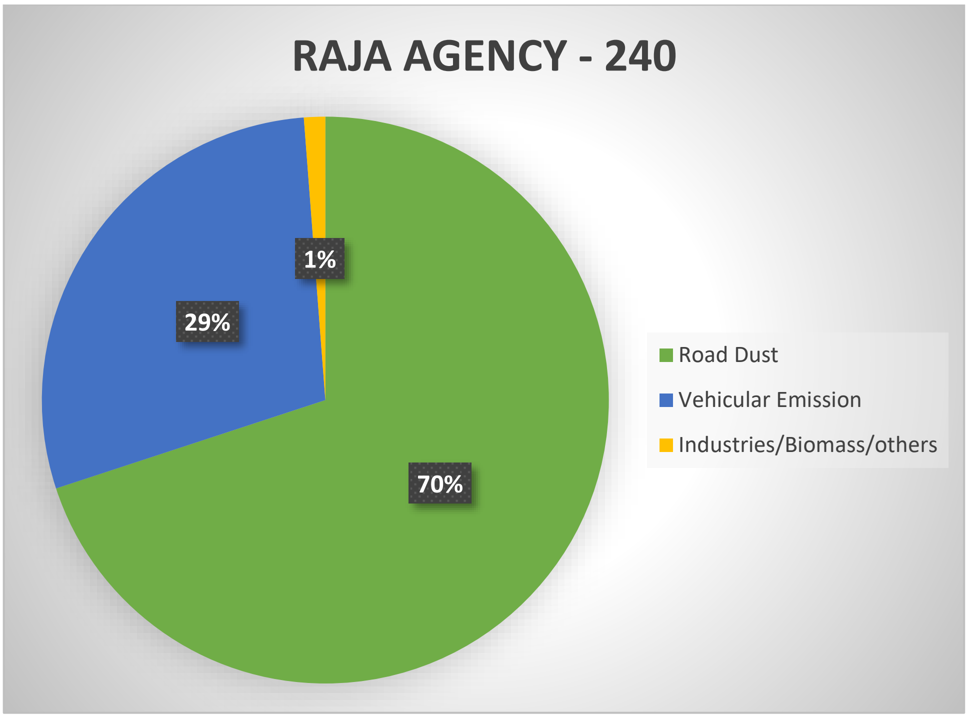
c)


Celseeni Colony - N1
1%
43%
56%
Road Dust
Vehicular Emission
Industries/Biomass/others

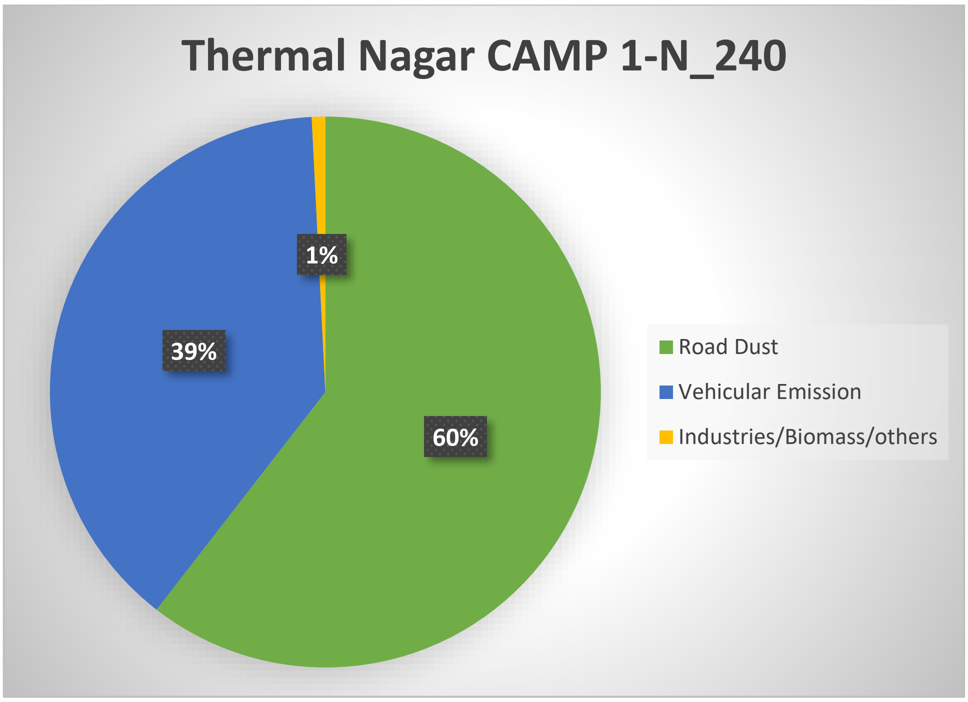
d)


AVM JEWELRY - 366
2%
41%
57%
Road Dust
Vehicular Emission
Industries/Biomass/others

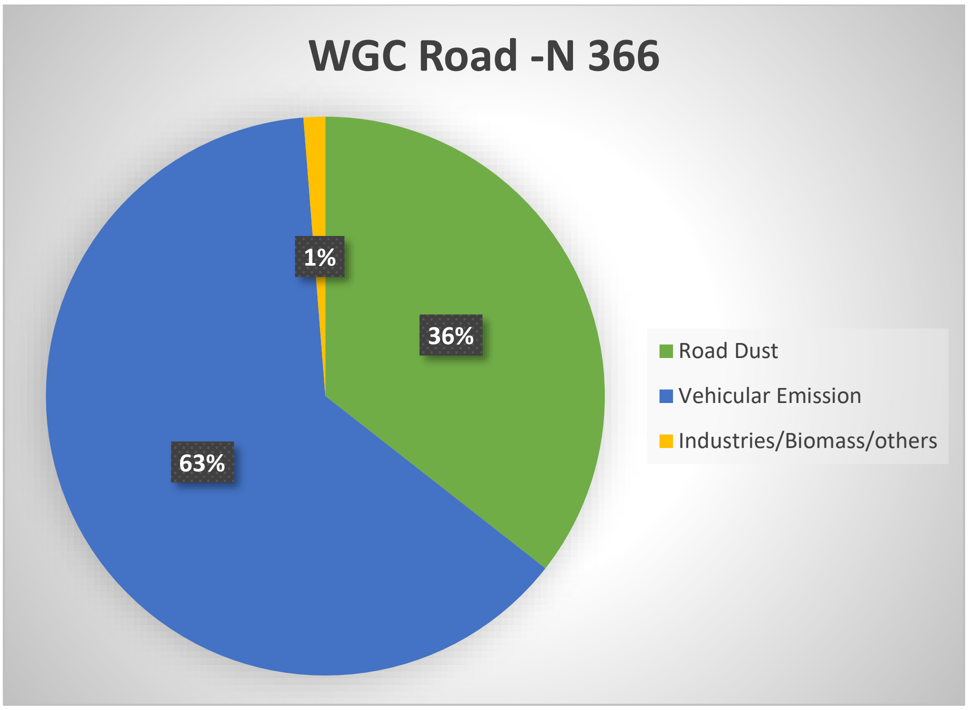
e)


RAJA AGENCY - 240
1%
29%
70%
Road Dust
Vehicular Emission
Industries/Biomass/others

f)



g)



h)

Figure 15 Source contribution using factor analysis

Table.13 shows that correlation of speciation in all the monitoring sites, this reveals correlation vary from 0.774 to 1.0. This correlation analysis helps to reveal the PM_{10} factor homogeneity across the sites. From Fig.15, it is clear that the main contribution of PM_{10} comes from road dust (Si) and combustion emission (carbon). The receptor modelling finding also in conformity with primary data findings of chemical characterization.

Table 13 Correlation of Pollutants with respect to monitoring Sites

	SIPCOT	AVM	RAJA	Thermal Nagar	WGC Road	Celseeni Colony	Raju Nagar	Meelavittan
SIPCOT	1.000	0.970	0.979	0.978	0.801	0.890	0.827	0.728
AVM	0.970	1.000	0.972	0.998	0.890	0.952	0.901	0.832
RAJA	0.979	0.972	1.000	0.984	0.774	0.861	0.778	0.682
Thermal Nagar	0.978	0.998	0.984	1.000	0.868	0.935	0.876	0.801
WGC Road	0.801	0.890	0.774	0.868	1.000	0.960	0.972	0.974
Celseeni Colony	0.890	0.952	0.861	0.935	0.960	1.000	0.982	0.950
Raju Nagar	0.827	0.901	0.778	0.876	0.972	0.982	1.000	0.985
Meelavittan	0.728	0.832	0.682	0.801	0.974	0.950	0.985	1.000

6. FUTURE PROJECTION OF VEHICULAR POPULATION

As on February 2019 the number of registered vehicles at Thoothukudi city is 2,55,523. The city is largely depending on personalized vehicles. With regard to private vehicles two wheelers accounts for 82% followed by cars 12 % of the total vehicular population (Fig.16). Commercial vehicle constitutes about 2% of the total vehicle population. Auto rickshaws constitute about 2% and trucks constitute about 2%. There are 4,327 registered three-wheeled vehicles called auto rickshaws and by February 2019 which are commercially available for renting within the city. In addition to the government operated city buses that are used for public transport, there are 162 registered private mini-buses that support local transportation. As on February 2019 data projected for year 2024 (Table.14 & Fig.17).

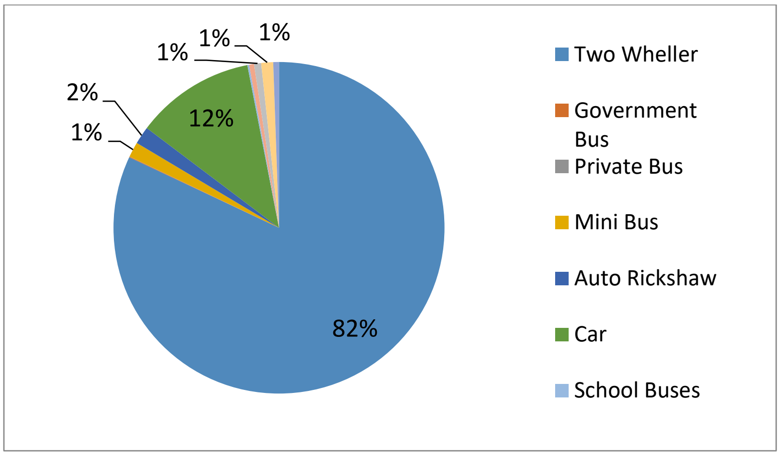


Figure 16 Vehicle Composition

Table 14 Vehicle Projected Data

S.No	Year	Total No. of Vehicle
1	2019	255523
2	2020	268299
3	2021	281714
4	2022	295800
5	2023	310590
6	2024	326119

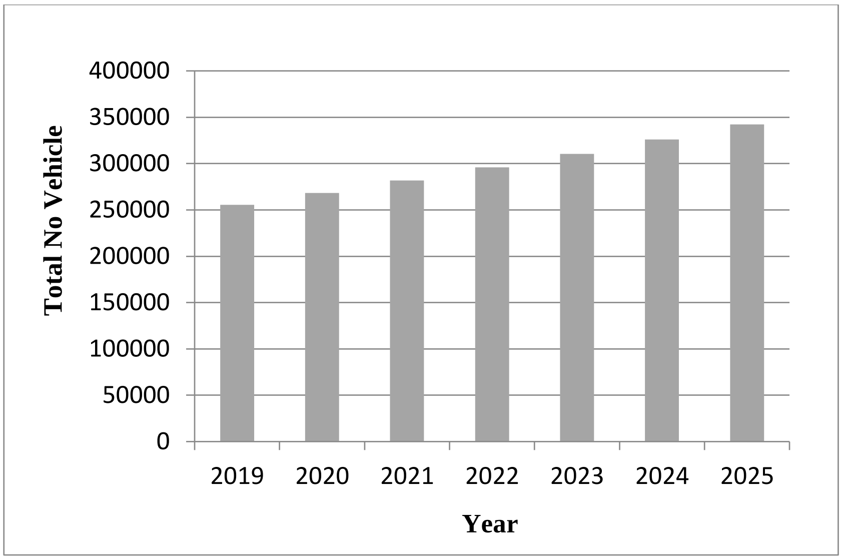


Figure 17 Projected Vehicular growth up to 2024

Environmental Impact

The vehicular pollutant emission (carbon monoxide, hydro carbon and nitrogen oxides) for various mode wise of vehicles were estimated and given in Table.15. While Vehicle Growth rate is high emission tends to increase due to increase in congestion level. Peripheral road development would to take care of the traffic moving towards city and decreases the congestion in city and this would perform well over a long run since the level of congestion gets sustained, the impact over environmental is also under control.

Motor vehicle emission is critical in estimating their impacts on local air quality and traffic related exposure and requires the collection of travel activity data over space and time and the development of emission inventories. Emission inventories developed based on complex emission model that provided exhaust and evaporative emission rates for total CO (Carbon monoxide), NOx, Green House Gases (GHGs) for specific vehicle type and flues. The quality of the travel activity data (Such as vehicle-miles travelled, Numbers of trips and types of vehicles). We can consider as vehicles miles travelled (per Km) and number of trips (one trips). % share fuel used for car (40% of Petrol, 55% of Diesel and 5% of Gas), 2-wheeler 100% of Petrol, 3wheeler (43% of Petrol, 38% Diesel, 20% of Gas) and Buses 100% Diesel consider for analysis emission. Average Occupation ratio of car, 2-wheeler, 3-wheeler and Bus are 3.03, 1.07, 4.10 & 23.08 respectively.

Table 15 Pollutant Emission for Mode Wise

Pollutant	Mode	Year (tonnes/day)					
		2019	2020	2021	2022	2023	2024
PM_{10}	CAR	0.0014	0.0015	0.0015	0.0016	0.0017	0.0018
	2W	0.0156	0.0164	0.0172	0.0181	0.0190	0.0200
	3W	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
	BUS	0.0003	0.0003	0.0004	0.0004	0.0004	0.0004
NO_x	CAR	0.0080	0.0090	0.0090	0.0100	0.0100	0.0110
	2W	0.0206	0.0216	0.0227	0.0239	0.0250	0.0263
	3W	0.0007	0.0008	0.0008	0.0009	0.0009	0.0008
	BUS	0.0110	0.0110	0.0120	0.0126	0.0133	0.0139
CO	CAR	0.0428	0.0449	0.0472	0.0495	0.0520	0.0081
	2W	0.2690	0.2824	0.2965	0.3114	0.3269	0.3433
	3W	0.0042	0.0045	0.0047	0.0049	0.0052	0.0049
	BUS	0.0060	0.0070	0.0070	0.0074	0.0078	0.0081
VOC	CAR	0.0063	0.0066	0.0069	0.0073	0.0077	0.0012
	2W	0.1337	0.1404	0.1475	0.1548	0.1626	0.1707
	3W	0.0022	0.0023	0.0024	0.0025	0.0026	0.0025
	BUS	0.0020	0.0020	0.0020	0.0020	0.0021	0.0022
CO_2	CAR	2.5006	2.6256	2.7569	2.8948	3.0395	0.4718
	2W	6.9028	7.2479	7.6103	7.9908	8.3904	8.8099
	3W	0.1977	0.2076	0.2180	0.2289	0.2403	0.2273
	BUS	0.5820	0.6110	0.6420	0.6739	0.7077	0.7430

From Table. 15, it is clear that the PM_{10} values, contributed by car, 2-wheeler and bus is progressively increasing. Effort should be made to minimize its contribution with proper traffic management.

7. SUMMARY

The level of PM_{10} concentration during this study at Thoothukudi city and from the past monitored data shows that it is mostly above the standard limit. This confirms the non-attainment city of Thoothukudi city for PM_{10} dust.

- Source apportionment study reveals that the main contribution of PM_{10} is from the road dust containing silica
- The water-soluble organic matter and elemental carbon is present in all the stations indicate the other source is burning of fuel emissions from vehicles fuel and biomass
- Dust particle characterization shows the heavy metals are within the limit
- The major cations and anions concentrations are present in all the samples. The sulphate and nitrate indicate the burning of fuels contribution to the dust. The potassium indicates the biomass burning contribution to the dust. The calcium and magnesium are from the alkaline source (construction-cement)
- The receptor modelling also confirmed the road dust and vehicular emission are the major factors contributing for the dust

8. RECOMMENDATIONS

The following recommendations are framed to control the particulate matter emission for Thoothukudi city.

- For controlling and minimizing the road dust, proper carpeting should be closed on both sides of the roads with the blacktopping. Immediate action to be taken by the Corporation for removing the accumulated dust regularly using mechanized sweeping
- For vehicular emission control, public transport should be increased. Policy decision to minimize the private vehicles and use of public transport to be encouraged

- Diesel driven vehicles should be controlled, if used retrofitting of particulate filters in the vehicles should be used for minimizing the organic particulate emission
- In highways and roads, tree plantation should be provided on both sides of the roads. Small herb plantations to be planted in the middle of the roads
- Industrial emission to be monitored for the stringent compliance
- Night-time burning of biomass should be restricted. Instead use of CNG/LPG should be recommended
- Number of air quality monitoring stations may be increased
- Health awareness due to the air pollution may be advised to the public and students

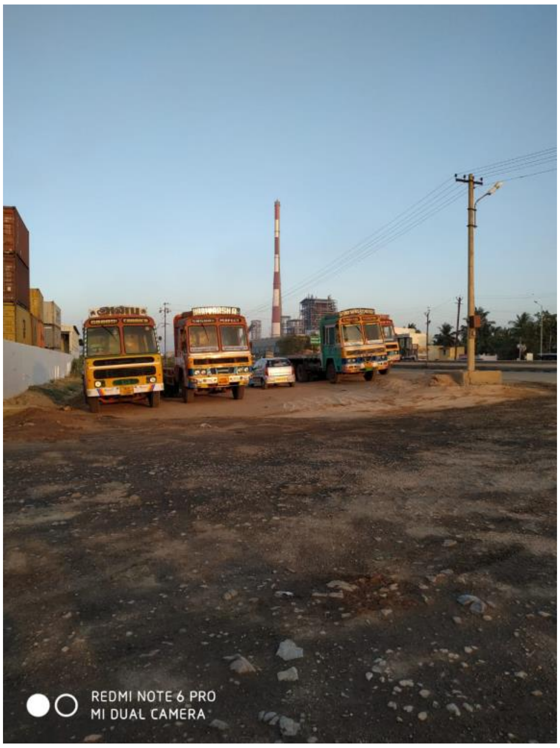
ANNEXURE -I

POTENTIAL SOURCES OF PM_{10}

Road side Fast Food Shops

Bakery and Night time Shop

Road side Dust Emission



Road Transport Emission

Vehicular Emission

Vehicular Emission

Roadside Suspended Dust Particles and Power Plant of Thoothukudi

Road Intersection at AVM Building

SIPCOT Bypass Road (Road paved Dust)

SALT Pans

PORT VOC Road

ANNEXURE-II

PHOTOGRAPHS OF SAMPLING SITES

Existing Sampling Locations of PM_{10} – TNPCB Office (SIPCOT)

Existing Sampling Locations of PM_{10} Raja Agencies Buildings (Highway)


Existing Sampling Location of PM_{10} – AVM Jewelry Building (Commercial)

Continuous Ambient Air Quality Monitoring Station

High Volume and Fine Dust Sampler at SIPCOT

New Locations Identified Tamil Nadu State Apex Co-Op Bank Ltd Building or/and location at a residential area.

Monitoring Site at Ceelseni Colony (Residential)