Emission Inventory and Modelling of Air Pollution Sources in Agra Region

(Final Report)

Submitted to

Climate and Clean Air Coalition Secretariat and UN Environment India

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Executive Summary

Agra Airshed

To delineate the Agra airshed, it was observed that during the winter the wind passes over an area from the upwind directions of west, north, and east of Agra and contributes to Agra's air. In other words, one has to account for predominant upwind directions and areas over which the wind passes and reaches Agra. Similar analysis showed that in January 2018, the prevailing wind direction was north-west except during the periods of 16^{th} to 20^{th} January and 21^{st} to 25^{th} January when the dominant wind directions were west and north, respectively, which also contributed to Agra's air.

The airshed for the winter season was obtained by superimposing the airsheds for different months and working out the union of all superimposed airsheds. Mathura, Bharatpur, Dholpur, Firozabad, Aligarh, Etah, and Hathras districts fall under the Agra airshed.

Emission Inventory

The emission inventory of Agra airshed and Agra city was prepared. The total population of the districts in Agra airshed is about 18.7 million (Census 2011). The maximum emissions are from Aligarh, owing to a huge power plant of 610 MW capacity and a large number of brick kilns (164 nos.). Mathura has a relatively high SO_2 emission because of a large oil refinery (8.0 million metric tons per annum capacity).

Brick kilns are the major contributors to all pollutants in the airshed. In PM_{10} (37 tons/d) and $PM_{2.5}$ (27 tons/d) the brick kiln's contribution is 66 – 69%, in CO (115 tons/d) and 40 – 45 % in SO_2 (63 tons/d). The contribution of brick kilns to NO_X (18 tons/d) emission is around 26 % and around 70% to black carbon (BC) (3.4 tons/d) emission. Although brick kilns constitute a major economic activity and drive the construction industry, theyneed to be brought under the formal sector with the best available technology and modern pollution control equipment.

There are approximately 1300 industries in the Agra airshed that are air polluting in nature. Nearly 55% of the industries have a captive electric power generator, referred to as diesel generator (DG) set, installed for emergency backup for electricity. There are about 566 boilers/furnaces that are operational in the airshed. The total emission in the airshed is: PM_{10}: 53 tons/d; $PM_{2.5}$: 41 tons/d; SO_2: 112 tons/d; NOx: 72 tons/d; CO: 182 tons/d; and BC: 5.2 tons/d.

There are two large industries in the Agra airshed: oil refinery at Mathura (about 40 km from the Agra city) and Harduaganj coal-based power plant in Aligarh, about 80 km from Agra. These two industries have large emissions of SO_2; the power plant accounting for 47% of total SO_2 emission and the refinery accounts for 24%.

The total PM_{10} emission load in Agra city is estimated to be 37 tons/d. The top four contributors to PM_{10} emissions are road dust (80%), industries (5%), vehicles (5%), and construction (2%). $PM_{2.5}$ emission load in the city is estimated to be 15 tons/d. The top four contributors to $PM_{2.5}$ emissions are road dust (63%), vehicles (11%), industries (10%), and domestic fuel burning (6%). SO_2 emission load in the city is estimated to be 2 tons/d; industries account for 53% of the total emission, vehicles contribute 18%, followed by hotels and restaurants (11%). NOx emission load in the city is estimated to be 19 tons/d. Nearly 85% of emission are attributed to vehicular emissions, followed by DG sets (2%), and industries (5%). The estimated CO emission is about 54 tons/d. Nearly 42% CO emissions are from vehicles, followed by industries (30%), domestic (9%), and about 5% from burning of Municipal Solid Waste (MSW).

Air Quality Modelling

The Weather Research and Forecasting (WRF) model for meteorology parameters was validated against the continuous air quality monitoring station's measured data. The model performed satisfactorily (a statistically significant coefficient of correlation) in predicting wind speeds in February, March, April, June, and September 2018. In general, the wind speeds were overestimated by a factor of 1.2. Furthermore, the time-series plot of observed hourly ambient temperature values with modelled values showed a good agreement for all the months of 2018. It was concluded that the WRF model provided realistic meteorology and the WRF outputs were used in air quality modelling.

The $PM_{2.5}$ modelled and observed levels over one year showed a good linear association - R^2 = 0.414 (for over 350 data points). However, the noteworthy point is that model underpredicts the concentration by a factor of more than 2.0. The probable reasons for underestimation by the model are: (i) over prediction of wind speed by the WRF model, (ii) inventory may be incomplete and some source may be missing and (iii) there is a substantial contribution of sources present outside Agra city. Since the linear association in the model-computed and observed levels is very good, the model could be used for decision-making and valuable insights.

Additionally, the deficit in the model and measured (referred to as unidentified) $PM_{2.5}$ levels were highest during the months of January-February and November- December. Also, it is worth noting that there was a sudden spike in these unidentified concentrations of $PM_{2.5}$ during the first week of November. This episodic spike in the unidentified $PM_{2.5}$ concentrations with an average value of 119 ug/m^3 in the city can be attributed to the influx from the surrounding regions outside of the city.

For a better insight, Agra city was divided into five regions (Figure 93). Regions 2 (north) and 3 (north-east) showed the highest $PM_{2.5}$ levels. The regions are densely populated and region 2 also has a major industrial area. The highest 24-hr average $PM_{2.5}$ concentrations were computed for all 12 months of the year 2018. It was observed that region 3 had the 24-hr peak $PM_{2.5}$ concentration at 298 ± 62 µg/m^3 followed by region 2 with 175 ± 63 µg/m^3 and region 1 with 140 ± 44 µg/m^3. Region 5 (south-east) had the least 24-hr average $PM_{2.5}$ at 76 ± 24 µg/m^3. The highest 24-hr average $PM_{2.5}$ concentrations were observed during the winter (November to February) while the lowest during the summer (May to July).

The highest contributing sources were the road dust in all the regions, followed by vehicular sources in regions 1, 4 and 5. Industrial sources were the second-highest contributors in regions 2 and 3. Domestic sources were the third-highest contributors in regions 1 and 4, where the residential population is concentrated, and industrieswere the highest contributors in region 5 (Table 29).

Overall city level contributors to $PM_{2.5}$ were road dust (64%), vehicles (13%), industry (9%), domestic (7%), and hotels (3%).

There is an envelope of $PM_{2.5}$ concentration plots that gets elongated along the prevailing wind direction (N-E) within the Agra city. The annual standard for $PM_{2.5}$ concentration (40µg/m^3) is exceeded in the National Highway 19 (NH-19) area.

The efflux of $PM_{2.5}$ emission from Agra city was examined in 8 directions up to 50 km from the centre of the city. The monthly average $PM_{2.5}$ concentration generally reaches a level of 5 - 9 µg/m^3 at a distance of around 15 km from the city. After about 30-40 km, contribution of the Agra city becomes negligible (i.e. < 2 µg/m^3).

The maximum annual concentration from the model used in this study was in the range of 100 – 167 µg/m^3 (Figure 191). The study by UEinfo (Urbanemissions.info) shows the maximum annual concentration in the range of 100-120 µg/m^3 (Figure 190). The two models are reasonably close in predicting peak annual concentration. The identified hotspots from both the models are also nearly in the same area (i.e. on NH19).

Control Measures and Actions

(i) Any form of garbage burning should be strictly stopped and monitored for its compliance. It will require infrastructure development (including access to remote and congested areas) for effective collection of MSW and disposal at the scientific landfill site.

(ii) Low-income group areas (e.g., Ghatiya Azam Khan, Bijlighar, Belanganj, Jeoni mandi, Chippi tola, Sadar Bhatti, Naiki Mandi, Jagdishpura, Bhim Nagar and Bhogipura) should focus on development of MSW collection system. Collection and disposal of the MSW should further improve primarily in regions 1 and 4 (Figure 93). Furthermore, landfills and waste to energy plants can be established for efficient handling of MSW.

(iii) Dumping of hazardous waste (oil, grease, and paint) has been observed. . Several residents in the locality of the Sikandra Industrial Area have reported instances of leather burning which needs to be strictly prohibited with immediate effect under the supervision of the Uttar Pradesh Pollution Control Board (UPPCB). It is recommended that there should be a separate industrial non-hazardous dump site for industrial waste, and industries should be disallowed from disposing of the waste on roads or in front of the industry or anywhere other than the designated site.

(iv) All construction and demolition (C&D) activities should fully comply with the C&D Waste Management Rules, 2016. If required, a C&D waste recycling facility must be created which is a common practice in large cities.

(v) Road dust is the largest source of pollution in the city. To effectively control this source, convert unpaved roads to paved roads. Municipal Council should carry out vacuum-assisted sweeping on all roads with silt roads greater than 3 gm/m^2. If the sweeping is done twice a month, the road dust emission will reduce by 42% (as suggested by the Federal Highway Administration (FHWA), United States Department of Transportation and the efficiency of different vacuum sweeping machines).

(vi) The vehicle emission contribution to air quality is the second important source after road dust. Out of about 3.5 tons/d emissions of PM_{10} and $PM_{2.5}$ from vehicles, over 80% is from diesel vehicles, especially from trucks and buses. Therefore, control measures have to focus on advanced technological intervention for diesel vehicles or switching to compressed natural gas (CNG) especially in local transportation, buses, and light commercial vehicles.

(vii) Retro-fitment of Diesel Particulate Filter (DPF): These filters have a PM emission reduction efficiency of 60-90%. If the diesel vehicle entering the city has been equipped with DPF, there is a reduction of 40% emission. This option must be explored as Bharat Stage VI fuel is now available.

(viii) Electric/Hybrid Vehicles should be encouraged. New residential and commercial buildings should provide charging facilities.

(ix) Many industries have induction furnaces that are highly polluting and are fitted with almost no pollution control devices. The maximum emissions occur when the furnace lids and doors are opened during charging, back charging, alloying, oxygen lancing (if done), poking, slag removal, and tapping operations. These emissions escape from the sides and top of the building. The emissions should be collected, channelized and arrested through the bag filters. To address this pollution caused by fugitive emissions, a fume gas capturing device has been developed and is commercially available. It is recommended that fume gas capturing hood followed by baghouse should be used to control air pollution.

(x) It has been observed that industrial waste (hazardous in nature) is mixed with MSW and burnt in several parts of Agra. There should be separate treatment, storage, and disposal facilities (TSDFs) for hazardous waste that should be developed under the guidance of UPPCB.

(xi) Industries located outside Agra City also contribute to the city pollution; this contribution is nearly 8 - 10% of the $PM_{2.5}$ levels. Brick kilns located outside Agra city are the major contributors to all pollutants in the airshed. In PM_{10} (37 tons/d) and $PM_{2.5}$ (27 tons/d) the contribution of brick kilns is 66 – 69%. Brick kilns constitute a major economic activity and drive the construction industry, hence, they need to be formalized and equipped with the best available technology and modern pollution control equipment. The priority is that all brick kilns in Agra and Firozabad districts should adopt ziz-zag and vertical shaft technology. Other districts should follow suit. The improvement in technology is expected to reduce the brick kilns' emission by 25%.

(xii) The two large industries in the Agra airshed - oil refinery at Mathura and Harduaganj coal-based power plant in Aligarh have large emissions of SO_2 - 24% and 47% of the total SO_2 emission, respectively. . These two industries should reduce their emission in a time-bound manner.

(xiii) The UPPCB office, Agra, should be strengthened in terms of manpower, sampling, analysis, assessment, and surveillance, including capacity building and laboratory upgradation.

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Acknowledgments

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1 Introduction

1.1 Background

Air pollution has emerged as a major challenge, particularly in urban areas. The problem becomes more complex due to the multiplicity and complexity of the air polluting source mix (e.g., industries, automobiles, generators, household fuel burning, roadside dust, construction activities, etc.). Indian cities have experienced phenomenal growth in terms of population, industry, and vehicles. The broad emission source categories of air pollution in an urban area include (i) transport (motor vehicles and railways), (ii) commercial establishments, (iii) industry, (iv) household cooking/heating, (v) fugitive and non-point sources, and (vi) biomass burning. There could also be some unique or specific sources in a particular area.

Industrial pollution has the potential to cause irreversible reactions in the environment and may pose a risk to human health. Since the carrying capacity of the environment is not unlimited and some areas or ecosystems are more susceptible to adverse environmental impacts than others, the unplanned and haphazard location of industries might substantially increase the risk. It is desirable that for existing industrial areas stressed under high ambient pollution levels, a systematic and effective action plan is developed and implemented in a time-bound manner rather than considering the closure of the industries. Agra is a large city (population 1.6 million) and occupies a special place in international tourism. The city has many historical monuments and the Taj Mahal is a world-renowned centre of attraction. There is a need that public health and monuments are protected from all-natural and anthropogenic occurrences of air pollution which may be harmful.

In Agra City, for long-term (2002 to 2013), Kumar and Shukla (2017) have reported levels of TSP (total suspended particulate size 100 µm or less; 275 – 376 µg/m^3), PM_{10} (particulate matter of size 10 µm or less; 133 - 178 µg/m^3), NO_2 (17 - 23 µg/m^3) and SO_2 (4 – 9 µg/m^3), and for the year 2011-2012, Bergin et al. (Bergin et al., 2015) have reported levels of $PM_{2.5}$ (particulate matter of size 2.5 µm or less; 60±39 µg/m^3) . In a recent study at Agra, Nagar et al. (2019) has shown that the air quality standards of PM_{10} and $PM_{2.5}$ exceed in Agra. It is important that Agra city is not looked at in isolation, rather it is necessary to take a regional perspective. It is important to evaluate the contribution of regional industrial sources in Agra's air pollution levels. The air quality problem in Agra is shifted from city-scale to regional scale which may cover some adjoining districts in the state of Uttar Pradesh (UP) and other states. The sources, emissions, transformations and broad effects of meteorology on air pollution need to be evaluated and quantified for the region and districts. There is a need to introduce the concept of the regional airshed management plan for air quality improvement of the region. The concept of the regional airshed management plan is already established in different countries such as British Columbia, Canada, and the USA, which showed improvement in air quality. A regional airshed can be defined as a geographical area having a discrete and common air mass, (all air pollution remains within such an air basin and does not pass out of its boundaries) including all pollution sources and pollution producing activities and affected population is covered in the airshed.

The Climate and Clean Air Coalition Secretariat and UN Environment India, New Delhi has recognized the potential air pollution impacts in Agra and sponsored this study to the Indian Institute of Technology (IIT) Kanpur to identify and quantify the contribution of air pollution sources from the industrial clusters located in the Airshed of the Agra City and prepare an action plan to control air pollution in the city of Agra and adjoining areas. This document constitutes the final report of the project sponsored to IIT Kanpur by UNEP, New Delhi.

1.2 Objective and Scope of the Study

The focus of the study is $PM_{2.5}$ and Black Carbon (BC). The scope of work is grouped under the following packages:

Package 1: Identify and delineate the boundary of Agra Airshed for the most effective air quality management.

Package 2: Prepare comprehensive industrial emission inventory for the base year 2018 at facility level using official data of UPPCB, CPCB, and other pollution control boards (PCBs) for Agra and the region (airshed).

Package 3: Prepare an emission inventory of other sources using secondary data.

Package 4: Summarize sectoral emissions in Agra and its airshed.

Package 5: Validate the Weather Research and Forecastingand dispersion model for meteorological parameters and ground-level concentrations against observed data.

Package 6: Carry out dispersion modeling using state-of-the-art models to apportion the contribution of sources (sector-wise; industries, power plants, brick kilns, vehicles, open fires, dust, domestic, etc.) to air pollution in the Agra City and its airshed.

Package 7: Carry out reverse modeling to assess the impact of emission from the Agra City to the surrounding areas (outside the city).

Package 8: Inter-compare the modeling results of this study with the results of other groups for the same domain.

Package 9: Develop and demonstrate sector-wise (including industry) policy control measures (two-three scenarios) on air quality improvements.

Package 10: Conduct five-day training on air quality monitoring, modeling and management to ten environmental officers of the state pollution control board and/or other agencies at IIT Kanpur.

Package 11: Conduct two workshops to present results to the local government and UPPCB during the project.

The overall methodology of the study and major tasks are presented in Figure 1.

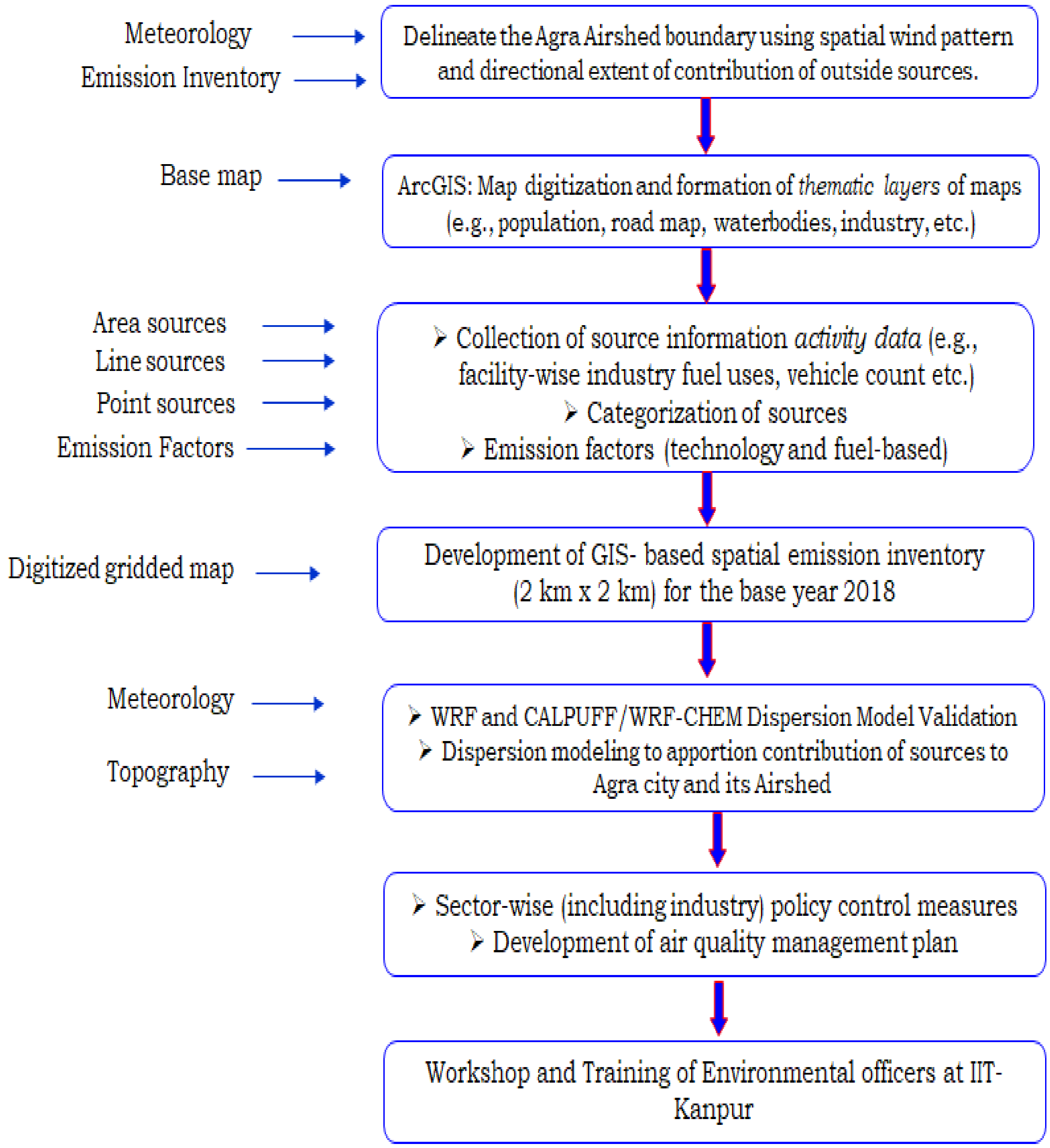


Figure 1: Overall Methodology and Major Tasks

1.3 Report Structure

The report is divided into 5 chapters. Brief description of each chapter is as under:

Chapter 1

This chapter presents the background of the study. The current status of the city in terms of air pollution is described by reviewing the previous studies. The objectives and scope of this study are also described in this chapter.

Chapter 2

This chapter presents a general description of Agra City including geography, demography,and climate. Taj Trapezium Zone (TTZ) is defined and the Agra Airshed is delineated in this chapter (Package 1).

Chapter 3

This chapter describes the methodology of developing an emission inventory of pollutants at different grids of the city. The chapter also presents and compares the grid-wise results of emission inventory outputs for various pollutants. The contributions of various sources towards air pollution loads (pollutant-wise) are presented herein (Packages 2, 3, and 4).

Chapter 4

This chapter presents the methodology used for dispersion modeling for $PM_{2.5}$ in the Agra City and its airshed. The contribution of various sources at receptor sites and overall scenario of sources that influence the air quality in the city and airshed is presented (Packages 5, 6, 7, 8, and 9).

Chapter 5

This chapter describes, explores and analyzes emission control options and provides analysis for various sources based on the modeling results from Chapter 4.

2 Agra Airshed

2.1 Agra City

Agra is a city in the State of Uttar Pradesh situated between the latitude 27.216 - 27.231 N and longitude 77.939 - 78.122 E on the bank of the river Yamuna (Figure 2).

Agra is the fourth-most populous city in Uttar Pradesh and 24th in India. Agra has a large number of tourists (0.7 million in 2018-19 (Lok Sabha, 2019)) visiting the city because of its various tourist attractions, most famous of which is the Taj Mahal, a UNESCO World Heritage Site.

Agra features semi-arid climate that borders on humid subtropical climate. The winters are mild, the summers are hot and dry, and the monsoon is moderate . Agra has a record as one of the hottest and one of the coldest towns in India. In summers, the city witnesses a sudden surge in temperature and at times, mercury goes beyond the 46 °C mark in addition to a very high level of humidity. During summer, the daytime temperature hovers around 46-50°C. Nights are relatively cooler and the temperature lowers to a comfortable 30°C.

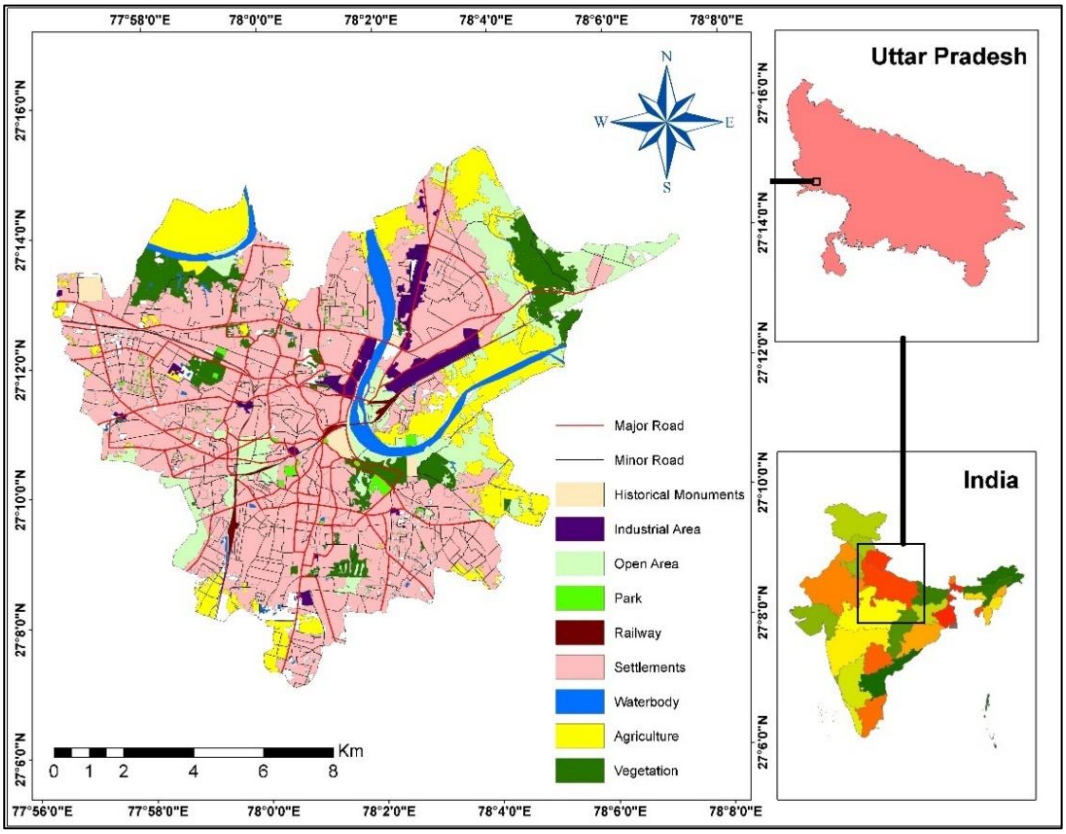


Figure 2: Land-Use Map of Agra City

2.2 Taj Trapezium Zone (TTZ)

Taj Trapezium Zone (TTZ), a trapezoid-shaped defined area of 10,400 sq km around the Taj Mahal, was delineated in 1994 for control of air pollution activities for the protection of the monument from pollution. The Taj Trapezium which is in the form of a trapezium (Figure 3) is bounded by Longitude 77°15’E on the West 78°30’E on the East and lines joining Latitude 27°45’N to Latitude 27° 30’N on the North and Latitude 26°45’ to 27° 00’N. The TTZ comprises of 6 districts - Agra, Mathura, Hathras, Etah, and Firozabad districts in Uttar Pradesh and Bharatpur district in Rajasthan, 20 tehsils and 38 blocks which are further divided into gram panchayats and villages. Taj Trapezium Zone Pollution (Prevention and Control) Authority regulates and organizes the air pollution control activities in the region.

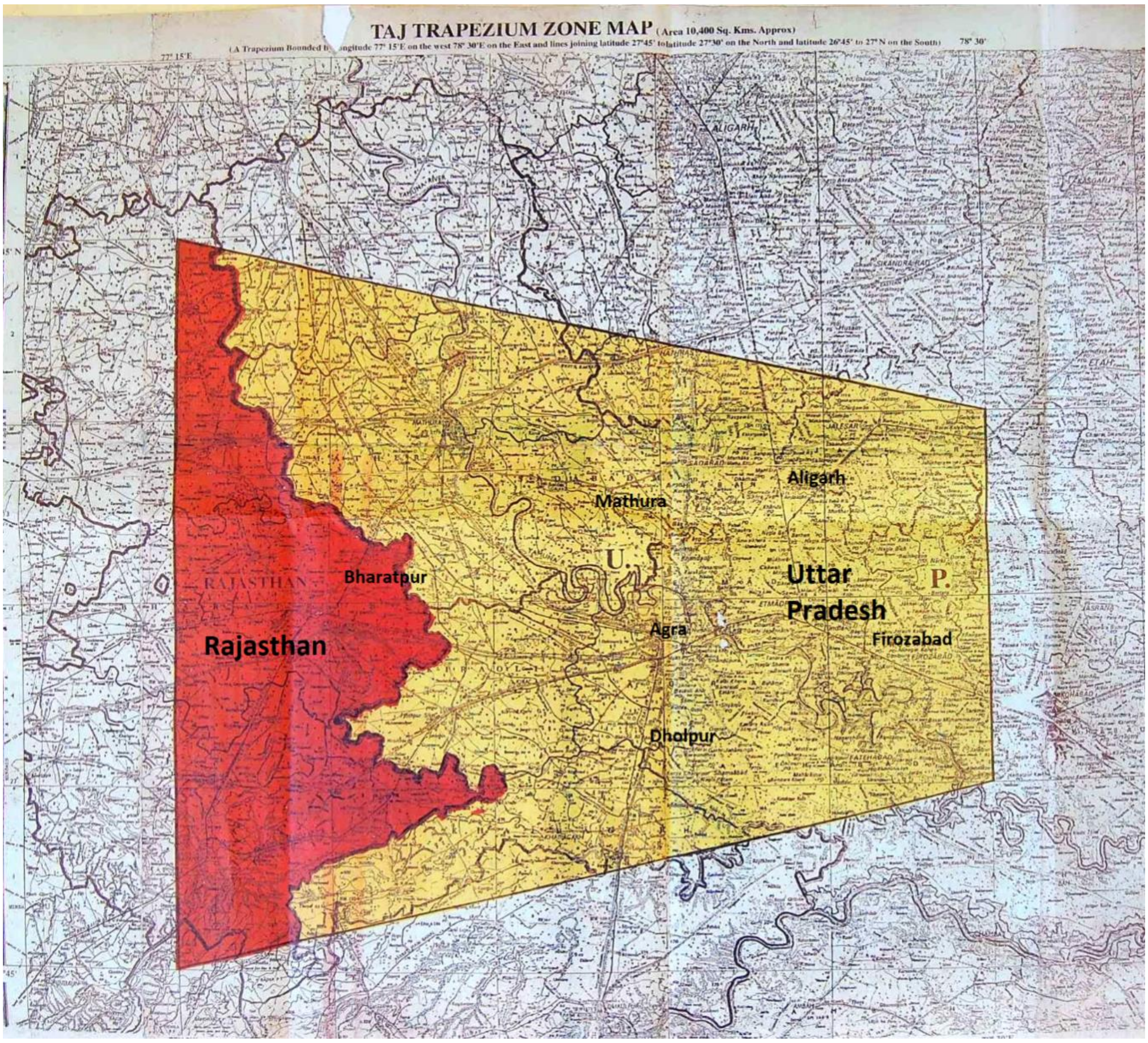


Figure 3: Taj Trapezium Zone Map (Source: TTZ pollution authority)

2.3 Delineation of Agra Airshed

(Package 1: Identify and delineate the boundary of Agra Airshed for most effective air quality management)

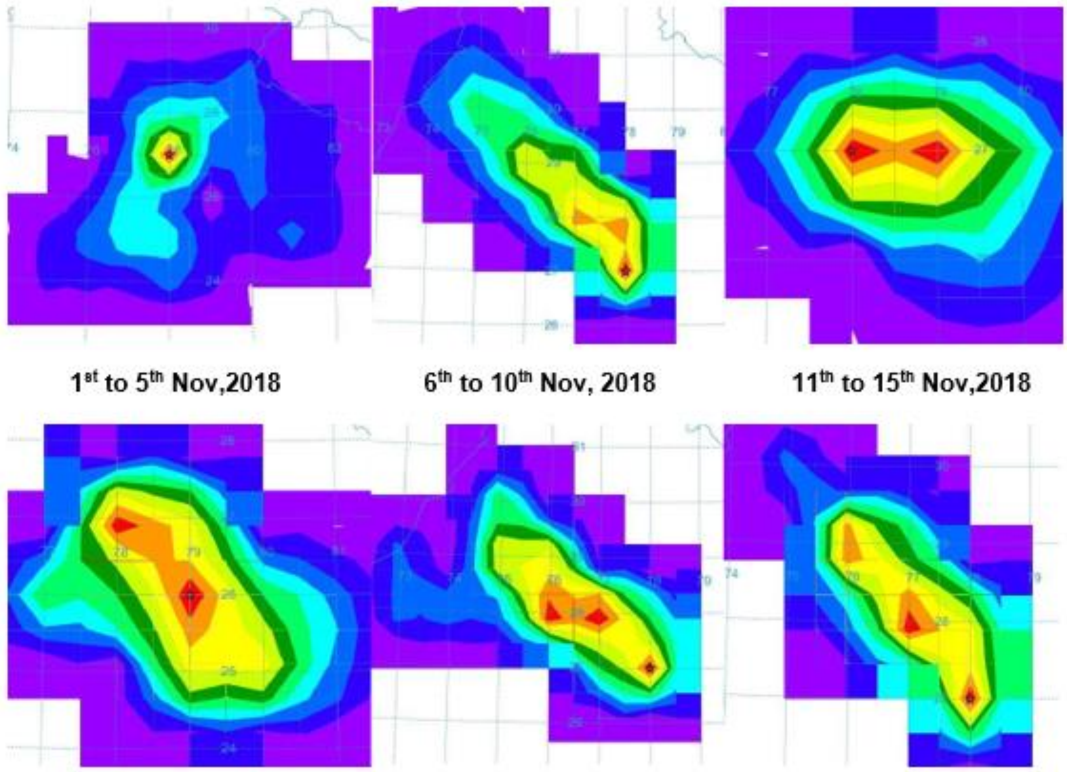
The meteorological data analysis was performed for the critical winter season, i.e., November, December 2018, and January 2019. The wind trajectories and speed were studied to identify the geographical extent of the airshed of Agra. The area over which wind blew over 30% of the time was considered as the area contributing air pollution to Agra.

As the wind blows over certain areas, it is likely to pickup $PM_{2.5}$ pollution from those areas. To assess this contribution, backward wind trajectories arriving into Agra were examined. Figures 4 - 6 present a percent number of wind trajectories passing over a certain area before reaching Agra in the winter season (November- December 2018 and January 2019).

For example, during 16th November – 30th November 2018, wind might start from anywhere (mostly from northwest), but most of its trajectory passes through the north of Agra (Figure 4). It implies all cities or emissions from the north will contribute to Agra's air pollution. It is noteworthy that most of the air mass starts from the northwest (i.e., Haryana and Uttar Pradesh) but by the time it arrives in Agra the air mass can almost pass over all areas around Agra (in all directions). This signifies that apart from emissions within the city, pollution from other cities is also be picked up and brought into Agra.

In a separate analysis, it is observed that the wind during December (Figure 5) may pass over an area from the upwind directions of west, north, and east of Agra and can contribute to Agra's air. In other words, we have to take some actions at the sources in these predominant upwind directions. Similar analysis showed that in January, 2019 the predominant wind direction was north west except during the periods of 16th - 20th January and 21st - 25th January when the dominant wind direction was west and north, respectively (Figure 6).

The airshed for the winter season was obtained (Figure 7) by superimposing the airsheds for different months and working out the union of all superimposed airsheds. Mathura, Bharatpur, Dholpur, Firozabad, Aligarh, Etah and Hathras districts fall under the Agra airshed.



1st to 5th Nov,2018 | 6th to 10th Nov, 2018 | 11th to 15th Nov,2018

16th to 20th Nov,2018 | 21st to 25th Nov,2018 | 26th to 30th Nov,2018

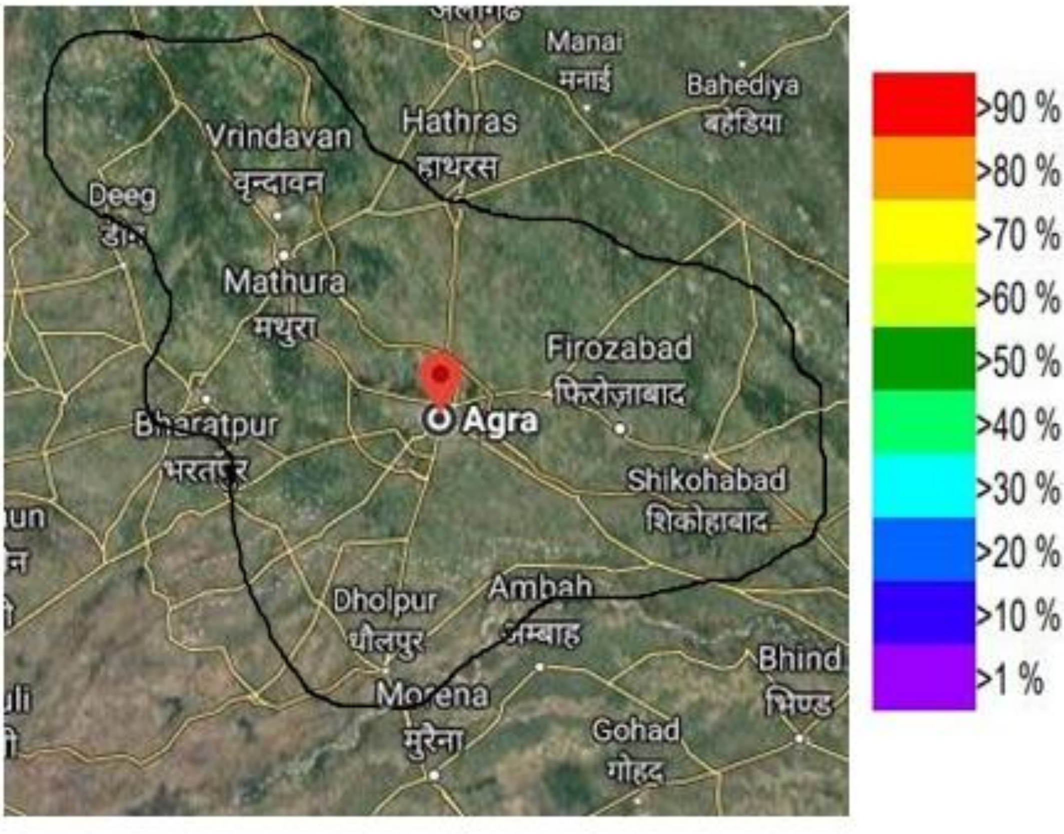


Figure 4: Wind Trajectory Contribution and Airshed Boundary in November 2018

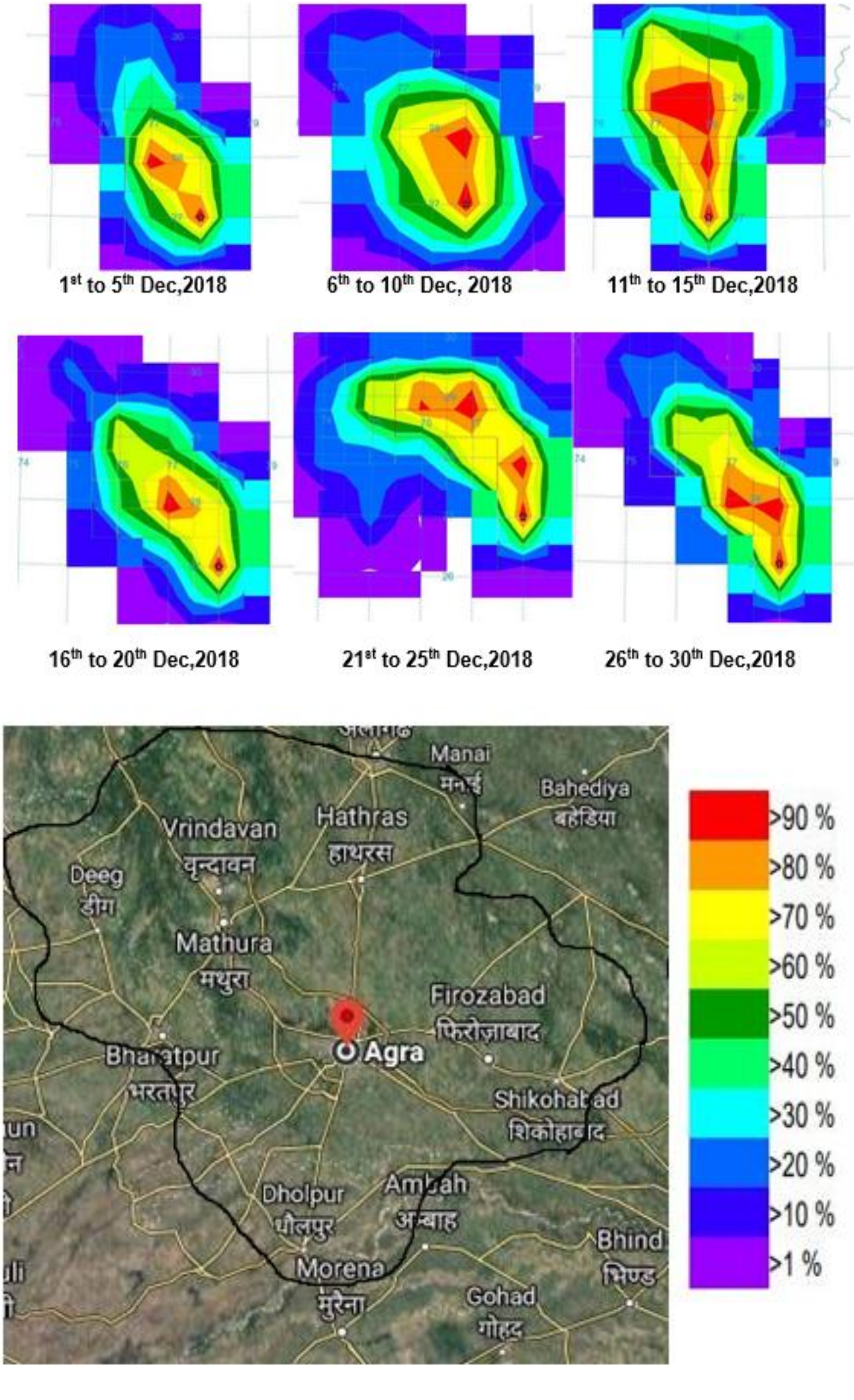


Figure 5: Wind Trajectory Contribution and Airshed Boundary in December 2018

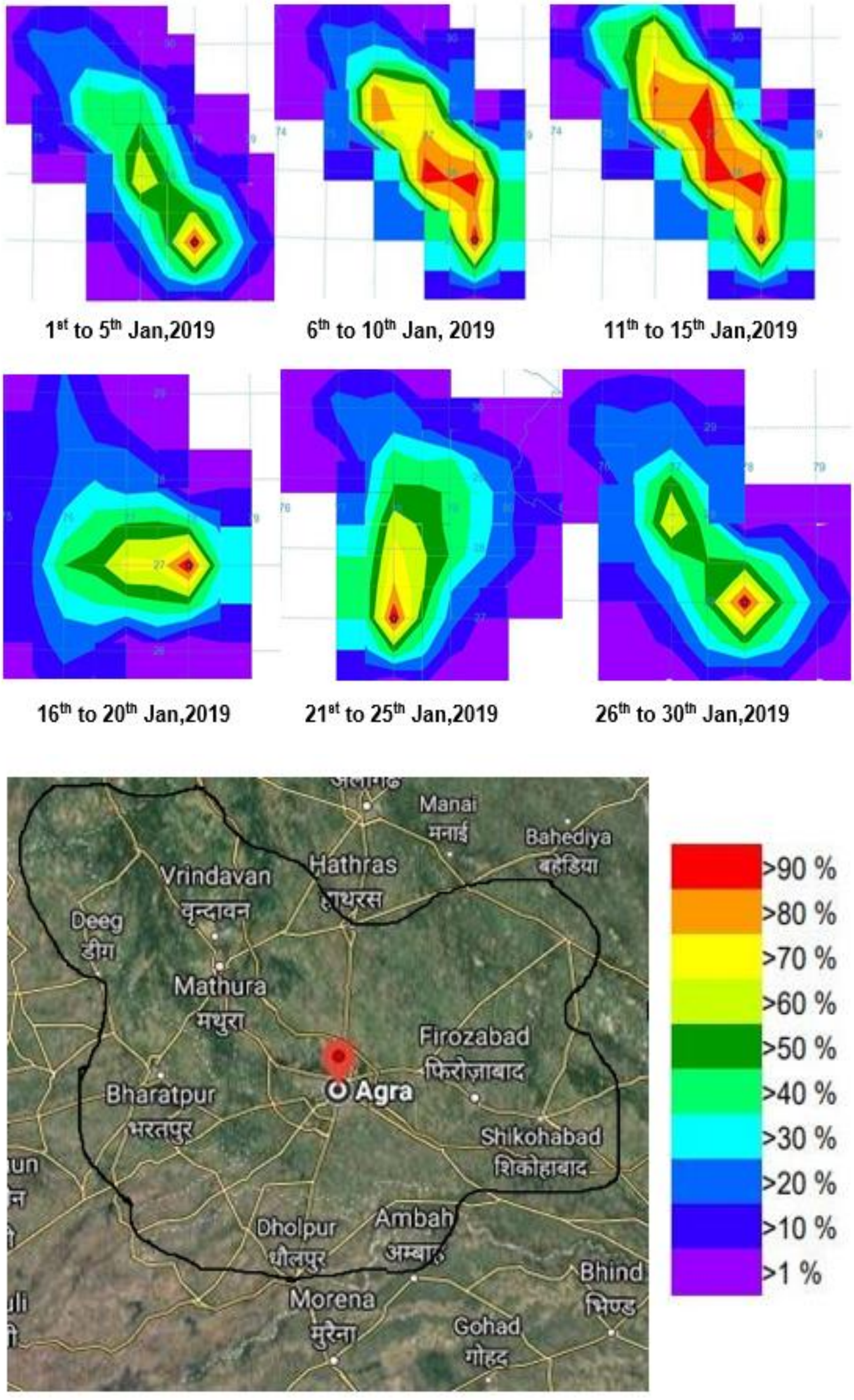


Figure 6: Wind Trajectory Contribution and Airshed Boundary in January 2019

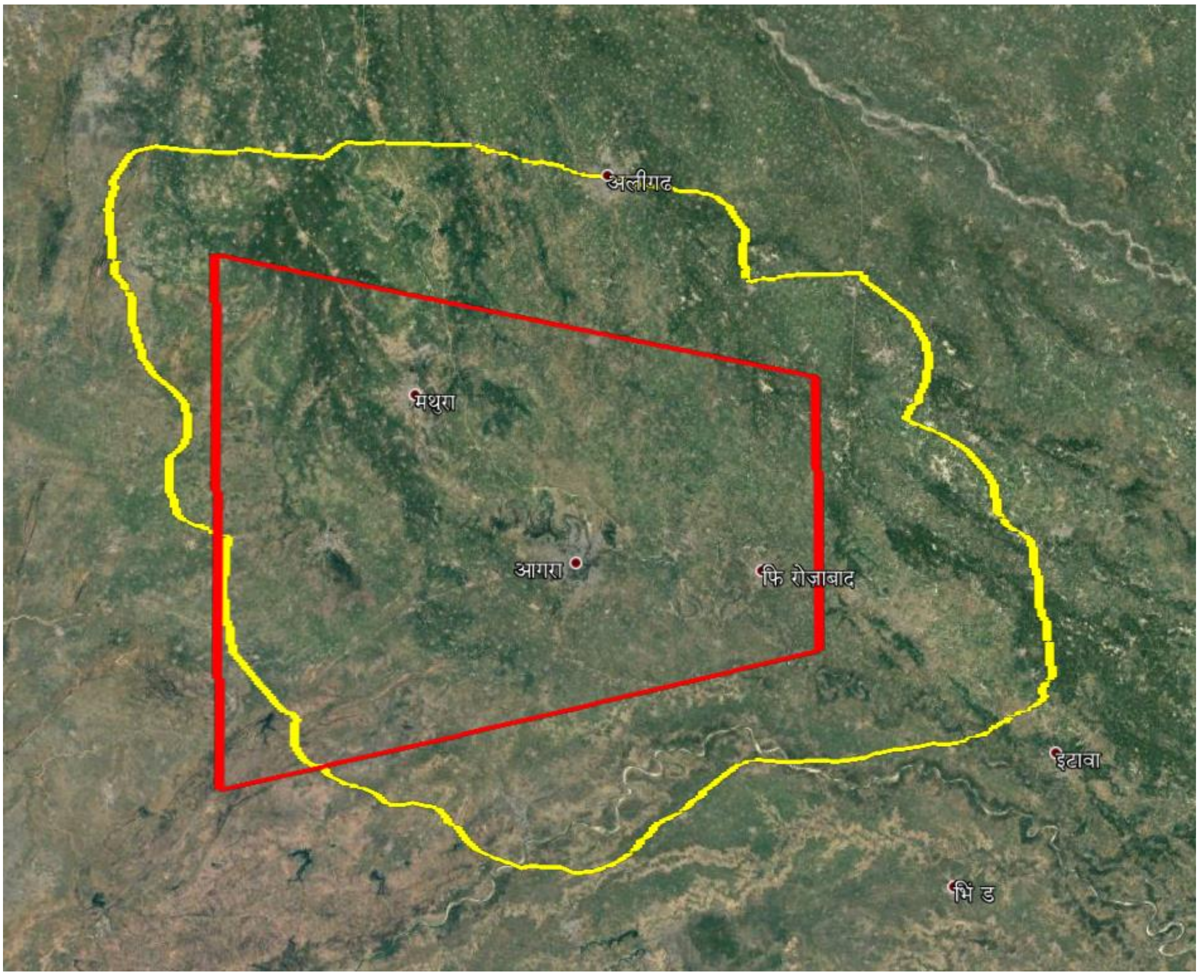


Figure 7: Agra Airshed (yellow) and TTZ Boundary (red)

3 Emission Inventory

Emission Inventory (EI) is a basic necessity for planning air pollution control activities. EI provides a reliable estimate of total emissions of different pollutants, their spatial and temporal distribution, and identification and characterization of main sources. This information on EI is an essential input to air quality models for developing strategies and policies. In this chapter, the emission inventory of the study area for the year 2018 is presented.

3.1 Methodology

The stepwise methodology adopted for this study is presented in Figure 8.

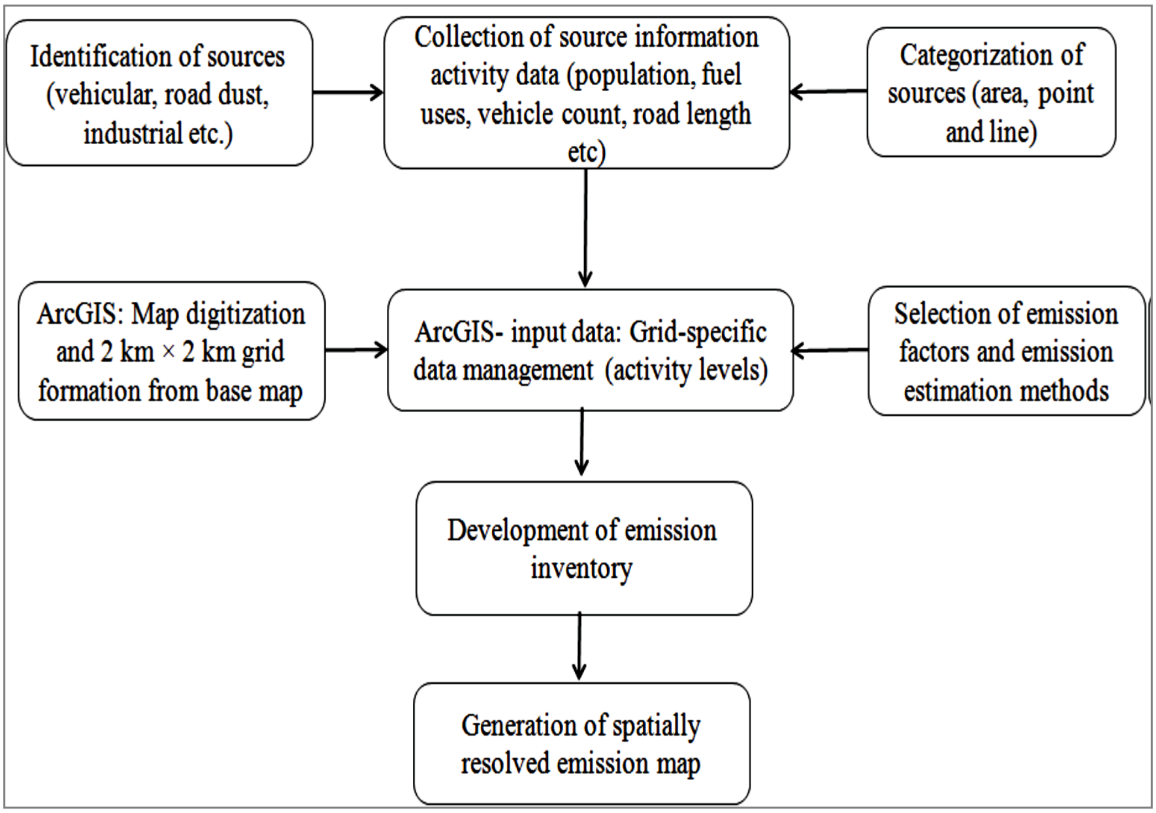


Figure 8: Stepwise Methodology for EI

Pollutants like PM_{10}, $PM_{2.5}$, NOx, SOx, CO, and BC are considered for developing EI. The major focus of the project is on industrial emissions. It was decided to develop an EI of all the industrial facilities lying within the airshed boundary. Also, an extensive exercise was conducted to develop Agra City's detailed emission inventory.

Emission Factors

An emission factor is a representative value that attempts to relate the quantity of a pollutant released to the atmosphere with an activity associated with the release of that pollutant. These factors are usually expressed as the mass of pollutants per unit mass of raw material, volume, distance traveled, or duration of the activity (e.g., grams of particulate emitted per kilogram of coal burnt). Such factors facilitate the estimation of emissions from various sources of air pollution. In most cases, these factors are simply averaging of all available data of acceptable quality and are generally assumed to be representative of long-term averages for all facilities in the source category. The general equation for emissions estimation is:

$$E = A \times EF \times (1 - ER/100) \qquad (1)$$

Where,

E = Emissions rate

A = Activity rate

EF = Emission factor, and

ER = Overall emission reduction efficiency, %

Table 1: Emission Factors (EF) used while estimating the emissions (Source: CPCB 2011)

Source		Units of Emission factor	PM_{10}	$PM_{2.5}$	NOx	SO_2	CO	BC
Domestic	Wood	g/kg	5.04	4.54	1.4	0.48	31	0.78
	Crop Residue	g/kg	11	9.90	0.49	0.12	58	0.74
	Dung	g/kg	5.04	4.54	1.4	0.48	31	0.47
	Coal	g/kg	20	18	3.99	13.3	24.92	1.64
	Kerosene	g/lit	0.61	0.55	2.5	4	4	0.18
	LPG	g/lit	2.1	1.89	1.8	0.4	0.4	0.04
DG Set		g/kwh	1.33	1.2	18.8	1.24	4.06	0.15
MSW Burning		g/kg	8	5.44	3	0.5	42	0.51
Brick Kiln	Wood	g/kg	15.3	13.7	1.4	0.2	115.4	
	Coal	g/kg	10.15	7.10	3.99	13.3	24.92	0.16
Industrial	LDO	g/lit	2.37	2.13	6.6	33.91	0.6	0.27
	HSD	g/lit	1.49	1.34	6.6	18.84	0.6	0.15
	Rice Husk	g/kg	11	9.9	0.49	0.12	58	1.25
	Wood	g/kg	17.3	15.57	1.3	0.2	126.3	1.98

	Sources	Units of Emission factor	PM_{10}	$PM_{2.5}$	NOx	SO_2	CO	BC
	Natural Gas	kg/(10)^6 m^3 (SCM)	121.6	109.4	2240	9.6	1344	13.9
	Coal	g/kg	10.15	1.05	11	9.5	0.25	0.03
	Diesel	g/lit	1.49	1.34	6.6	18.84	0.6	0.15
Vehicle	2 Wheelers	g/vkt	0.035	0.03	0.29	0	2.12	0.02
	3 Wheelers	g/vkt	0.27	0.24	0.5	0	0.54	0.15
	4 Wheelers	g/vkt	0.06	0.05	0.25	0	1	0.09
	LCV	g/vkt	0.64	0.58	3.1	0	1.86	0.19
	Bus	g/vkt	0.82	0.74	9.46	0	8.4	0.49
	Truck	g/vkt	0.82	0.74	9.46	0	8.4	0.34
Construction		kg/day/m^2	0.0025	0.0006	-	-	-	

Table 1 gives the values of emission factors used while calculating the emissions. The airshed boundary (Figure 9) is digitized and divided into 5 km x 5 km grids (Figure 10).

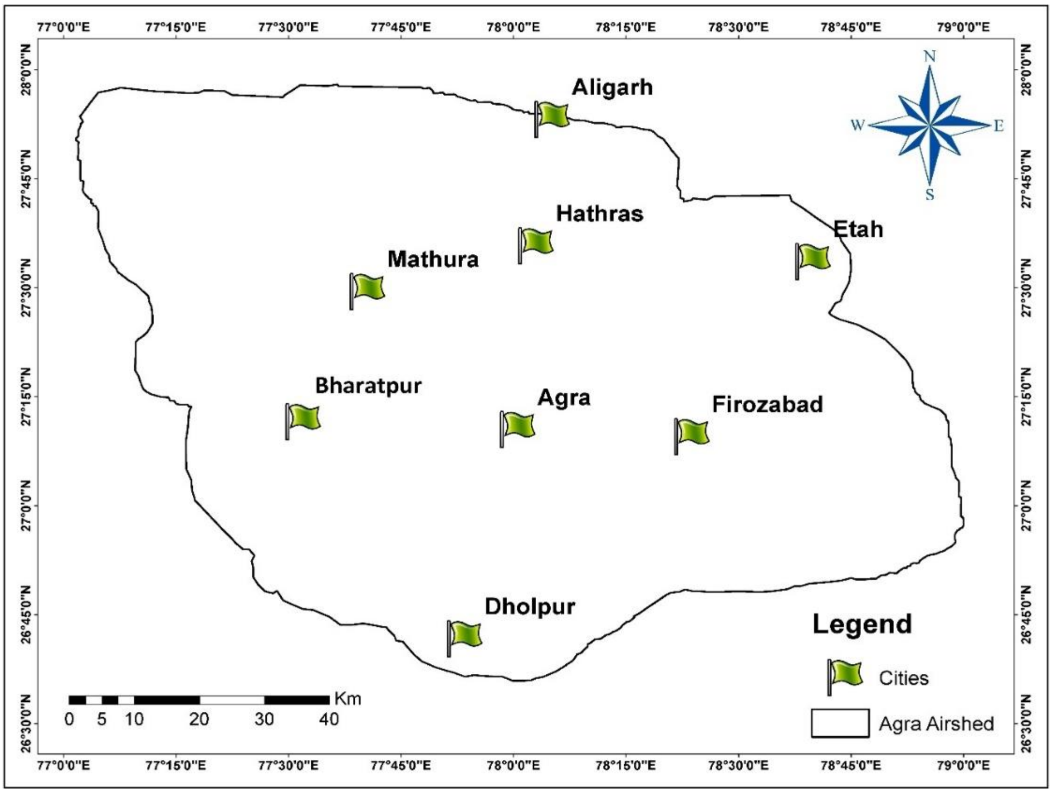


Figure 9: Airshed Map of Agra showing major cities.

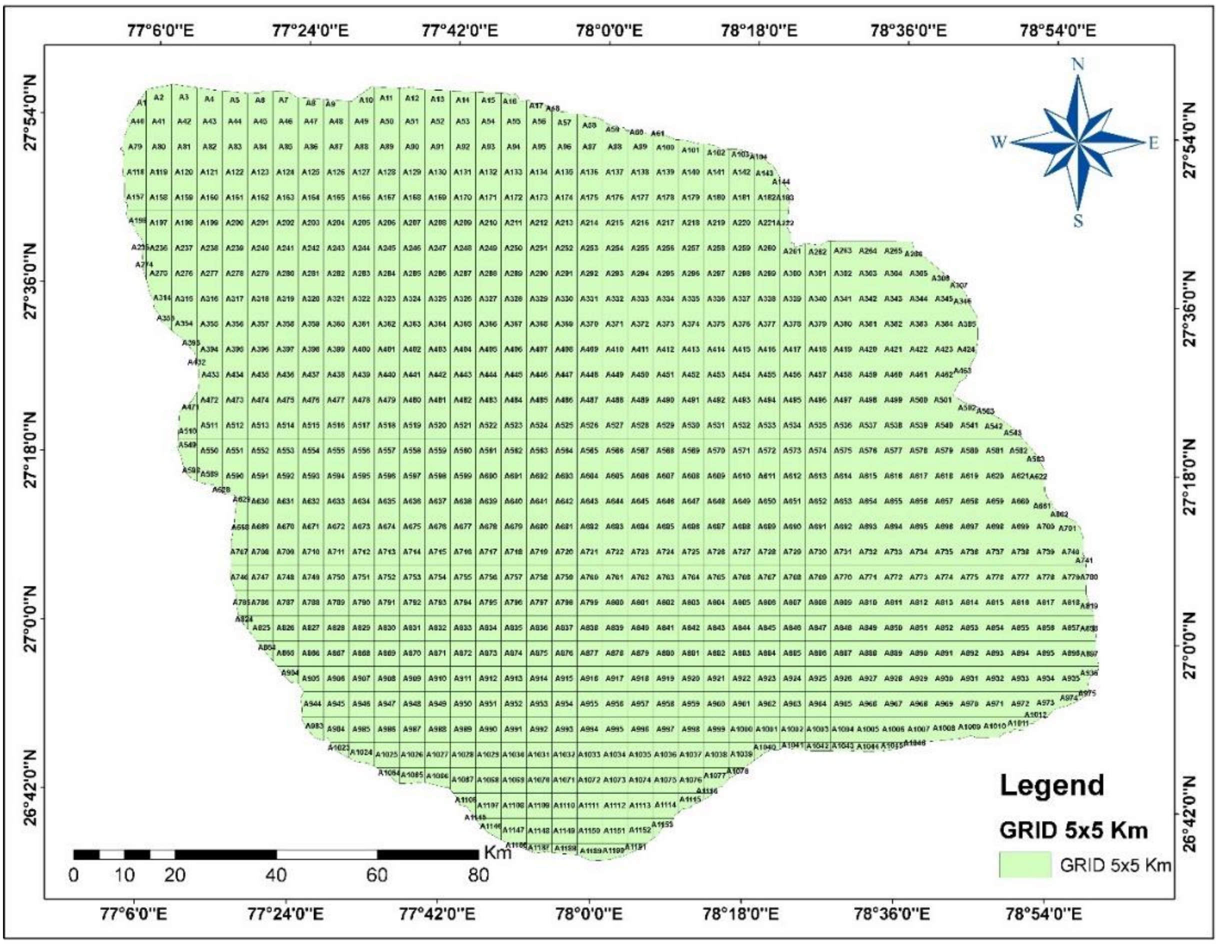


Figure 10: Airshed Map with 5 km x 5 km Grid

3.2 Emission Estimation in Agra Airshed

3.2.1 Industrial Sources

Industrial data were obtained from the CPCB and UPPCB. The collected information was compiled in the required format with a unique ID of each source. All the industrial sources at the facility level were geo-tagged. The industrial processes, diesel generators, and brick kilns were considered as industrial sources which may affect the air quality in the region. The CPCB emission factors (CPCB 2011) were used in the present study to estimate the emissions.

Brick Kilns

Brick kilns are amongthe major contributors to air pollution. The information on the number of the brick kilns and activity data were collected from CPCB, UPPCB, and Rajasthan State Pollution Control Board (RSPCB) and through satellite imagery. There are approximately 1200 brick kilns in the airshed of Agra (Figure 11 and Figure 12).

A survey was conducted in the study area to collect activity data (fuel usage, number of bricks per day, etc.) and the locations were identified through satellite imagery. An assumption was made that 50% of the brick kilns were on Zig Zag technology and remaining on conventional (Bull-Trench) technology (EF varies for two technologies). Some brick kilns were present just at the border of the airshed which have also been accounted for in the present study. Wood and coal are the prominent fossil fuels being used in these brick kilns. The emissions of various pollutants such as SO_2, NO_x, PM_{10}, $PM_{2.5}$, CO, and BC were estimated for each grid from the activity data as per the fuel type and the technology used.

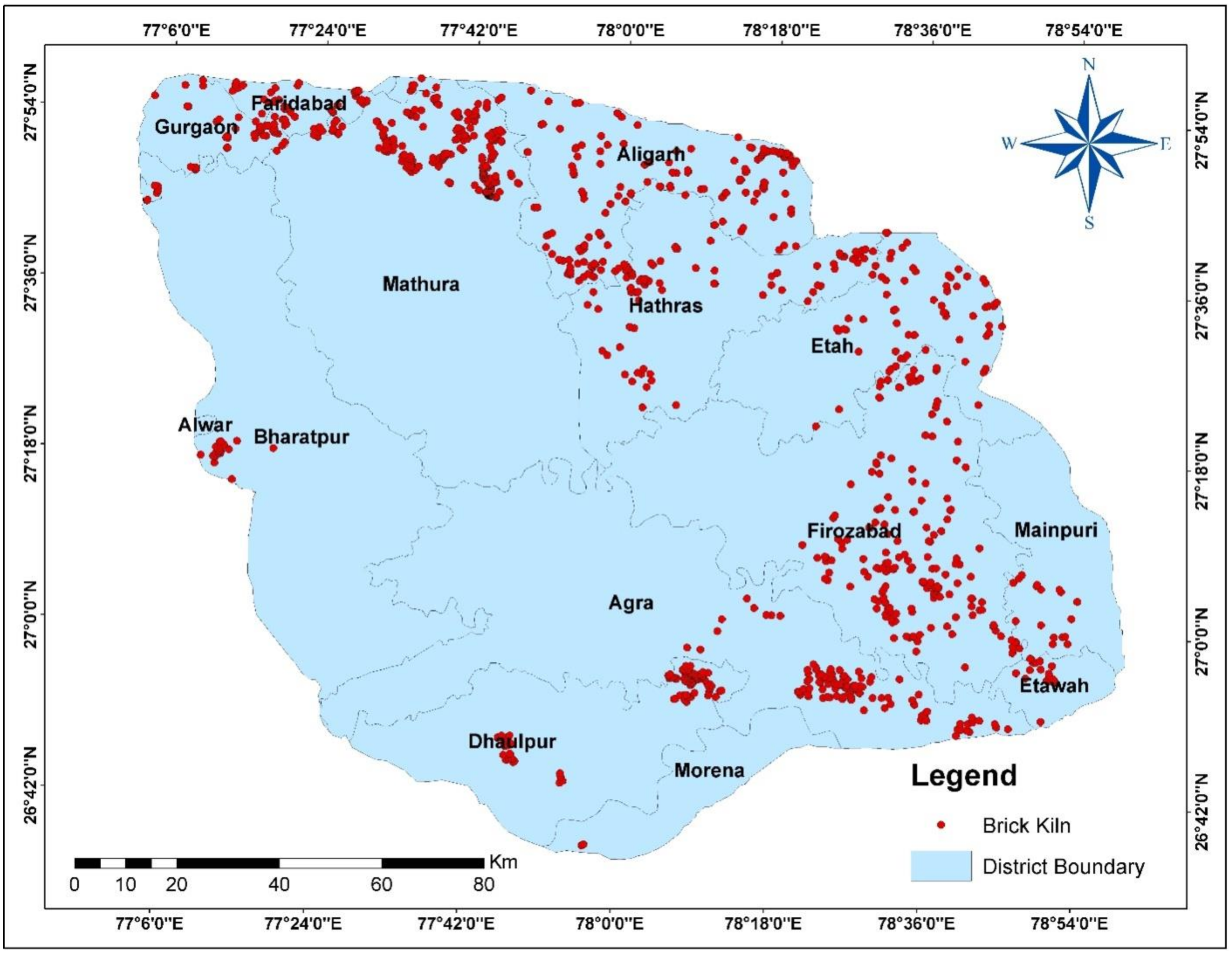


Figure 11: Brick Kiln Locations in the Agra Airshed

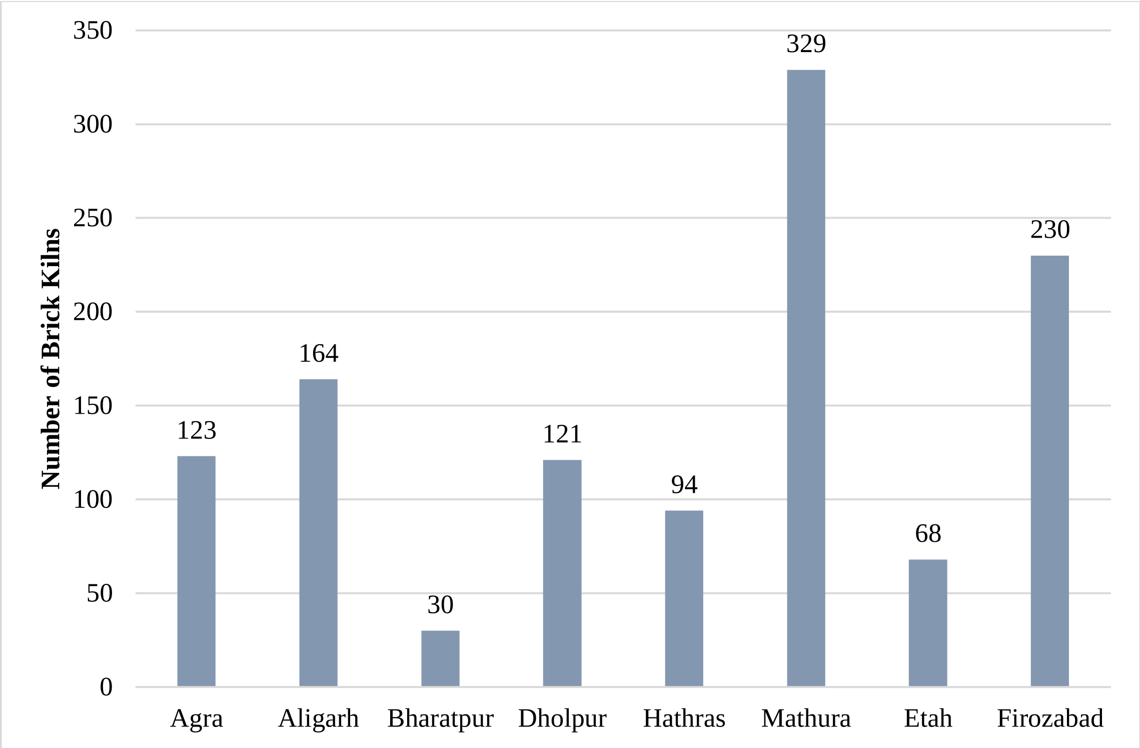


Figure 12: Brick Kilns operating in the Agra Airshed (Total 1200 Brick Kilns)

The emissions from brick kilns have been estimated using equation (1) and the results (rounded off to nearest integer) are shown in Figures 13 to 18.

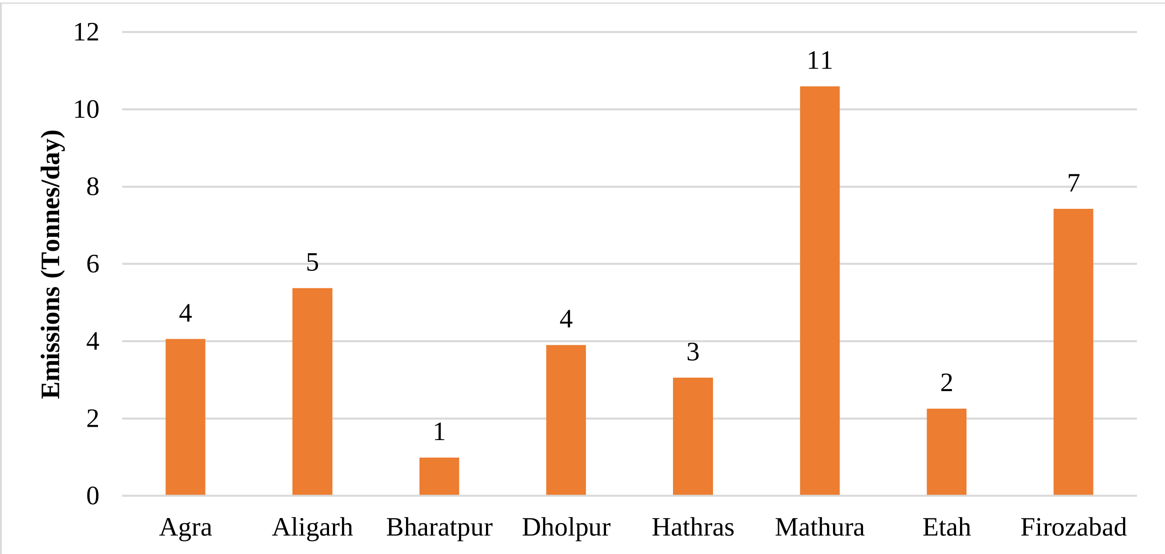


Figure 13: PM_{10} emission from Brick Kilns (Total = 37 tons/day)

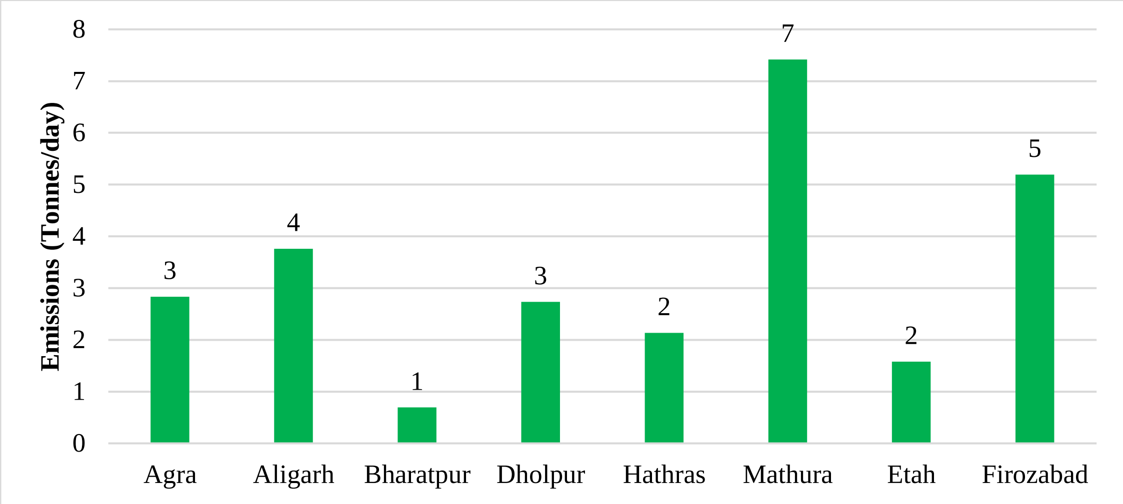


Figure 14: $PM_{2.5}$ emission from Brick Kilns (Total = 27 tons/day)

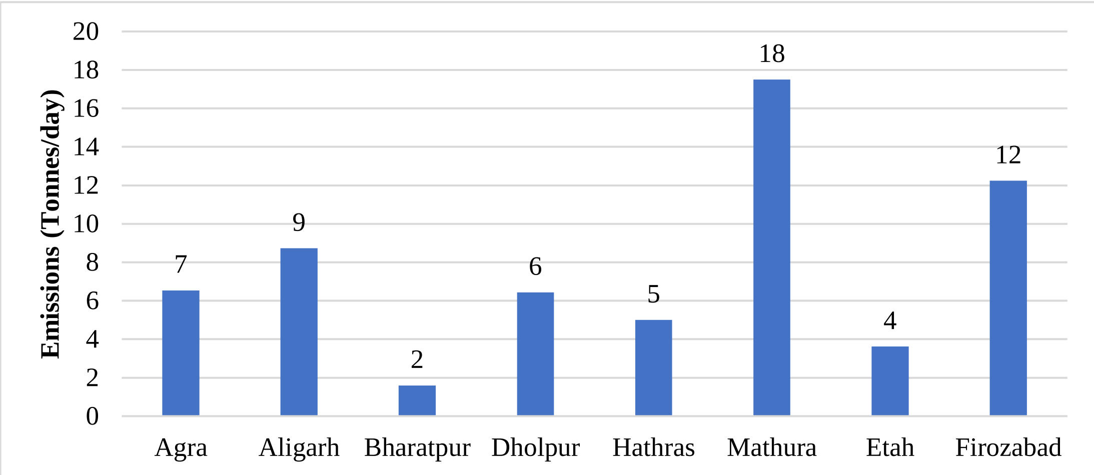


Figure 15: SO_2 emission from Brick Kilns (Total = 63 tons/day)

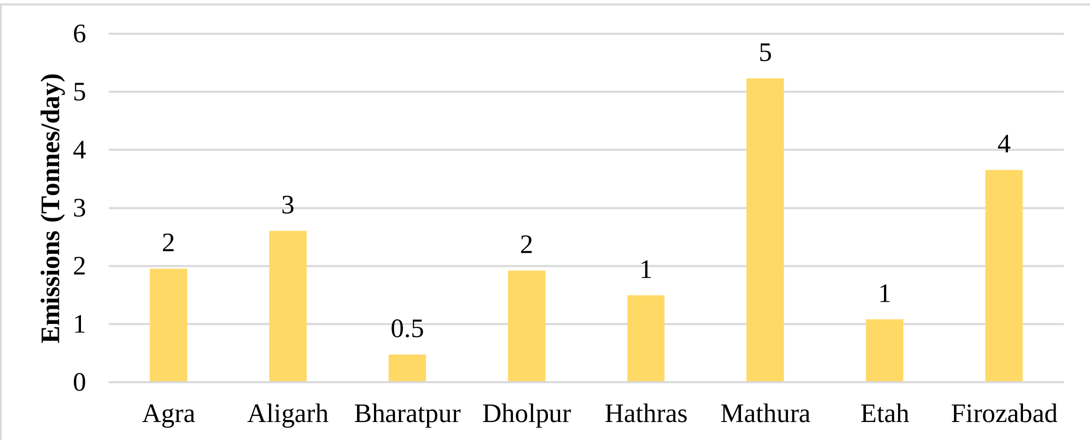


Figure 16: NO_x emission from Brick Kilns (Total = 18 tons/day)

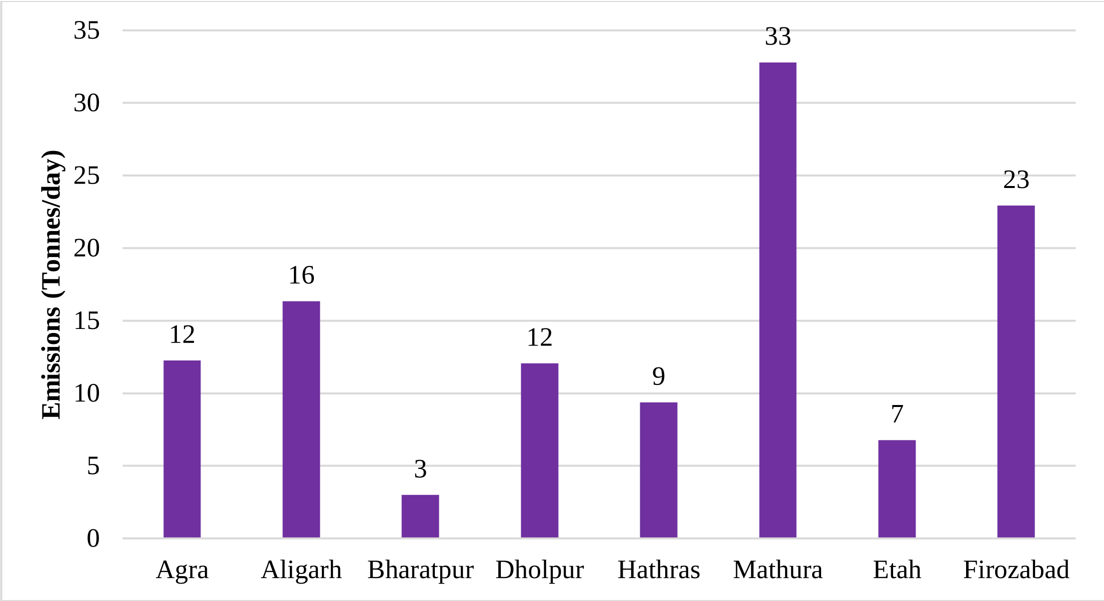


Figure 17: CO emission from Brick Kilns (Total = 115 tons/day)

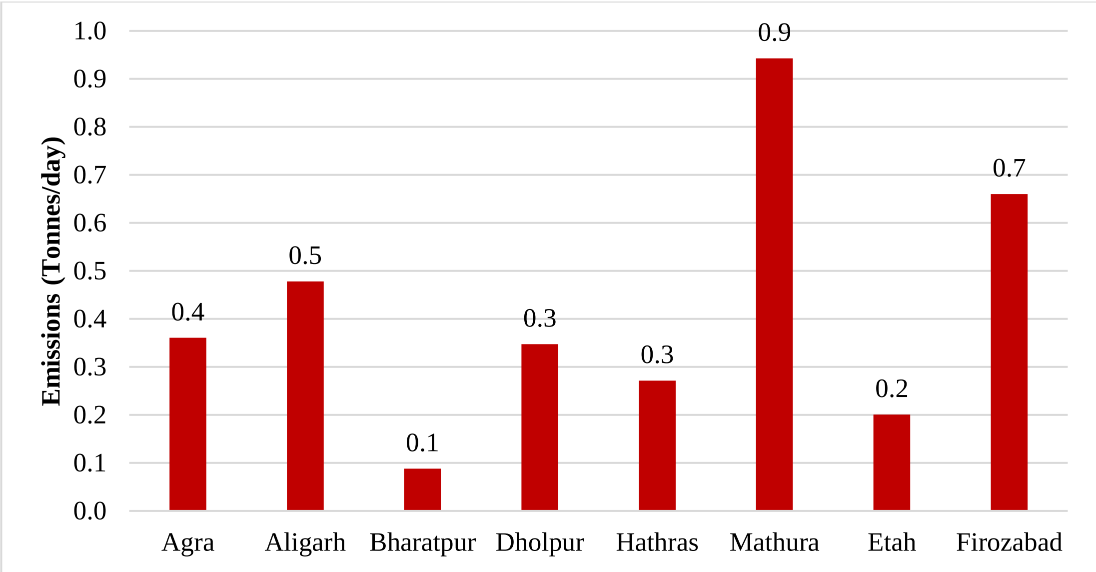


Figure 18: BC Emission from Brick Kilns (Total = 3.4 tons/day)

The spatial maps for PM_{10}, $PM_{2.5}$, SO_2, NO_x, CO and BC are shown in Figures 19 to 24.

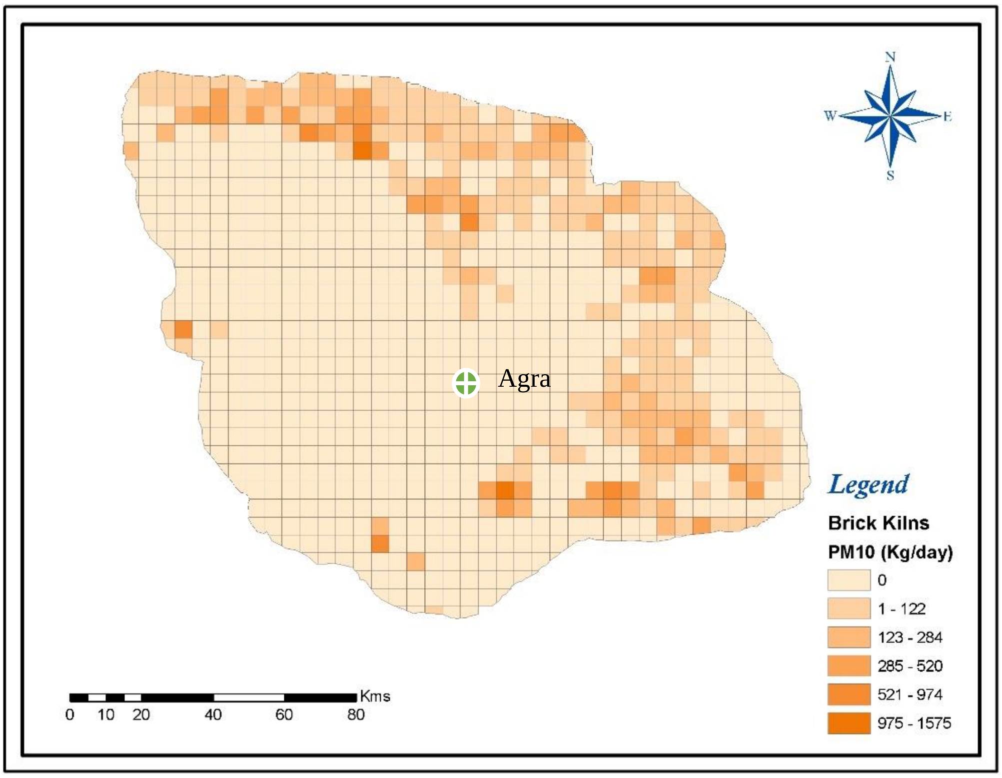


Figure 19: Spatial Map of PM_{10} Emission from Brick Kilns

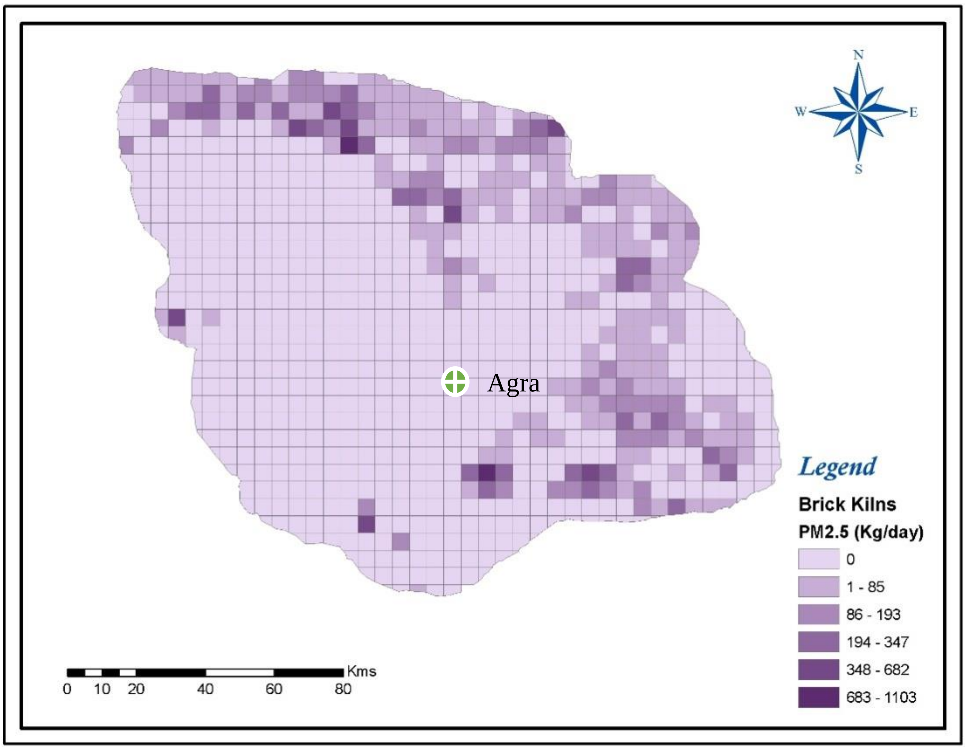


Figure 20: Spatial Map of $PM_{2.5}$ Emission from Brick Kilns

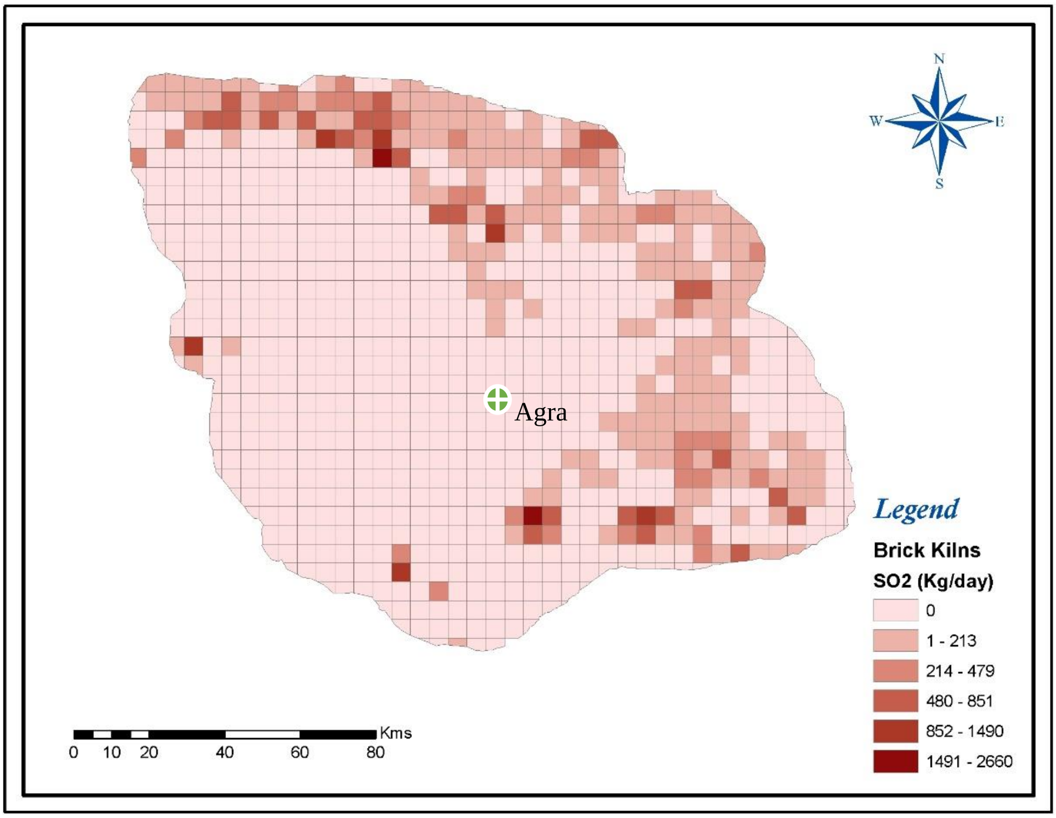


Figure 21: Spatial Map of SO_2 Emission from Brick Kilns

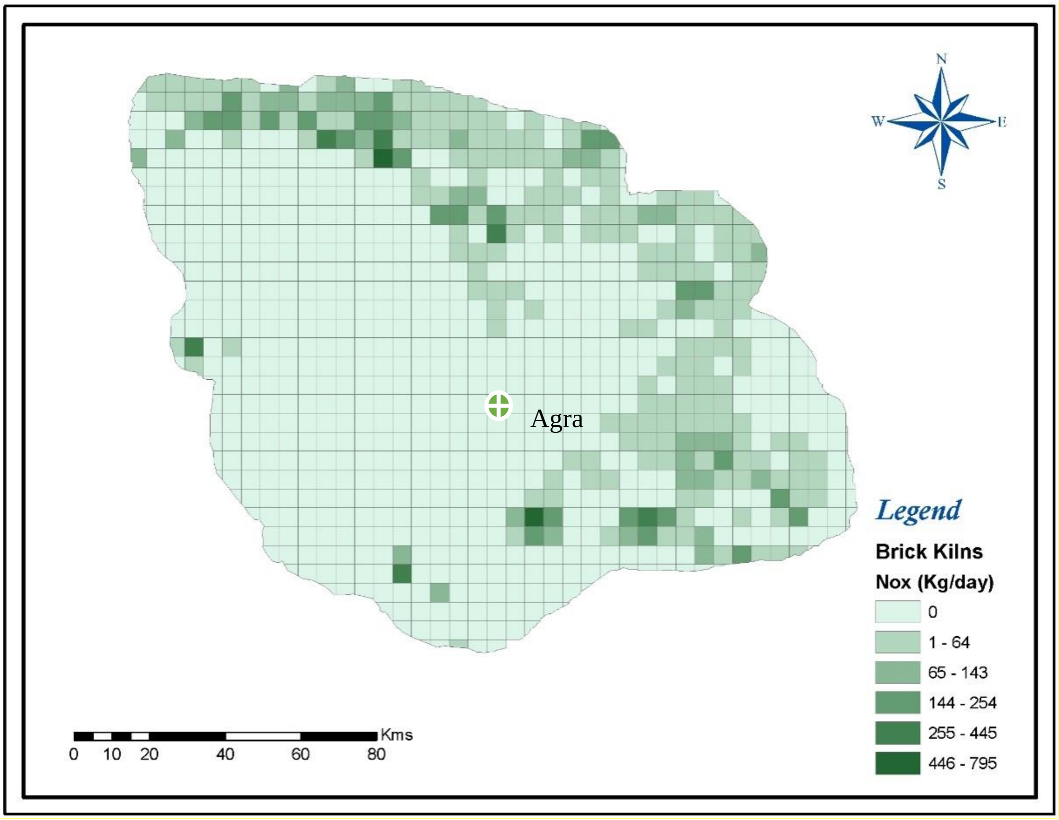


Figure 22: Spatial Map of NO_x Emission from Brick Kilns

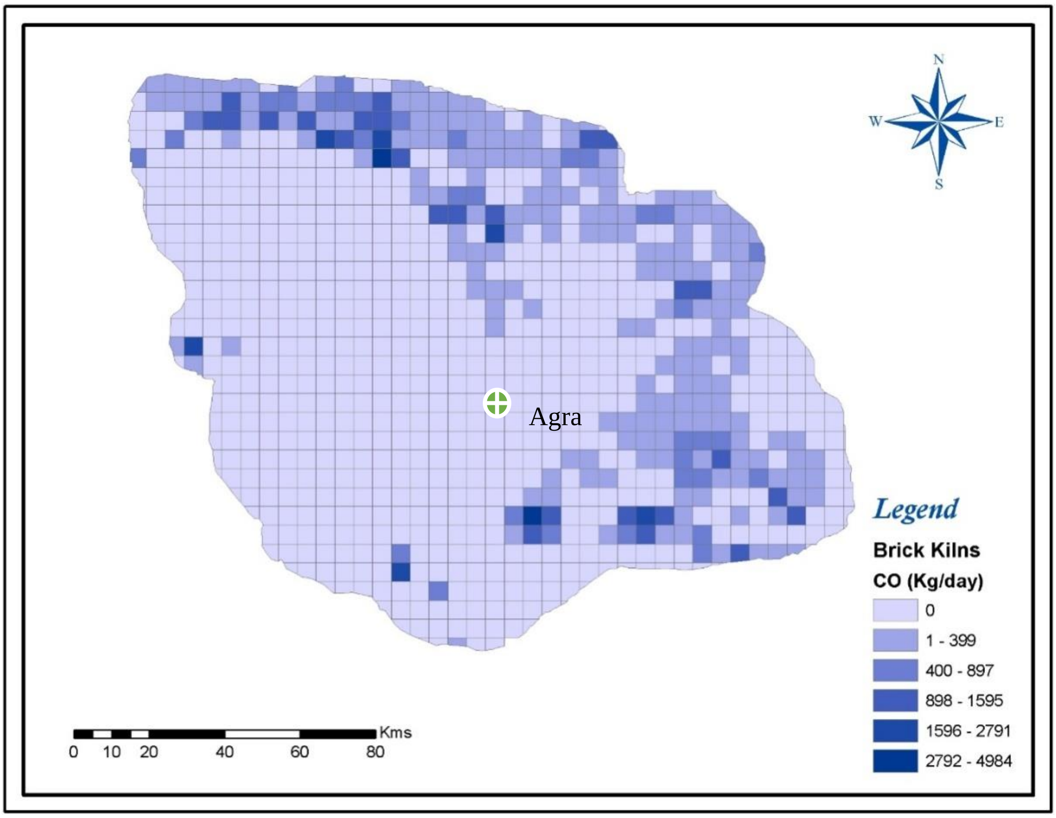


Figure 23: Spatial Map of CO Emission from Brick Kilns

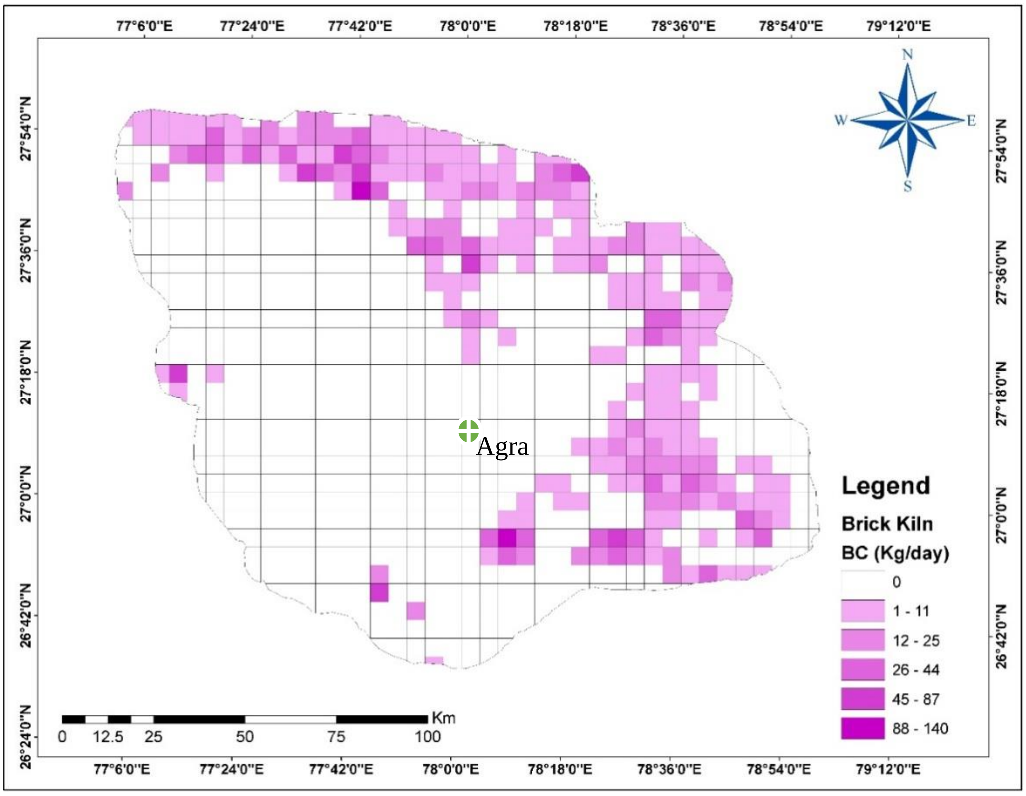


Figure 24: Spatial Map of BC Emission from Brick Kilns

Industries (other than Brick Kilns)

The information on the number of industrial facilities and activity data were collected from CPCB and UPPCB. There are approximately 1300 industries that are air polluting in nature and require consent to operate from the state pollution control board. Nearly 55% of the industries have a captive electric power generator (DG set) installed for emergency backup for electricity. These generators run on diesel and natural gas.

Natural gas, wood, agricultural waste, and coal are the prominent fuels that are used in the industrial processes. The emissions of various pollutants such as SO_2, NO_x, PM_{10}, $PM_{2.5}$, CO, and BC were estimated for each grid from the activity data as per the fuel type and the process used. The location of industries is shown in Figure 25.

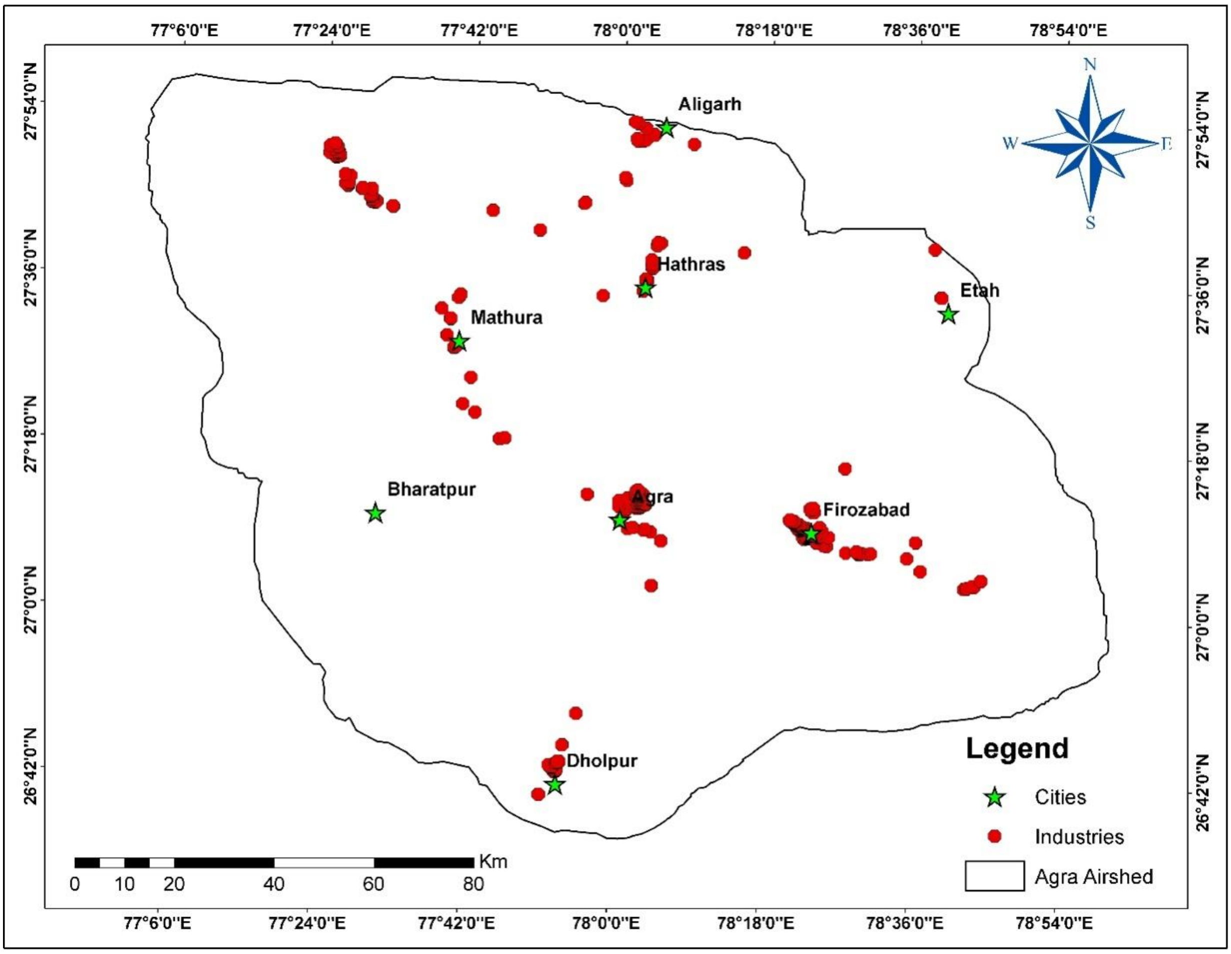


Figure 25: Industries Locations in the Agra Airshed

The emissions from industries have been estimated using equation 1 and the results are shown in Figures 26 to 31. Bharatpur district does not have any process industries which are air polluting in nature.

The emissions at Mathura and Aligarh are substantially high due to the presence of an oil refinery at Mathura, and Harduaganj thermal power plant in Aligarh. The emission from Aligarh is more due to the usage of coal, wood, and crop residue in the industrial processes.

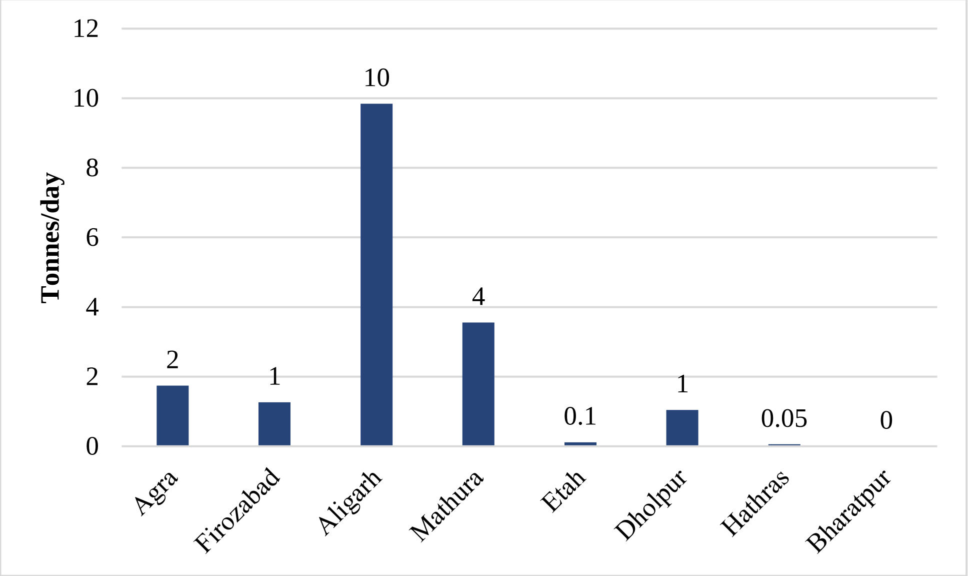


Figure 26: PM_{10} Emission from Industries (Total = 17.6 tons/day)

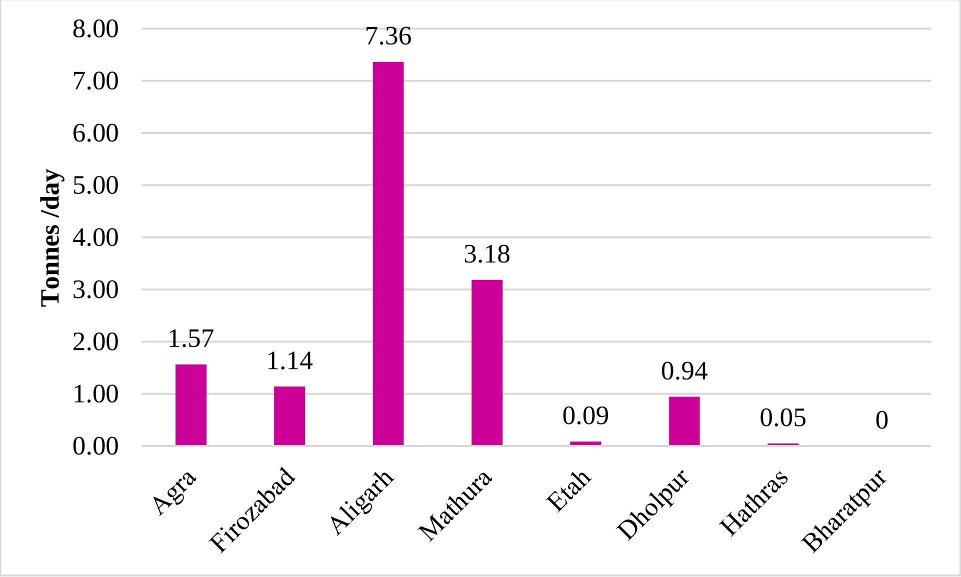


Figure 27: $PM_{2.5}$ Emission from Industries (Total = 14.3 tons/day)

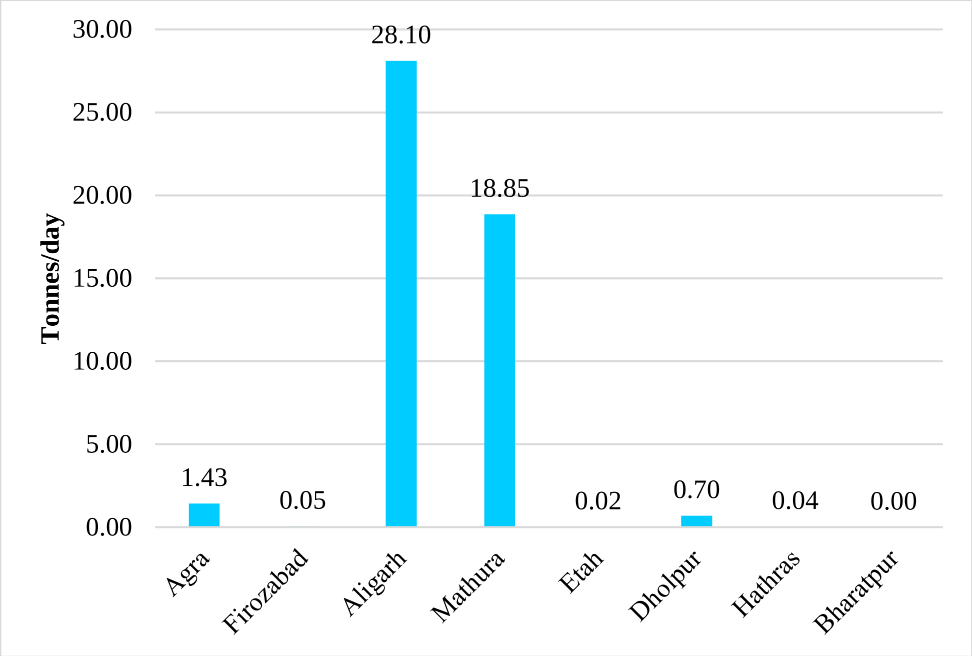


Figure 28: SO_2 Emission from Industries (Total = 49.2 tons/day)

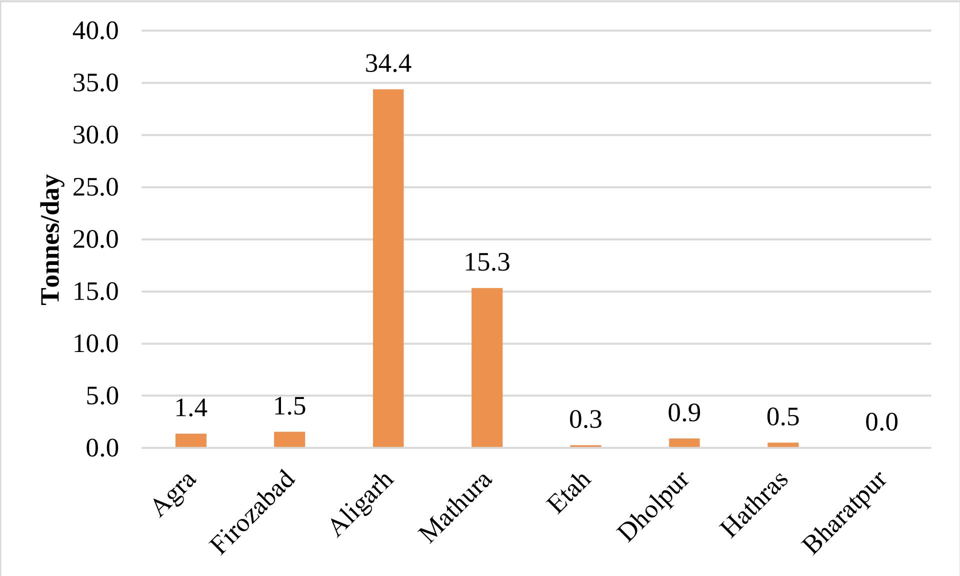


Figure 29: NOx Emission from Industries (Total = 54.3 tons/day)

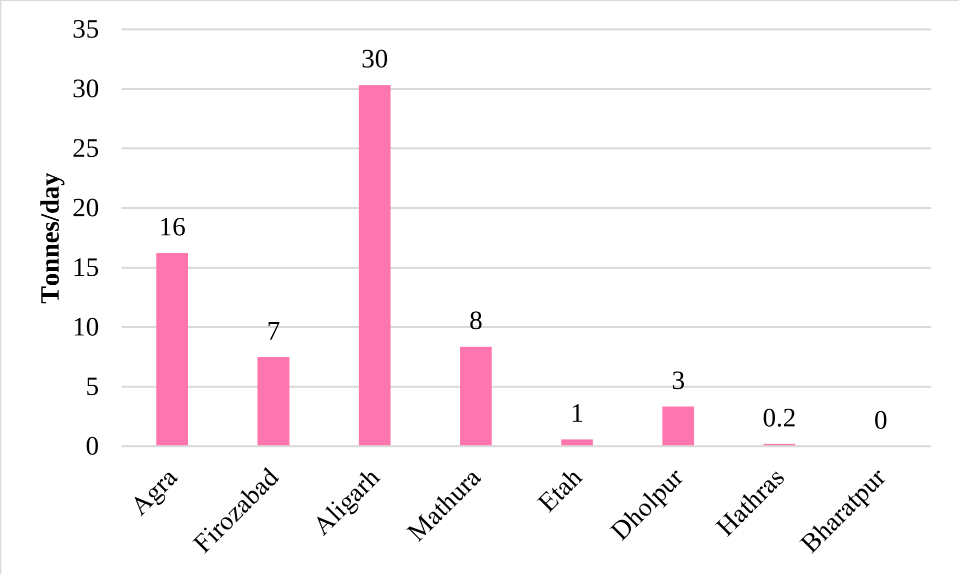


Figure 30: CO Emission from Industries (Total = 66.5 tons/day)

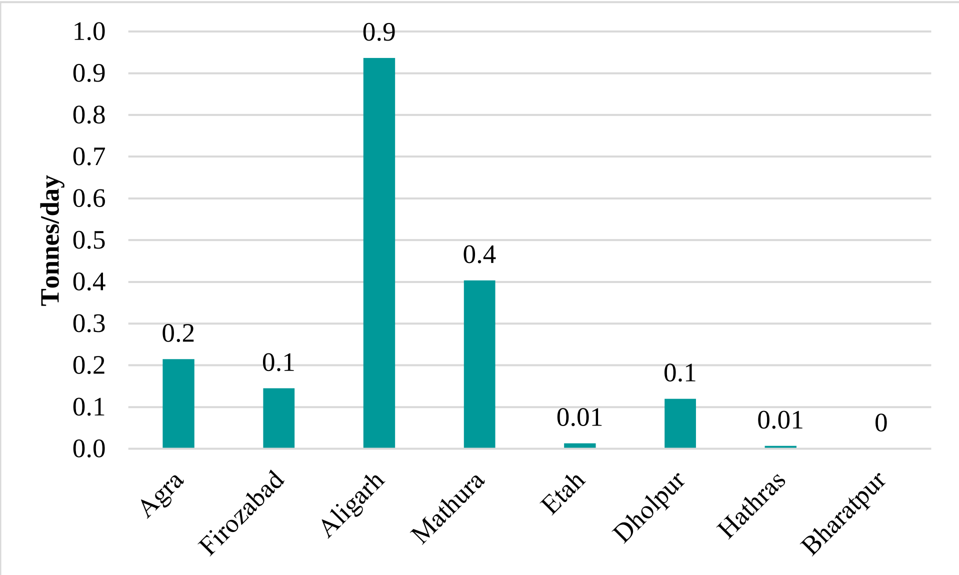


Figure 31: BC Emission from Industries (Total = 1.8 tons/day)

The details of district-wise emissions are presented in Tables 2 to 8.

Table 2: Furnace/Boiler/DG Sets Details in Etah district (Emissions in kg/day)

Boiler/Furnace Type	Fuel used in Boiler/Furnace/DG Sets	No. of Furnaces/ Boilers/DG Sets	PM_{10}	$PM_{2.5}$	SO_2	NOx	CO	BC
Boiler	Husk	2	99	69	1	4	522	11
Hot Air Generator	Wood	1	1.3	0.9	0.02	0.1	9	0.1
DG Sets	Diesel	37	18	16	17	253	55	2
Total		40	118	86	18	257	586	13

Table 3: Furnace/Boiler/DG Sets Details in Agra district (Emissions in kg/day)

Boiler/Furnace Type	Fuel used in Boiler/Furnace/DG Sets	No. of Furnaces/ Boilers/DG Sets	PM_{10}	$PM_{2.5}$	SO_2	NOx	CO	BC
Baby Boiler	Diesel(3), Gas(2)	5	8	7	98	40	7	1
Boiler	Diesel(7), Natural Gas(5)	12	39	35	449	210	41	5
Induction Furnace	Electricity	36	116	104	0	0	0	13
Annealing Furnace	Natural Gas	1	0.029	0.026	0.0001	1.08	0.60	0.001
Cupola Furnace*	Gas and Coke Bed	48	1524	1372	790	436	16016	190
Pit furnace	Gas	5	0.138	0.124	0.001	5	3	0.006
Tank furnace	Gas	2	1	0.9	0.03	18	10	0.1
Thermic Fluid Heater	Diesel	1	7	6.7	48	33	6	1
DG Set	Diesel (56), Gas(61)	117	44	40	41	625	141	5
Total		227	1739	1566	1426	1368	16225	215

*The emission factors were taken from USEPA AP-42. Since the furnaces are gas-based with some uses of coke, the emissions are expected to be less than the stated quantity.

Table 4: Furnace/Boiler/DG Sets Details in Firozabad district (Emissions in kg/day)

Boiler/Furnace Type	Fuel used in Boiler/Furnace/DG Sets	No. of Furnaces/ Boilers/DG Sets	PM_{10}	$PM_{2.5}$	SO_2	NOx	CO	BC
Boiler	Bagasse(1), Wood(1), Husk(5), Gas(5)	12	1182	1064	14	73	6717	135
Tank Furnace	Gas	46	24	21	11	440	264	3
Folding Furnace	Gas	2	0.14	0.13	0.01	3	2	0.01
Furnace	Gas	1	0.036	0.033	0.003	1	0.403	0.004
Hot Air Generator	Gas	1	0.44	0.39	0.03	8	5	0.05
Pot Furnace	Gas	51	7	7	4	137	82	0.8
Pot/Tank/Folding Furnace	Gas	110	31	28	4	571	342	4
DG Set	Gas(5), Diesel(40)	45	21	19	20	303	65	2
Total		268	1266	1139	53	1536	7477	145

Table 5: Furnace/Boiler/DG Sets Details in Aligarh district (Emissions in kg/day)

Boiler/Furnace Type	Fuel used in Boiler/Furnace/DG Sets	No. of Furnaces/ Boilers/DG Sets	PM_{10}	$PM_{2.5}$	SO_2	NOx	CO	BC
Power plant (Coal)	Coal	1	2495	1103	24955	28895	657	140
Uncategorized Boiler	Diesel(1), Coal(8), Wood(17), Rice Husk(9)	35	3524	2906	1328	1649	14006	369
Bhatti	Wood	3	623	561	7	47	4547	71
Re-Heating Furnace	Coal	4	67	60	63	73	2	8
Cupola Furnace	Coal(3), Hard Coke(2)	5	609	548	570	660	15	70
Induction Furnace	Electricity	5	275	246	0	0	0	31
Lead Melting Pot	Wood	1	1038	934	12	78	7578	119
Oil Fired Furnace	Diesel	2	36	32	452	158	14	4
Pyrolysis Reactor	Wood	2	415	291	5	31	3031	37
Pit Furnace	Coal	1	609	548	570	660	15	70
DG Set	Diesel	231	150	135	140	2123	458	17
Total		295	9841	7364	28102	34374	30323	936

Table 6: Furnace/Boiler/DG Sets Details in Hathras district (Emissions in kg/day)

Boiler/Furnace Type	Fuel used in Boiler/Furnace/DG Sets	No. of Furnaces/ Boilers/DG Sets	PM_{10}	$PM_{2.5}$	SO_2	NOx	CO	BC
Baby Boiler	Wood	2	6	5	0.1	0.4	42	1
Boiler	Wood	2	6	5	0.1	0.4	45	1
Furnace	Coal	1	2	2	2	2	0.05	0.2
Pit Furnace	Coal	2	3	3	3	3	0.07	0.3
Round Arch Furnace	Coal	1	2	2	2	2	0.05	0.2
Thermopack	Coal	1	0.4	0.3	0.4	1	0.01	0.06
DG Set	Diesel	68	35	32	33	496	107	4
Total		77	54	48	41	504	194	7

Table 7: Furnace/Boiler/DG Sets Details in Dholpur district (Emissions in kg/day)

Boiler/Furnace Type	Fuel used in Boiler/Furnace/DG Sets	No. of Furnaces/ Boilers/DG Sets	PM_{10}	$PM_{2.5}$	SO_2	NOx	CO	BC
Annealing Furnace	LSHS	1	5	4.6	73	14	1	1
Boiler	Wood(4), Husk(1), Biofuel(4),Diesel(3)	12	446	402	32	42	3153	51
Cupola Furnace	Electricity and Coke Bed	6	21	19	20	23	1	2
Induction Furnace	electricity	15	4	4	0	0	0	1
Mandir Furnace	Coal	12	6	5.6	6	7	0.2	0.7
Pot Furnace	Wood(1),Coal(9)	10	23	21	7	9	114	3
Rotary Furnace	Coal	8	526	474	544	585	15	60
DG Set	Diesel	27	15	13	14	209	45	1
Total		91	1046	943	696	889	3329	120

Table 8: Furnace/Boiler/DG Sets Details in Mathura district (Emissions in kg/day)

Boiler/Furnace Type	Fuel used in Boiler/Furnace/DG Sets	No. of Furnaces/ Boilers/DG Sets	PM_{10}	$PM_{2.5}$	SO_2	NOx	CO	BC
Blowing column	Diesel	2	60	54	754	264	24	7
Boiler	Agricultural Waste(9), Gas(8), Coal(6), Diesel(2)	25	1301	1171	1462	1101	6287	149
Gas Fired Furnace	Gas	3	9	8	1	168	101	1
Cupola Furnace	Gas	4	15	13	1	269	161	2
Heating burner	Diesel	1	30	27	377	132	12	3
Hot Air Generator	Coal(2), Diesel(1), Gas(5)	8	233	210	567	352	124	27
Incinerator	Gas(1), Diesel(1)	2	71	64	904	317	29	8
Melting Furnace	Gas	2	3	2.72	0.24	56	34	0.3
Oil fired Thermo-pack	Diesel	1	30	27	377	132	12	3
Oil Refinery	Sulphur Recovery, Gas, fuel oil	1	112	86	10141	4005	67	11
Fuel Heater	Agricultural Waste(2), Gas(31), Coal(8), Diesel(12)	53	639	575	2935	1362	94	73
Thermo-pack	Coal(2), Diesel(1)	3	598	538	909	748	25	68
DG Set	Diesel	200	454	409	423	6420	1386	51
Total		305	3555	3185	18851	15326	8356	403

The spatial maps of industrial emissions of PM_{10}, $PM_{2.5}$, SO_2, NO_x, CO, and BC are shown in Figures 32 to 37.

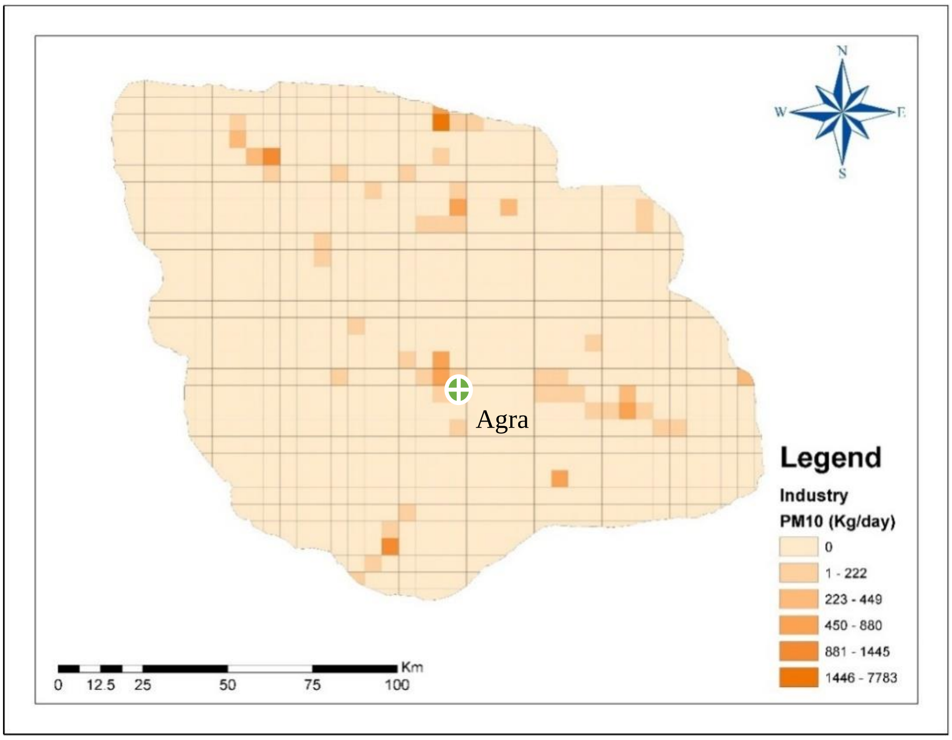


Figure 32: Spatial Map of PM_{10} Emission from Industries

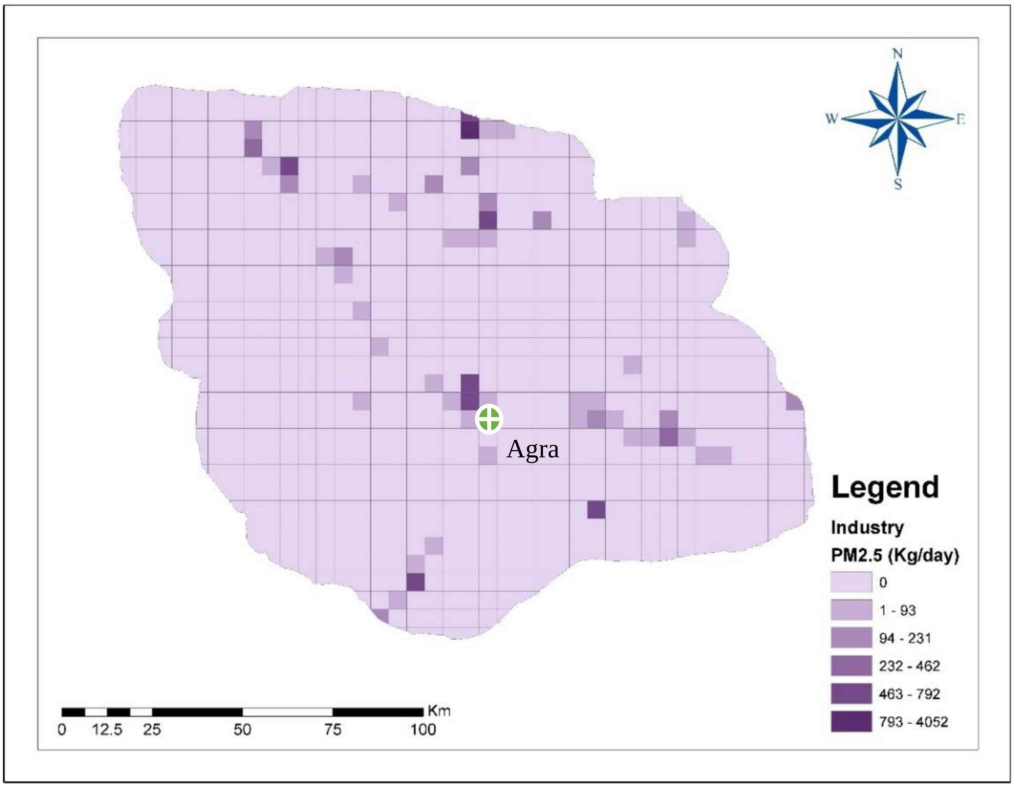


Figure 33: Spatial Map of $PM_{2.5}$ Emission from Industries

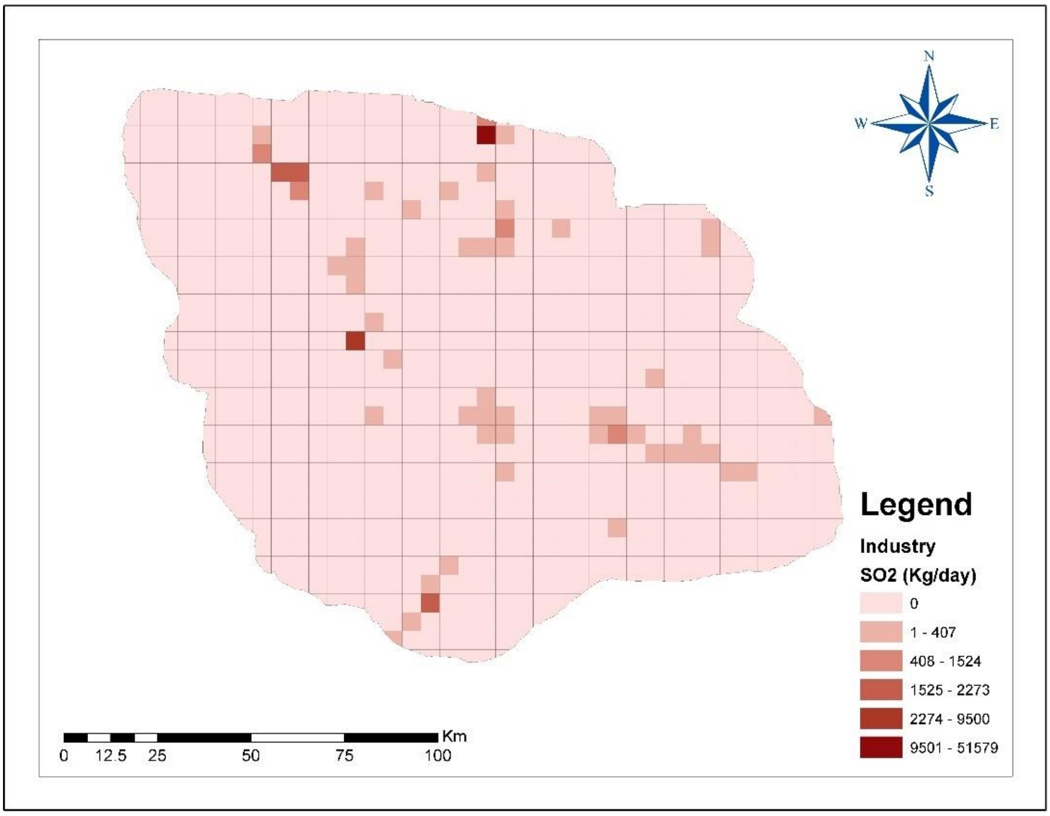


Figure 34: Spatial Map of SO_2 Emission from Industries

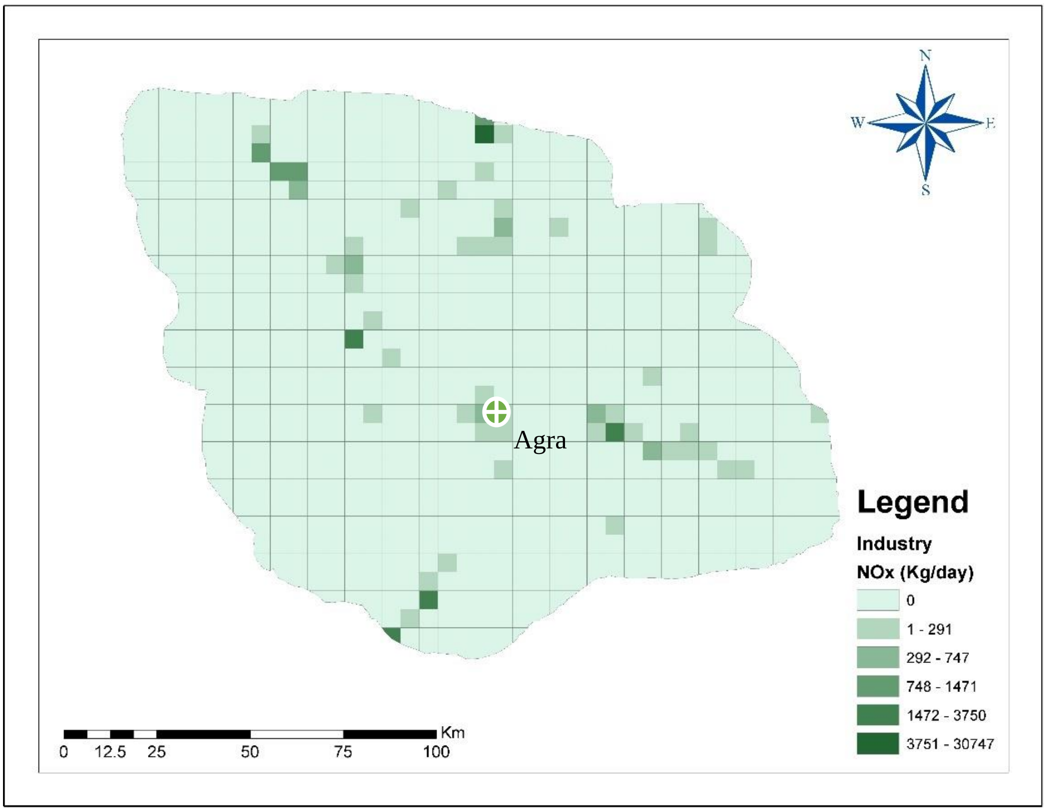


Figure 35: Spatial Map of NOx Emission from Industries

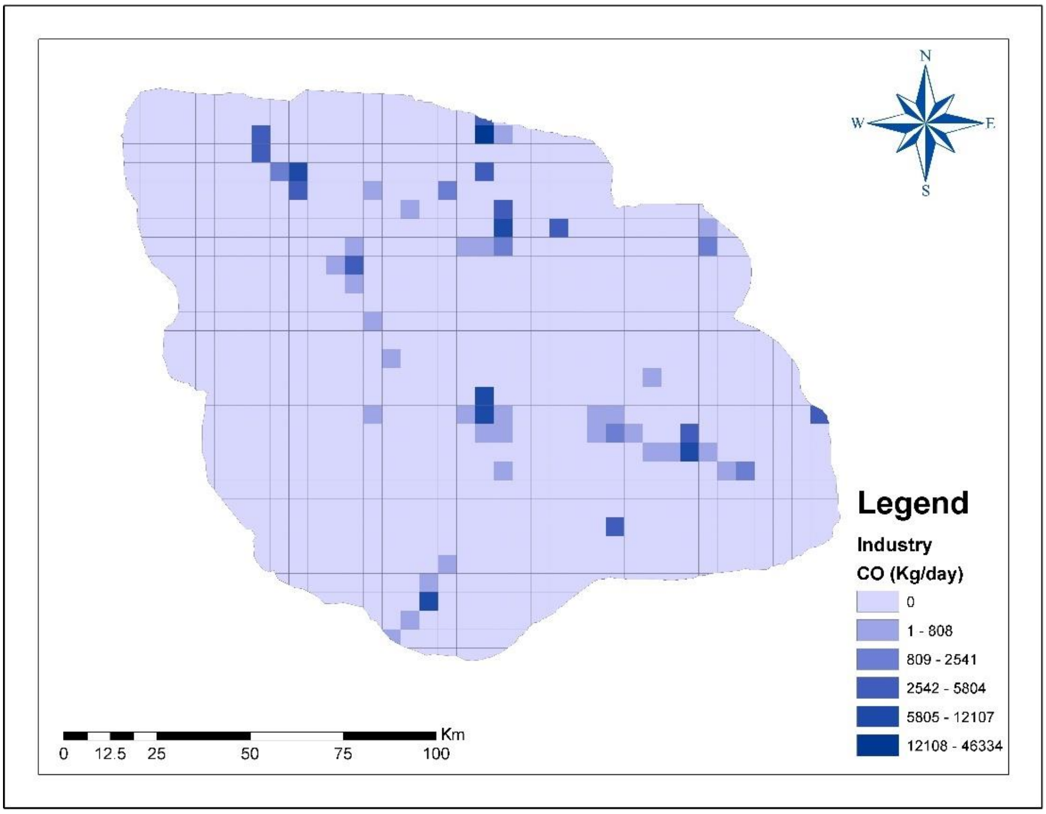


Figure 36: Spatial Map of CO Emission from Industries

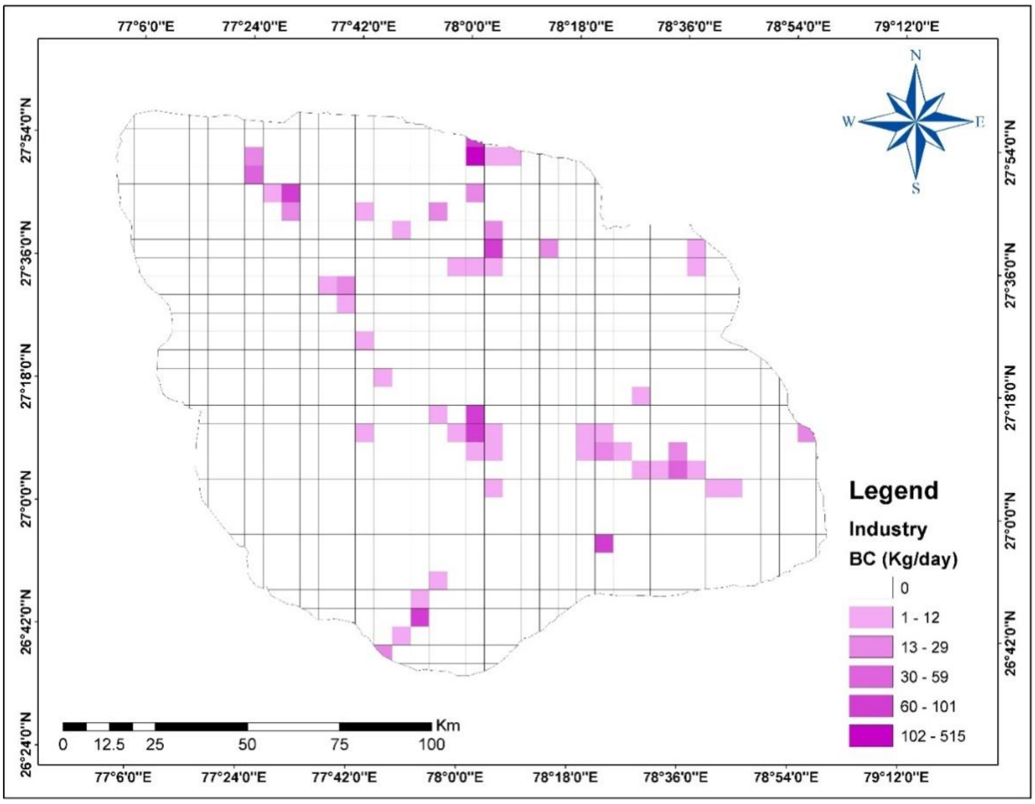


Figure 37: Spatial Map of BC Emission from Industries

There are about 566 boilers/furnaces that are operational in the Agra Airshed and contribute to particulate as well as gaseous emissions.

In the Agra district, there are a total of 26 boilers/furnaces, out of which 15 have shifted to natural gas and electricity and only a few industries are using wood. There are a few induction furnaces (Table 3) that emit a large amount of particulate matter as control measures are not adequate except for some units.

In Firozabad, there are about 223 boilers/furnaces (Table 4) that are operational, and the majority of them run on natural gas.

In Aligarh, there are about 64 boilers/furnaces (Table 5) that are operational, and a large contribution is due to the use of coal, wood, and other solid fuels. The majority of solid fuel-based industries use multi-cyclone as an air pollution control device.

Overall industrial emissions

The overall industrial emissions (PM_{10}, $PM_{2.5}$, SO_2, NO_x, CO, and BC) from different districts in the airshed are presented in Tables 9 to 14.

Table 9: PM_{10} Emissions (kg/day) (Total = 52963 kg/day)

District	Boilers	Furnaces	Oil Refinery	Power Plants	DG sets	Brick Kilns	Others
Agra	47	1641	0	0	44	4000	7
Firozabad	1182	62	0	0	21	7000	0
Aligarh	3524	1596	0	2495	150	5000	2076
Mathura	1301	27	112	0	454	11000	1
Etah	99	0	0	0	18	2000	1
Dholpur	446	585	0	0	15	4000	0.4
Hathras	12	7	0	0	35	3000	5
Bharatpur	0	0	0	0	0	1000	0
Total	6611	3918	112	2495	737	37000	2090

Table 10: $PM_{2.5}$ Emissions (kg/day) (Total = 41277 kg/day)

District	Boilers	Furnaces	Oil Refinery	Power Plants	DG sets	Brick Kilns	Others
Agra	42	1477	0	0	40	3000	6.7
Firozabad	1064	56	0	0	19	5000	0
Aligarh	2906	1434	0	1103	135	4000	1786

Mathura	1171	24	86	0	409	7000	1441
Etah	69	0	0	0	16	2000	1
Dholpur	402	528	0	0	13	3000	0
Hathras	10	6	0	0	32	2000	0.3
Bharatpur	0	0	0	0	0	1000	0
Total	5664	3525	86	1103	664	27000	3235

Table 11: SO_2 Emissions (kg/day) (Total = 112186 kg/day)

District	Boilers	Furnaces	Oil Refinery	Power Plants	DG sets	Brick Kilns	Others
Agra	547	790	0	0	41	7000	48
Firozabad	14	19	0	0	20	12000	0
Aligarh	1328	1655	0	24955	140	9000	24
Mathura	1462	2	10141	0	423	18000	6823
Etah	1	0	0	0	17	4000	0
Dholpur	32	650	0	0	14	6000	0
Hathras	0.1	7	0	0	33	5000	0.4
Bharatpur	0	0	0	0	0	2000	0
Total	3384	3123	10141	24955	688	63000	6895

Table 12: NO_x Emissions (kg/day) (Total = 72754 kg/day)

District	Boilers	Furnaces	Oil Refinery	Power Plants	DG sets	Brick Kilns	Others
Agra	250	460	0	0	625	2000	33
Firozabad	73	1152	0	0	303	4000	8
Aligarh	1649	1551	0	28895	2123	3000	156
Mathura	1101	493	4005	0	6420	5000	3307
Etah	4	0	0	0	253	1000	0
Dholpur	42	638	0	0	209	2000	0
Hathras	1	7	0	0	496	1000	0.5
Bharatpur	0	0	0	0	0	500	0
Total	3120	4300.9275	4005	28895	10429	18500	3505

Table 13: CO Emissions (kg/day) (Total = 181989 kg/day)

District	Boilers	Furnaces	Oil Refinery	Power Plants	DG sets	Brick Kilns	Others
Agra	48	16030	0	0	141	12000	6
Firozabad	6717	690	0	0	65	23000	5
Aligarh	14006	46	0	657	458	16000	15156
Mathura	6287	296	67	0	1386	33000	320

Etah	522	0	0	0	555	7000	9
Dholpur	3153	131	0	0	45	12000	0
Hathras	87	0	0	0	107	9000	0
Bharatpur	0	0	0	0	0	3000	0
Total	30820	17192	67	657	2757	115000	15496

Table 14: BC Emissions (kg/day) (Total = 5238 kg/day)

District	Boilers	Furnaces	Oil Refinery	Power Plants	DG sets	Brick Kilns	Others
Agra	6	203	0	0	5	400	1
Firozabad	135	8	0	0	2	700	0
Aligarh	369	183	0	140	17	500	227
Mathura	149	3	11	0	51	900	189
Etah	11	0	0	0	2	200	0.1
Dholpur	51	68	0	0	1	300	0
Hathras	2	1	0	0	4	300	0.05
Bharatpur	0	0	0	0	0	100	0
Total	723	465	11	140	82	3400	417.15

3.2.2 Emission estimate from secondary data

Table 15 presents the emission estimate of PM_{10}, $PM_{2.5}$, SO_2, NO_x, CO, BC, and NMVOC (non-methane volatile organic compounds) in the Agra Airshed (Edgar v4.3.2, 2018). The maximum emission for all pollutants is from households, mostly cooking. Industrial emission for $PM_{2.5}$ is about one-third of the total $PM_{2.5}$ emissions. The maximum emission is from households followed by road transport. The NMVOC which is responsible for secondary organic aerosol formation and ozone is mostly emitted from households, road transportation, and solvent usage. The estimates in Table 15 for industrial emission from Edgar v4.3.2 (Janssens-Maenhout et al., 2017) is about 2.5 times higher than the estimates from present study which includes industries which have valid consent and are currently in operation after having accounted for pollution control devices.

Table 15: Other sectoral emissions in the airshed (tons/day)

Other sectoral emissions	BC	CO	NOx	NMVOC	PM10	PM2.5	SO2
Energy Building (Household)	20	2098	40	325	323	167	66
Combustion manufacturing	18	507	117	99	93	81	140

Agricultural Waste burning	2	307	12	20	25	24	2
Power Industry	1	20	82	2	33	22	110
Road transportaion	4	1247	167	137	10	9	4
Railway pipeline off road transport	0	3	12	1	4	4	0
Oil refineary transformation	1	148	5	86	20	3	0
Chemical processes	0	0	0	3	1	1	1
Solvents and product use	0	0	0	212	0	0	0
Total	**47**	**4329**	**434**	**885**	**509**	**310**	**323**

3.2.3 Inferences from Industrial Emission Inventory

Table 16 presents the overall industrial emission inventory in the Agra Airshed. The total population of the districts in the Agra Airshed is about 18.7 million (Census 2011). The maximum emissions are from Aligarh, which has a large power plant of 610 MW capacity and a large number of brick kilns (164 nos.). Mathura has a relatively high SO_2 emission because of a large oil refinery (8.0 million metric tons per annum capacity). The major inferences from emission inventory analysis are presented below.

Table 16: Overall Industrial Emission Inventory (tons/d) of the Agra Airshed

District	PM_{10}	$PM_{2.5}$	SO_2	NOx	CO	BC
Agra	5.7	4.6	8.4	3.4	28.2	0.6
Firozabad	8.3	6.1	12.1	5.5	30.5	0.8
Aligarh	14.8	11.4	37.1	37.4	30.3	1.4
Mathura	14.6	10.2	36.9	20.3	41.4	1.3
Etah	2.1	2.1	4.0	1.3	7.6	0.2
Dholpur	5.0	3.9	6.7	2.9	15.3	0.4
Hathras	3.1	2.0	5.0	1.5	9.2	0.3
Bharatpur	1.0	1.0	2.0	0.5	3.0	0.1
Total	**54.6**	**41.3**	**112.2**	**72.8**	**165.5**	**5.2**

Brick Kilns

Brick kilns are major contributors to all pollutants in the airshed. In PM_{10} and $PM_{2.5}$, the brick kilns' contribution is 66 – 69%, in CO and in $SO_{2,}$ their contribution is 40 – 45%. Contribution to NO_X emission from brick kilns is around 26% and to BC emission is around 70%.

Emissions from Large Units

Thetwo large industries in the Agra Airshed - the oil refinery at Mathura and Harduaganj coal-based power plant in Aligarh have adequate control of particulate matter but have large uncontrolled emission of SO_2; power plant accounting for 47% of total SO_2 emission and refinery accounts for 24%.

3.3 Emission Inventory of Agra City

3.3.1 Data Collection

The primary and secondary activity data were collected by the IIT Kanpur team. For example, construction and demolition data were collected through field surveys and validated by satellite imageries. Road dust sampling was done at 16 locations. A physical survey of industrial areas was also done. The main sources of secondary data collection were UPPCB, Census of India, CPCB, Airport Authority of India (AAI), Indian Railways, Agra Development Authority, Public Works Department, Transport Department, and Toll Plazas. The information was also been collected through internet search and by visiting various relevant websites.

3.3.2 Source wise emission inventory

While the emission inventory for cities in the airshed was limited to industries, in the Agra City, all sources have been included. A team of professionals visited the study area and collected information on industries, DG power generator sets, brick kilns, and other sources within the Agra City and these sources are described below.

Diesel Generator Sets (DG sets)

The locations of the DG sets are shown in Figure 38. The industries used the DG sets as a backup power source. Approximately 80 DG sets were installed in industries and run on diesel and natural gas (source: consent data). Based upon an industrial survey, it was found that the DG sets operated for two hours per day. The unit of the activity data for DG sets was the KWh energy generation. There were no air pollution control devices installed in DG sets. The calculation was based on equation (1), where ER, overall efficiency reduction was taken as zero. The total emissions from DG sets are shown in Figure 39.

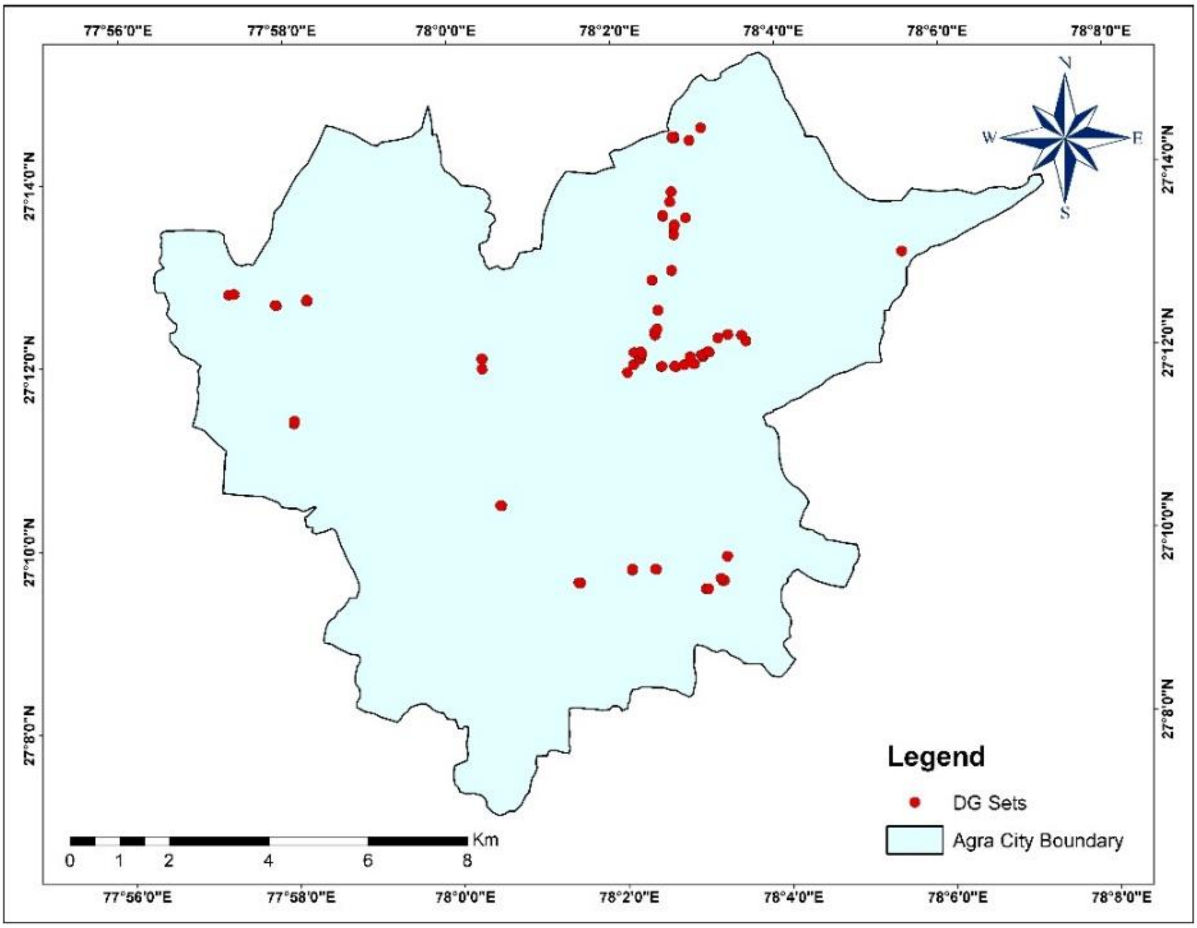


Figure 38: Locations of Industrial DG Sets

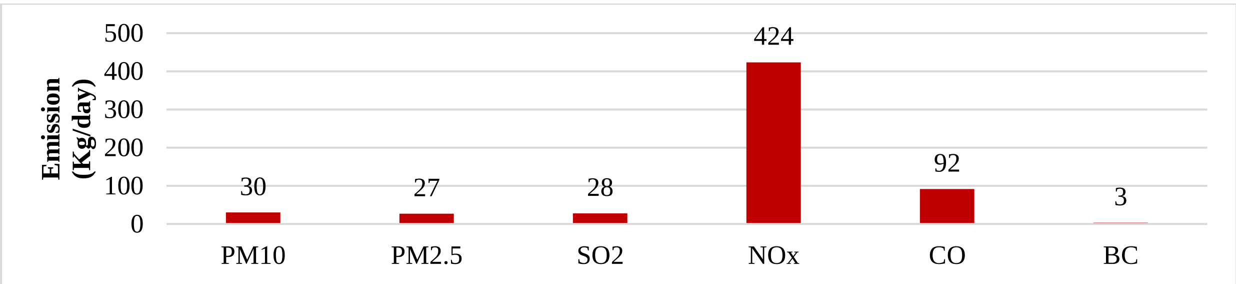


Figure 39: Emission Load (kg/day) from DG Sets

Industries

There were over 100 industrial units in Agra (Figure 40). A total 102 boilers and furnaces existed in these industrial units. There were 48 cupola furnaces and 36 induction furnaces operating in industries within the Agra City. The cupola furnace and induction furnace, as informed, operated for a limited period, i.e., 1.5 to 2.0 months during the year. The emission from these furnaces was considered for their operating period and normalized for the year. Cyclones and multi-cyclones were installed as air pollution control devices. The calculation was based on equation (1), where ER, overall efficiency reduction was taken as 50% for particulate matter. The overall emissions estimated from the different types of boilers, furnaces, etc., are presented inTable 17.

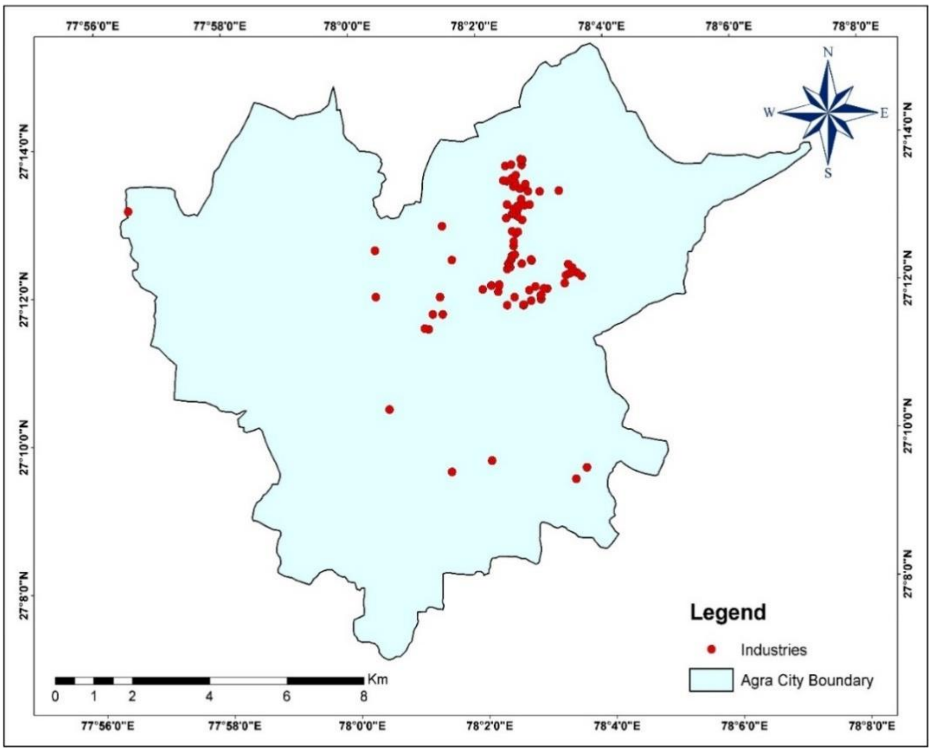


Figure 40: Location of Industries

Table 17: Furnace/Boiler/DG Sets Details in Agra (Source: Consent Data, UPPCB)

Boiler/Furnace Type	Fuel used in Boiler/Furnace/DG Sets	No. of Furnaces/ Boilers/DG Sets	PM_{10}	$PM_{2.5}$	SO_2	NOx	CO	BC
			(kg/day)					
Baby Boiler	Diesel (2)	2	4	3.6	51.0	18.0	2.0	0.5
Boiler	Diesel (5), Natural Gas (3)	8	6	5.1	42	40	12	1

Induction Furnace	Electricity	36	116	104	0	0	0	13
Annealing Furnace	Natural Gas	1	0.1	0.1	0.0	1	1	0.007
Cupola Furnace*	Natural Gas, Coke Bed	48	1524	1372	790	436	16016	190
Pit furnace	Gas	5	0.13	0.12	0	3.0	2.0	0.01
Tank furnace	Gas	2	1	0.8	0.0	18.0	10.0	0.1
DG Set	Diesel (38), Gas (41)	79	30	27	28	424	92	3
Total		181	1681	1513	911	940	16135	207

*The emission factors were taken from USEPA AP-42. Since, the furnaces are gas-based with some uses of coke, the emissions are expected to be less than the stated quantity.

The information on stack parameters, fuel type and consumption were obtained from UPPCB. The CPCB emission factors were used to calculate the emission. The emission of pollutants from industries is shown in Figure 41.

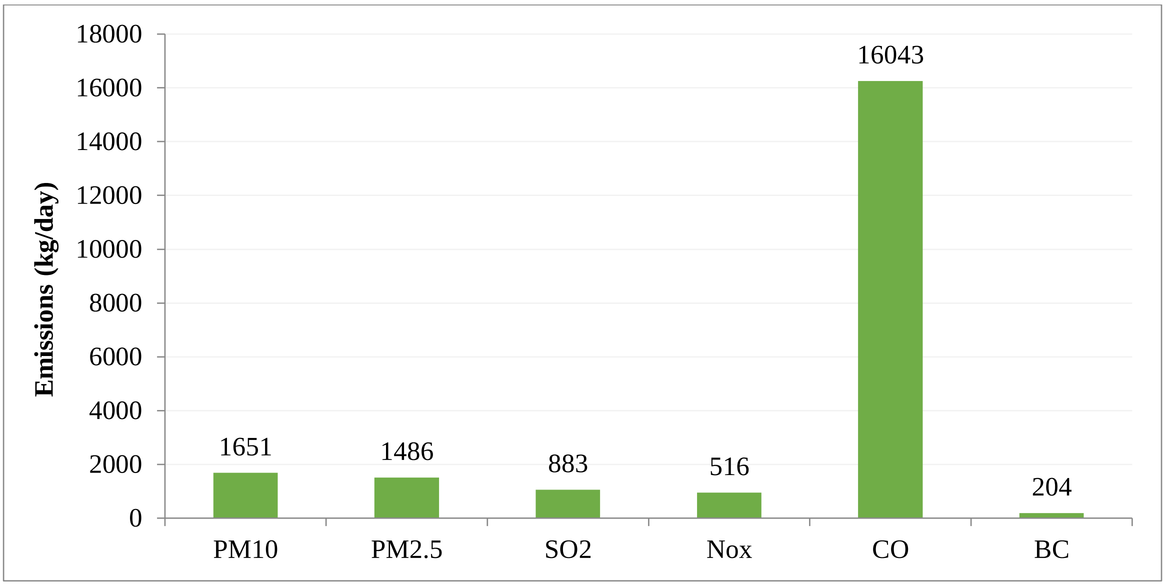


Figure 41: Emission Load from Industries

Hotels and Restaurants

The primary survey was conducted by the IIT Kanpur team to identify the hotels and restaurants with a sitting capacity of more than ten persons (Figure 42). The major areas for hotels and restaurants were Tajganj, Fatehabad Road, Raja ki Mandi Station, Agra Cantonment Station, Sanjay Palace, SikandraBodla Sectors 4, 5, 6, 7, and 8, Bhagwan Talkies, and Agra Fort Station.

During the field survey, it was observed that some hotels and restaurants used a small amount of coal/wood as fuel in tandoors. The total number of big hotels and restaurants was approximately 1300. Liquified Petroleaum Gas (LPG) was used as a common fuel except in tandoors. The team estimated that for a restaurant with a capacity of 15 people, the LPG consumption was about 10 kg/day based on the estimated number of meals served. In most of the cases, it was found that there were no pollution control devices installed at these facilities. The emissions of various pollutants (SO_2, NOx, PM_{10}, $PM_{2.5}$, and CO) were estimated from the activity data from each fuel type. The overall emission from this area source (Hotels/Restaurants) is shown in Figure 43.

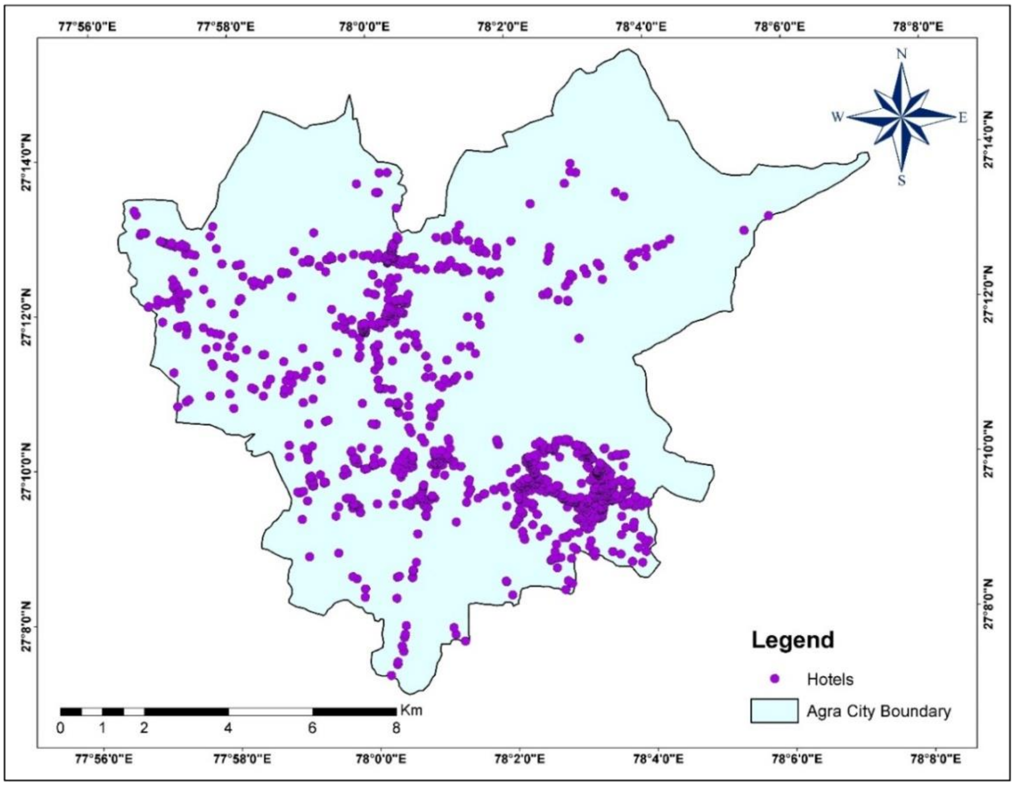


Figure 42: Location of Hotels and Restaurants

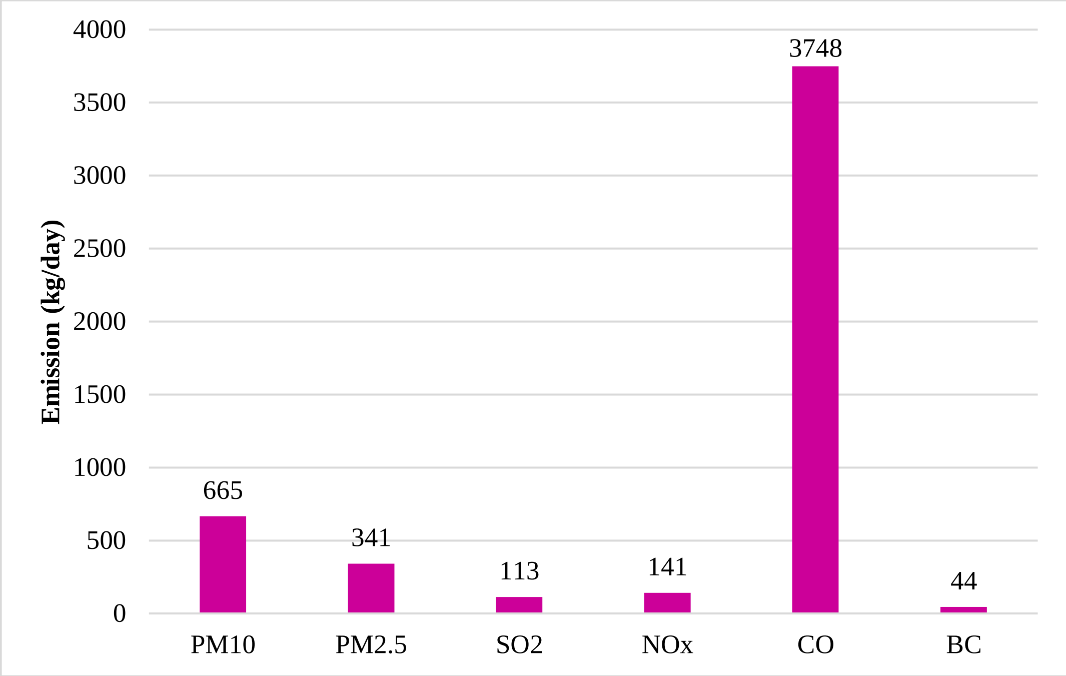


Figure 43: Emission Load from Hotels and Restaurants

Hospitals

A detailed survey was undertaken to assess the hospital emissions. DG sets were used as a power backup and were the only source of air pollution. The power supply in the city was good. It was found during the survey that these DG sets in hospitals operated for 2 hours per day. The unit of the activity data for DG sets was their KWh energy generation. There were no air pollution control devices installed in the DG sets. The calculation was based on equation (1), where ER, overall efficiency reduction was taken as zero. The emission load from hospitals is given in Figure 44. Maximum emissions for the hospitals were for NOx. The locations of Hospitals in Agra City were geo-tagged and are given in Figure 45.

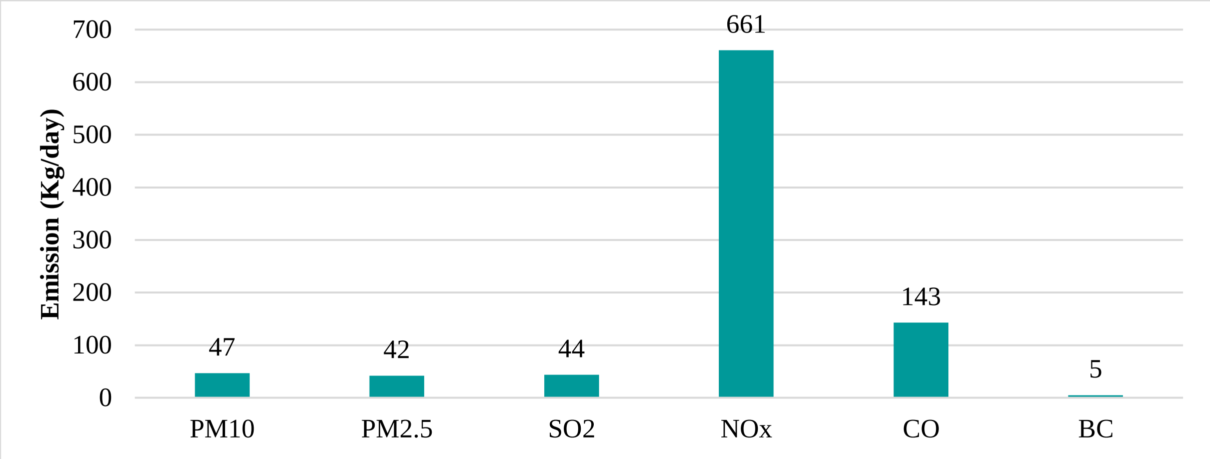


Figure 44: Emission Load from Hospitals (kg/day)

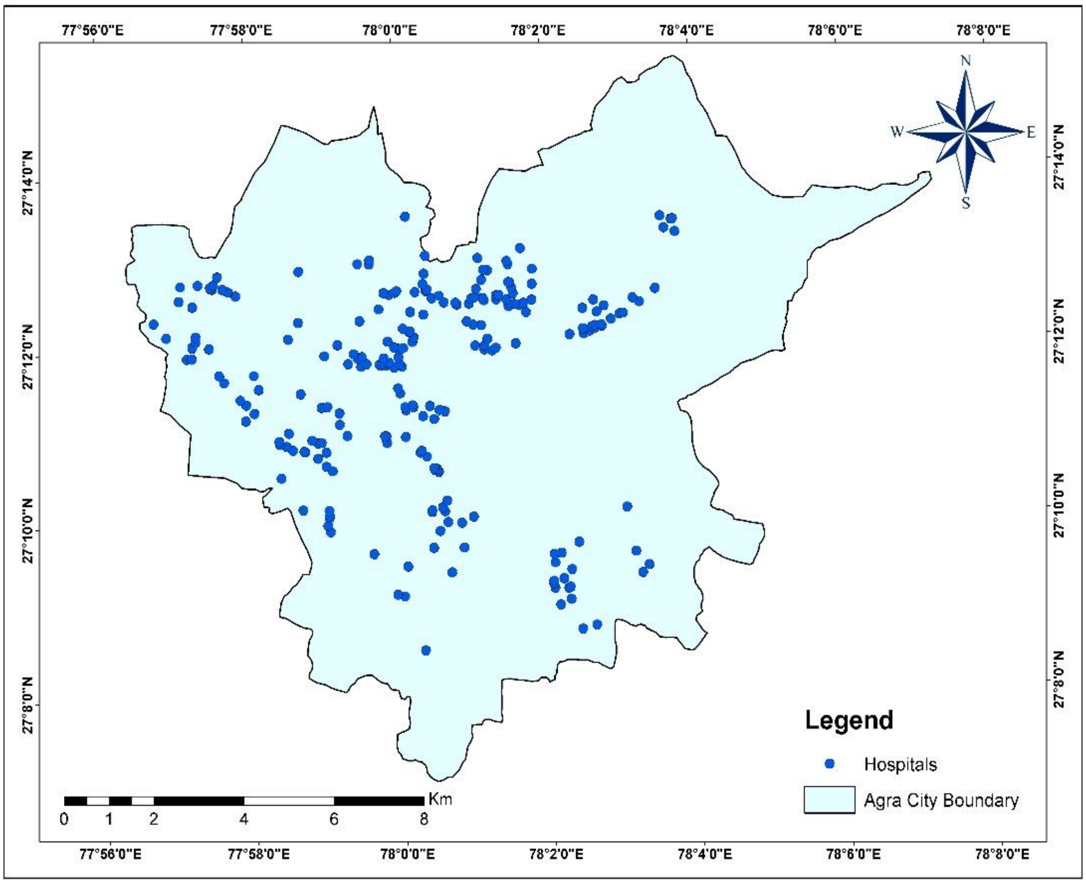


Figure 45: Locations of Hospitals in Agra City

Municipal Solid Waste burning

The refuse or municipal solid waste (MSW) burning depends on solid waste generation and the extent of disposal and infrastructure for collection. This emission is expected to be large in the regions of economically weaker strata of the society which do not have proper infrastructure for collection and disposal of MSW. The solid waste generation depends on the nature of the locality in that region, for instance, if the area has high commercial activity, or high population density, there will be more garbage generation.

A detailed survey was conducted according to the land-use pattern of the Agra City. Major commercial areas identified were Sanjay Palace, Shahganj, Subhash Bazaar, Agra Fort, Fatehabad Road, Jaipur House, Sikandra Bosla Sectors 6, 7 and 8, Bhagwan Talkies, Belanganj, Baluganj, Sadar Bazaar, Raja Ki Mandi Market, St. John's Crossing, Maithan, Pathwari, Bagh Muzaffar Khan, Wazirpura, and Hari Parwat Crossing. Major residential areas (with high population density) were Ghatia Azam Khan, Mantola, Tajganj, Naiki Mandi, Loha Mandi, and Idgah. The residential areas with moderate population density were Jaipur House Colony, Saket Nagar, Janakpuri, Vijay Nagar Colony, Khandari, and Kamla Nagar. Residential areas with low population density were Sanjay Palace, Subhash Park, Sadar Bazaar, Laweys Colony, and Dayalbagh. Major institutional areas were Dayalbagh, Khandari, and MG Road.

An extensive survey was conducted in these localities for 3 hours in the morning and 3 hours in the evening. The survey observations indicated that there were more MSW burning incidents in the morning compared to the evening, typically starting around 6 am. MSW burning was not observed in the afternoon and then resumed in the evening.

The measurements of the garbage lying in the area were also taken . For example, if the area of a collection point was 1.0 m^2, and height was 0.3 m, the garbage volume of that collection point was 1.0*0.3 = 0.3 m^3. The dry density of garbage was taken as 800kg/m^3 so the mass of garbage on that street became 800*0.3 = 240 kg. The number of MSW-burning incidents were recorded in the identified survey area. These incidents were mapped according to the ward population. The methodology estimates that about 2% of the MSW was being burnt in each ward of the city.

The emission factors given by CPCB (2011) and AP-42 (USEPA, 2000) were used for estimating the emissions from MSW burning. The emissions from MSW burning are presented in Figure 46.

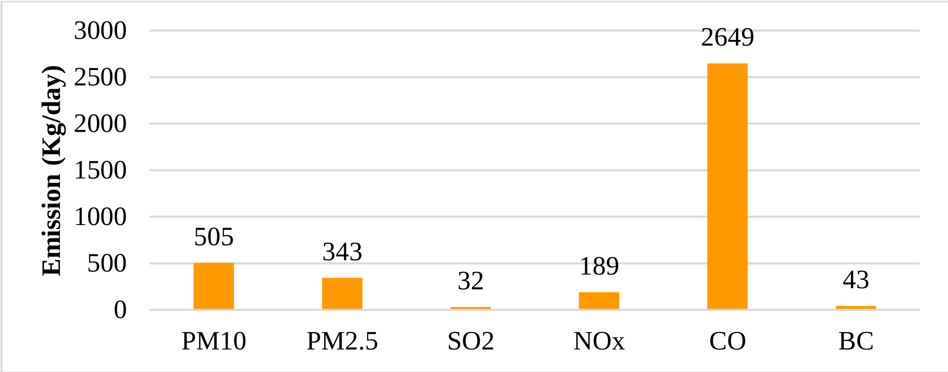


Figure 46: Emission Load from MSW Burning

Construction and Demolition

A detailed survey was undertaken to assess construction and demolition activities. The satellite imagery was also used to identify the construction activities. The information regarding major construction activities was obtained from Agra Development Authority, State Public Works Department (PWD), Central Public Works Department (CPWD) and Municipal Corporation and the detailed survey was conducted thereafter. At almost all construction sites, it was found that the construction material and the debris were being stored outside the construction premises, near the road, lying open and uncovered. At the site of flyover construction at the Inter-State Bus Terminal (ISBT), the construction material lay dumped in the middle of the road. The areas under construction activities were calculated based on survey data and Geographic Information System (GIS) mapping. These construction activities were geotagged in the Agra City boundary limits (Figure 47). The emission factors given by AP-42 (USEPA, 2000) were used for estimating the construction and demolition emissions. Total emissions from construction and demolition activities are presented in Figure 48.

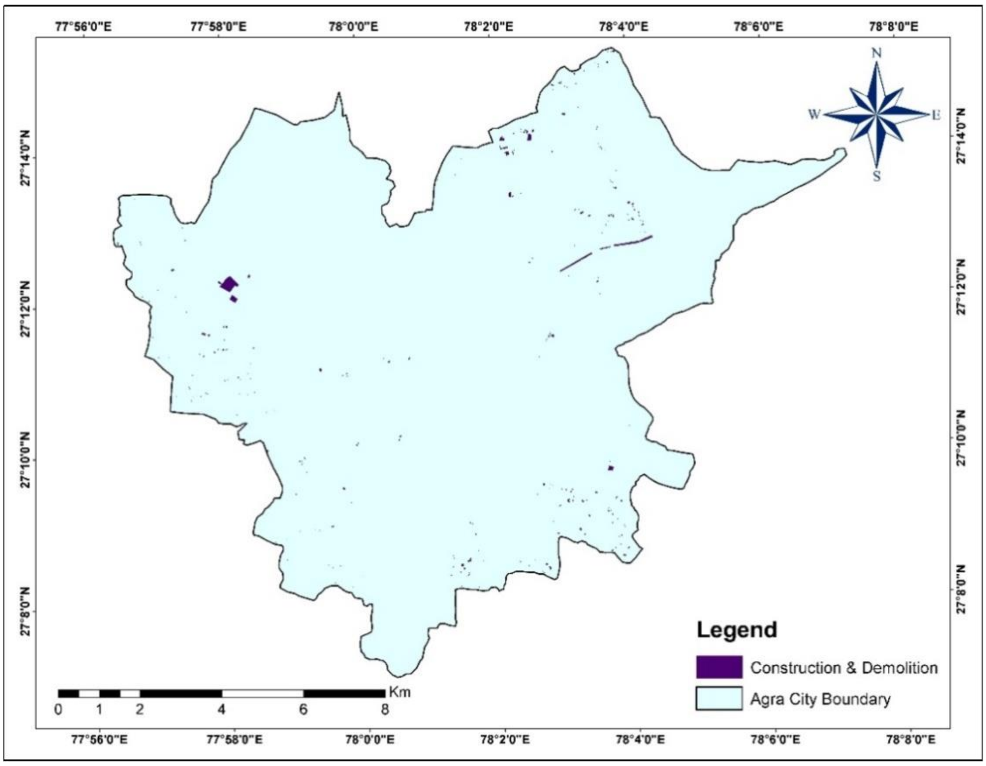


Figure 47: Construction/Demolition Sites

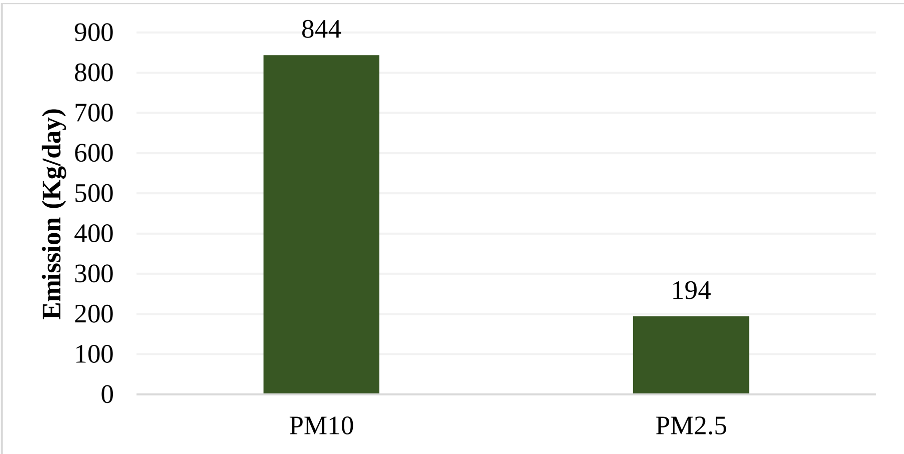


Figure 48: Emission Load from Construction and Demolition Activities (kg/day)

Domestic Sector

The interior boundaries in the map (Figure 49) show the administrative boundaries of wards in the Agra City. The Agra City consists of 100 wards as shown in Figure 49. There are four zones: (i) Chatta Zone with 30 wards (ii) Hari Parvat Zone with 21 wards (iii) Loha Mandi Zone with 26 wards and (iv) Taj Ganj Zone with 23 wards. The fuel consumption pattern shows LPG consumption (85%) (CRISIL Report), wood (10%), dung (3%), coal (1%), and crop residue

(1%). The slum area details were obtained from Agra Municipal Corporation and an on-field survey was conducted by the IIT Kanpur team. There were approximately 250 areas identified as slums with majority residents livingbelow the poverty line. The majority of the slum areas were using wood and dung as fuel sourcesfor cooking. Although they had been provided LPG cylinders, due to their economic conditions the refilling was not frequent.

After obtaining the area of wards, the emission density for each ward was calculated for different pollutants (PM_{10}, $PM_{2.5}$, SO_2, NOx, and CO). The emission factors given by the CPCB (2011) and AP-42 (USEPA, 2000) were used for each fuel type.

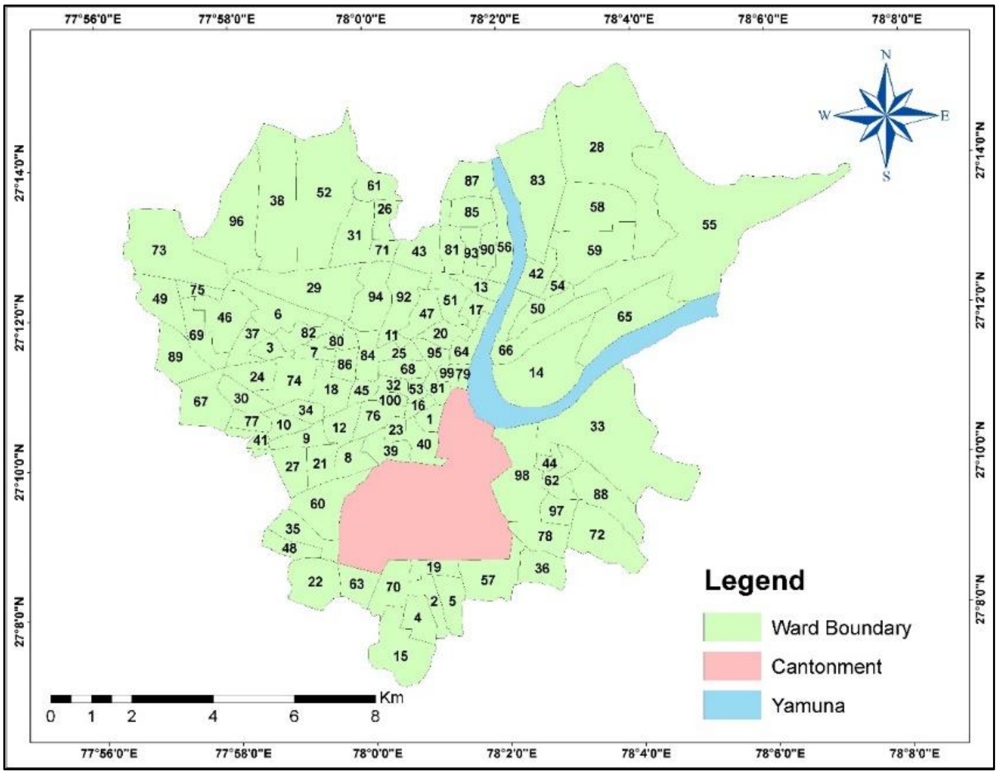


Figure 49: Wards in Agra

The overall emission from domestic sources is presented in Figure 50. For spatial distribution of different pollutants, emission per capita, in each ward and village was calculated, as activity data was available based on per capita. The emission density in terms of kg/day/m^2 in each ward was calculated based on population and area of the ward for different pollutants (PM_{10}, $PM_{2.5}$, SO_2, NOx, and CO) as per the following formula:

Emission Density (kg/day/m^2) = Emission of Ward (kg/day) / Ward Area (m^2)

For calculating emission in a grid that may contain more than one ward, the area of the fraction of each ward falling inside that grid was calculated and with the help of emission density of the ward, the emissions were calculated as per the following formula:

$$Grid.Emission = \sum_{i=1}^{N} (\text{ area of fraction ward i in grid X emission density of ward, i})$$

Where N= no. of wards in the grid

The spatial distribution of emissions from the domestic sector is shown in Figures 95 to 99.

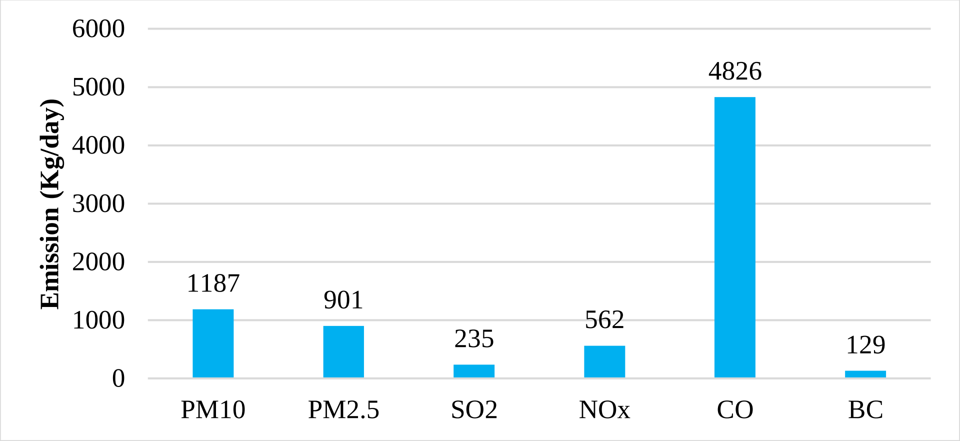


Figure 50: Emission Load from Domestic Sector (kg/day)

Vehicular Emissions

Parking Lot Survey

To obtain the information on prevalence of vehicle technology types operating in the city and fuel used, parking lot questionnaire surveys (engine technology and capacity, vehicle age, fuel use, etc.) were conducted at 15 locations (Sanjay Place, Municipal Corporation Office, Bhagwan Talkies, Dayalbagh, Taj-Mahal, Agra Fort, Shahganj, Raja ki Mandi, Cantonment Railway Station, Hari Parwat, Sadar Bazar, Belanganj, Baluganj, Jaipur House, and Bodla Crossing) in the city of Agra. Out of the total of 9258 vehicles surveyed, the breakdown was: 5474 2-Wheelers; 687 3-Wheelerss; 2427 4-Wheelers, 101 Light Commercial Vehicles (LCVs), 124 Buses, and 445 Trucks. During the parking lot survey, it was found that 3-Wheelers, LCVs, and City Buses ran on CNG and trucks ran on diesel, and that 90% of the fleet were post-2005 manufactured. Approximately 25% percent of 4-Wheelerss used diesel and the remaining 75% used gasoline. Automotive Research Association of India (ARAI)

(2011) and CPCB (2011) emission factors were used to calculate the emissions. Figure 51 and Figure 52 present parking lane survey results for 2-Wheelers and 4-Wheelers in terms of engine size and year of manufacturing. This information is vital in calculating the emission from vehicles on the road. The emission factors vary considerably for engine size, fuel uses, and age of the vehicles.

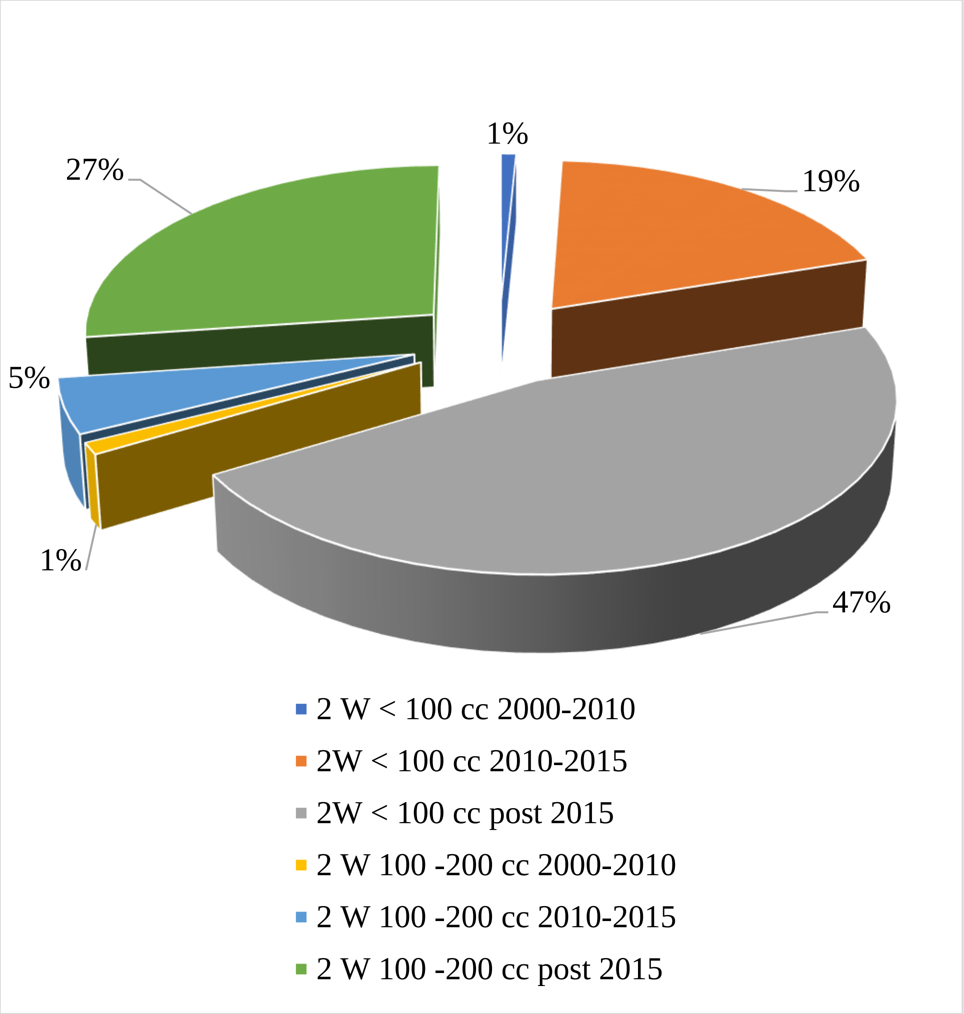


Figure 51: Distribution of 2-Wheelers in the Study Area (Parking Lot Survey)

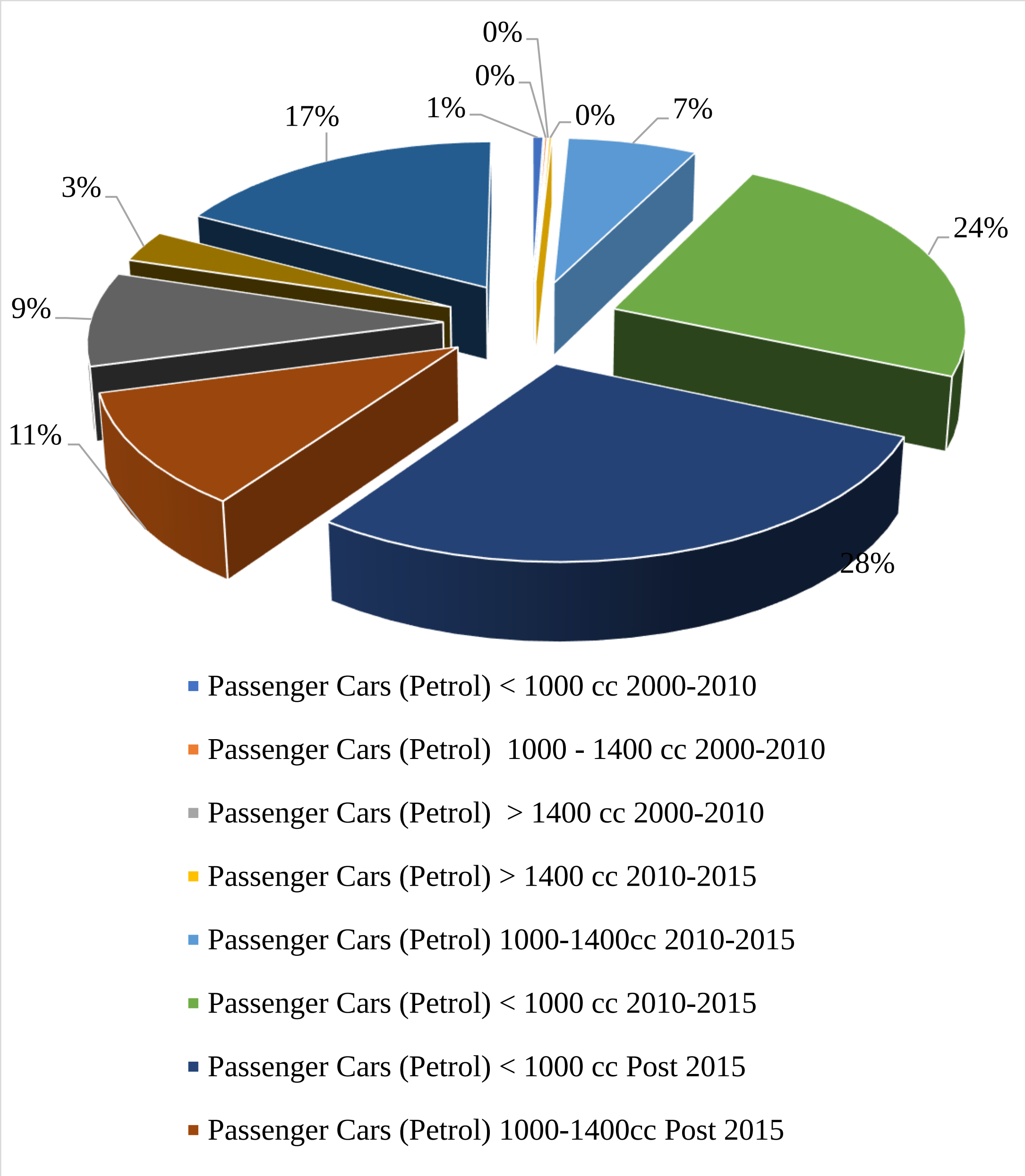


Figure 52: Distribution of 4-Wheelers in the Study Area (Parking Lot Survey)

The emission contribution of each vehicle type in the city of Agra is presented in Figures 53 to 58.

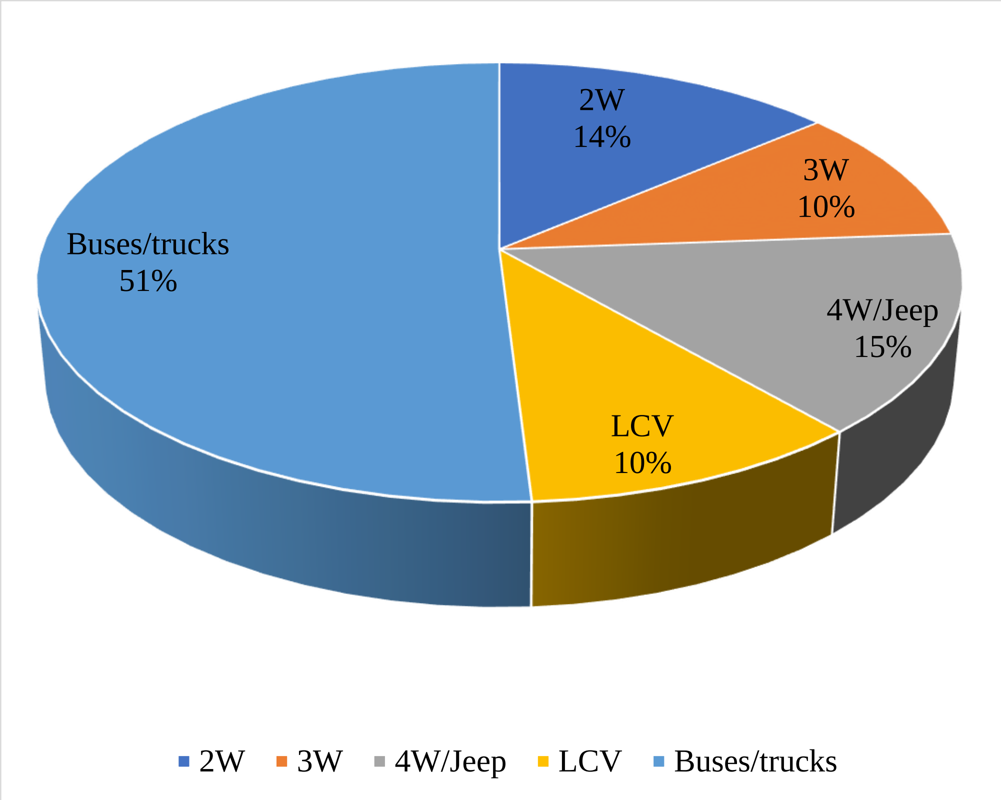


Figure 53: PM_{10} Emission Load Contribution of Each Vehicle Type (1832 kg/day)

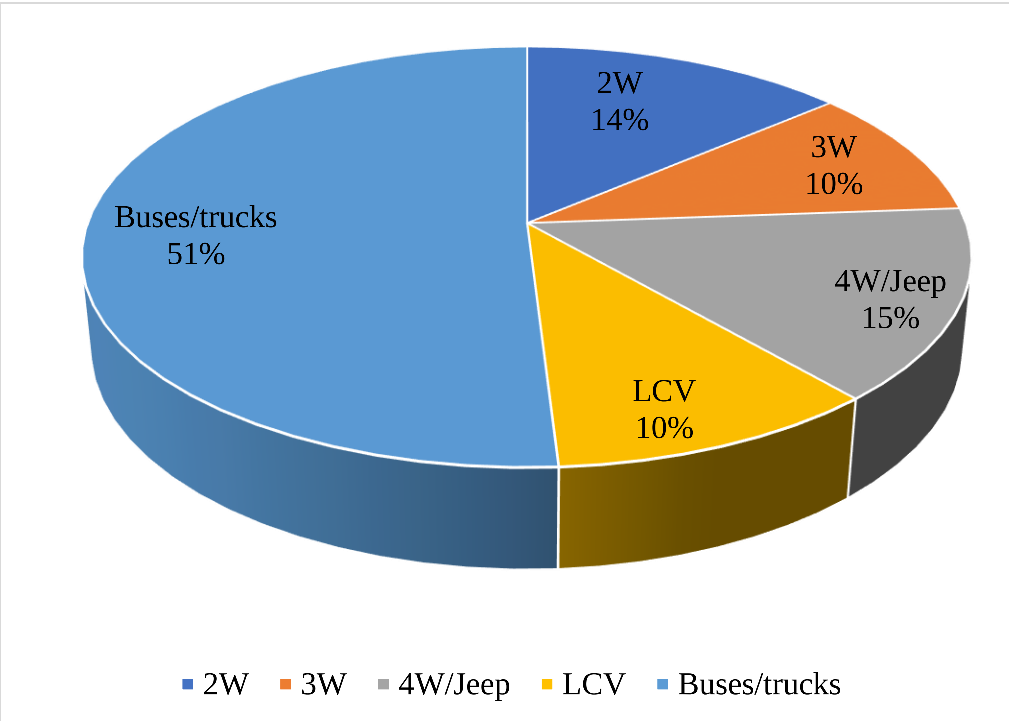


Figure 54: $PM_{2.5}$ Emission Load Contribution of Each Vehicle Type (1649 kg/day)

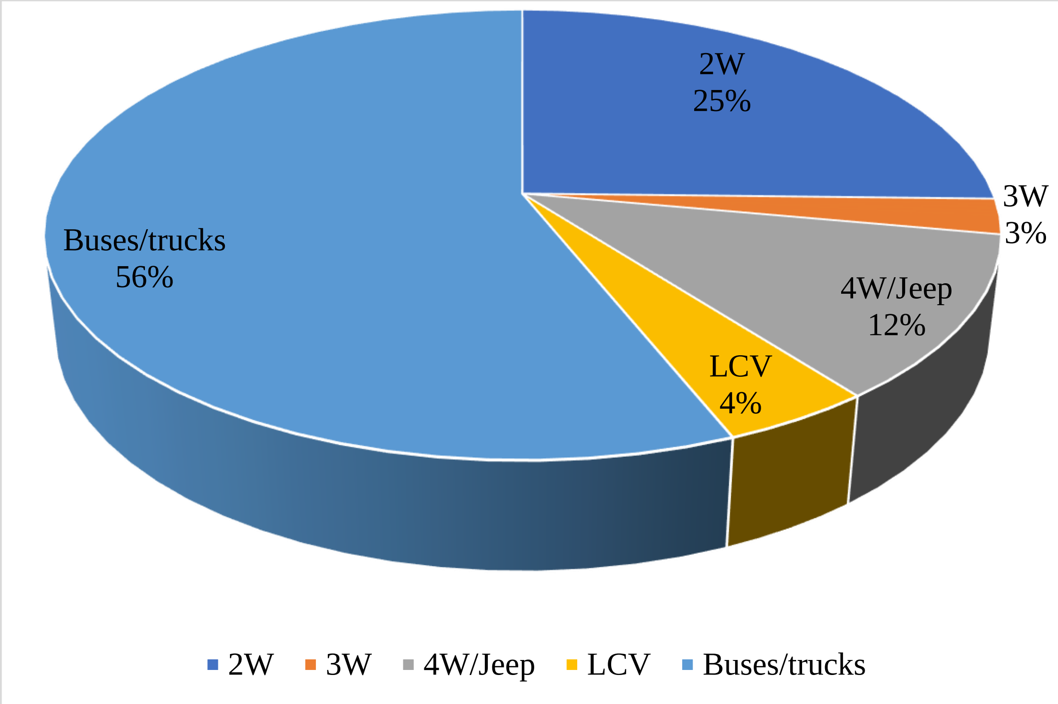


Figure 55: NO_x Emission Load Contribution of Each Vehicle Type (16651 kg/day)

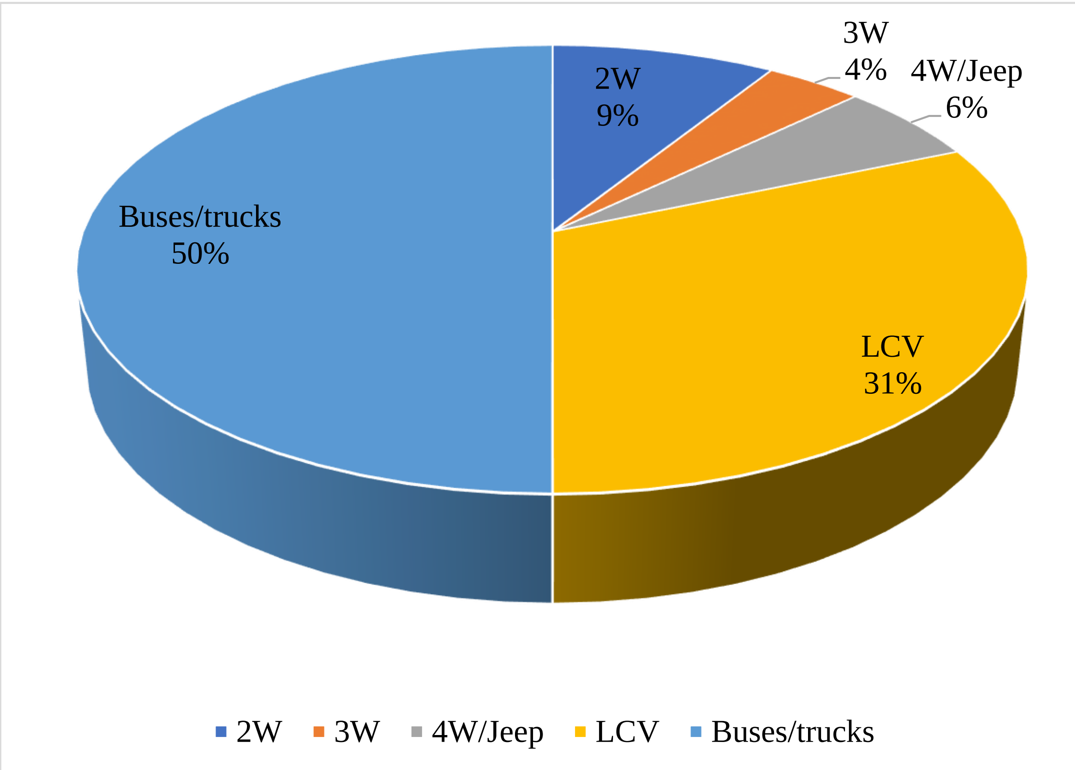


Figure 56: SO_2 Emission Load Contribution of Each Vehicle Type (363 kg/day)

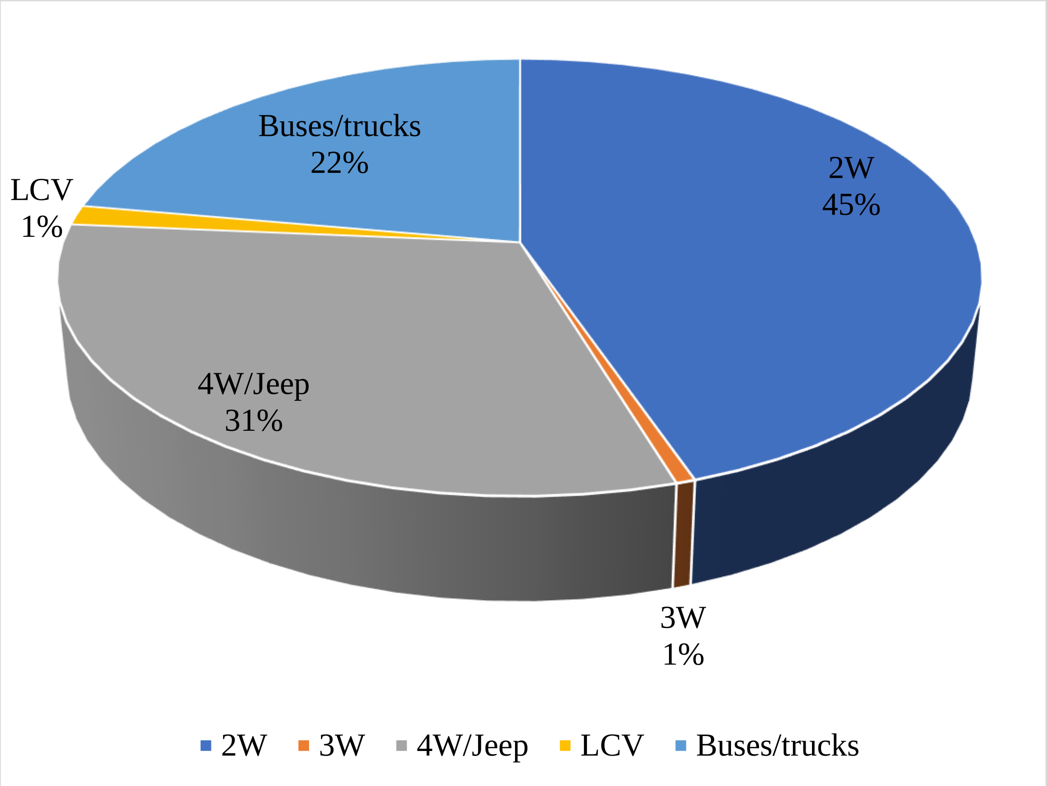


Figure 57: CO Emission Load Contribution of Each Vehicle Type (22576 kg/day)

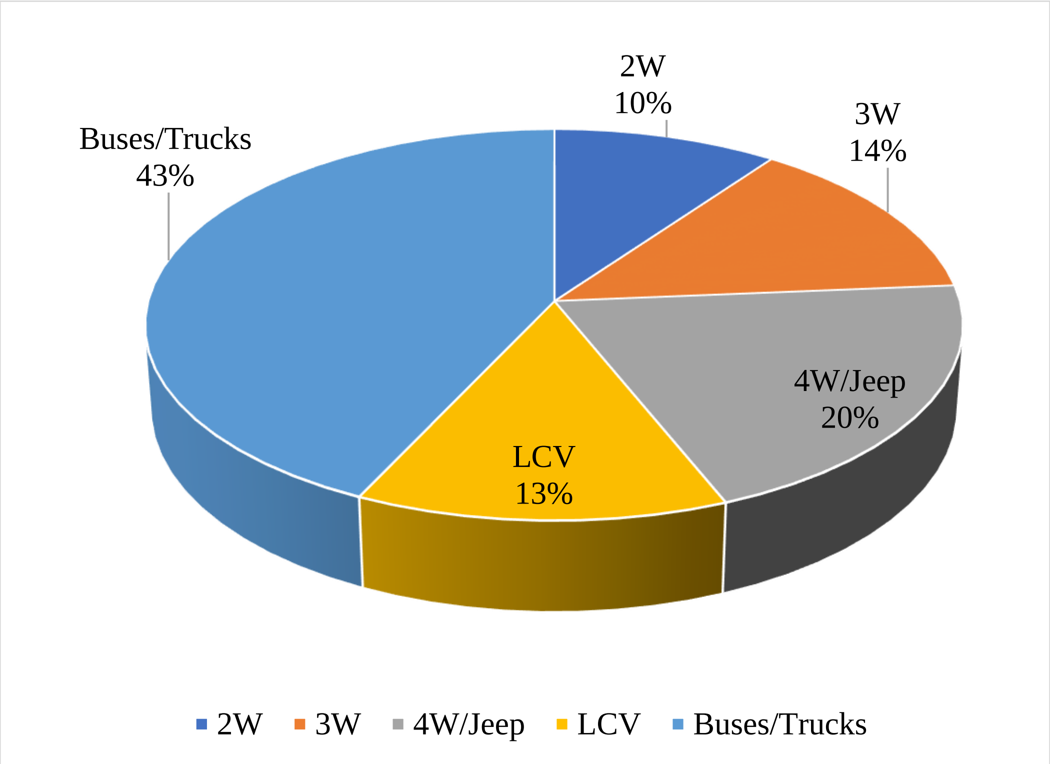


Figure 58: BC Emission Load Contribution of Each Vehicle Type (210 kg/day)

Vehicular - Line Sources

The average daily flow of vehicles in each hour for 2-Wheelers, 3-Wheelers, 4-Wheelers, LCVs, Buses, and Trucks at 16 locations were obtained through video recordings at crossings (Figure 59). From these 16 traffic locations, the data were extrapolated for the remaining grid cells. Road lengths in each grid for major and minor roads were calculated from the digitized maps using the ArcGIS tool, ArcMap, and extracted into the grids. The information on traffic flow from traffic counts was translated into the vehicles on the roads in each grid. Wherever it was feasible, either traffic flow was taken directly from the traffic data, and for interior grids, traffic from medium roads going the highways was taken to flow in the interior part of the city. The emissions from each vehicle category for each grid were estimated and summed up.

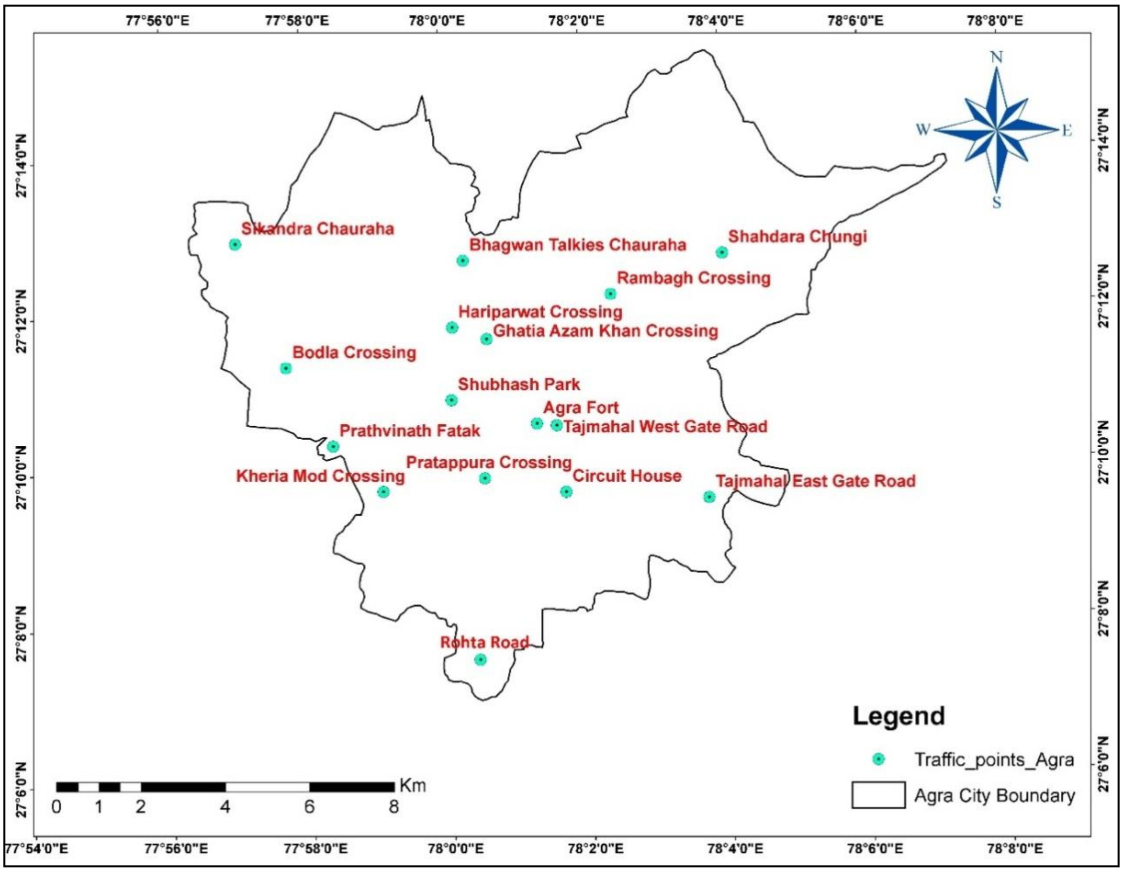


Figure 59: Traffic location considered for vehicle emission in the city of Agra

The emissions from railway locomotives were not taken into considerations, as the emissions were negligible in comparison with the vehicles and other sources. The emission from vehicles is shown in Figure 60.

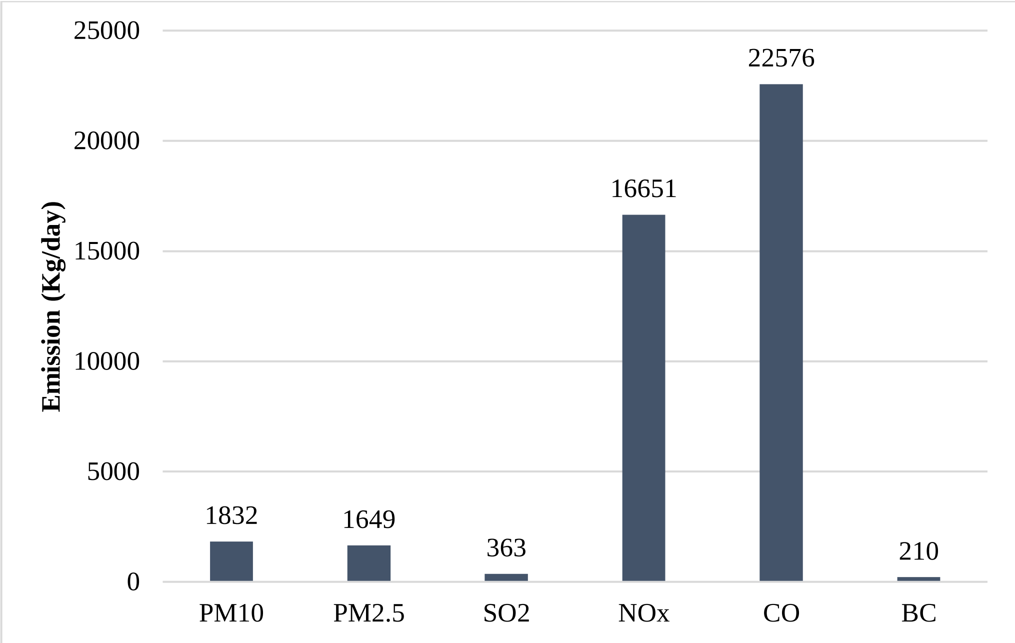


Figure 60: Emission Load from Vehicles (kg/day)

Paved and Unpaved Road Dust

Dust emissions from paved and unpaved roads have been found that vary with the 'silt loading' present on the road surface and the average weight of vehicles traveling on the road. The term silt loading (sL) refers to the mass of the silt-size material (equal to or less than 75 µm in physical diameter) per unit area of the travel surface. The quantity of dust emissions from the movement of vehicles on a paved or unpaved road can be estimated using the following empirical expression:

$$E_{ext} = [\ k\ (sL)^{0.91} \times (W)^{1.02}\ ]\ (1 - P/4N) \qquad (2)$$

Where

E = particulate emission factor (having units matching the units of k)

sL = road surface silt loading (grams per square meter) (g/m^2)

W = average weight (tons) of the vehicles traveling the road

E_{ext} = annual or other long-term average emission factors in the same units as k

P = number of "wet" days with at least 0.254 mm (0.01 in) of precipitation during the averaging period

N = number of days in the averaging period

k: constant (a function of particle size) in g VKT^{-1} (Vehicle Kilometer Travel)

The silt loads (sL) samples from 16 locations were collected (
Figure 61). Then the mean weight of the vehicle fleet (W) was estimated by giving the weightage to the percentage of vehicles of all types with their weight. Then the emission rate (g VKT^{-1}) was calculated based on equation (2). VKT for each grid was calculated by considering the tonnage of each road. Then finally the emission loads from paved and unpaved roads were found out by using equation(2). The PM_{10} and $PM_{2.5}$ emission from road dust was 29,595 kg/day and 9,227 kg/day, respectively. Silt load varied a lot. In the winter and monsoon season, it was less due to moisture and dew atmospheric conditions. The emission load from road dust is given in Figure 62.

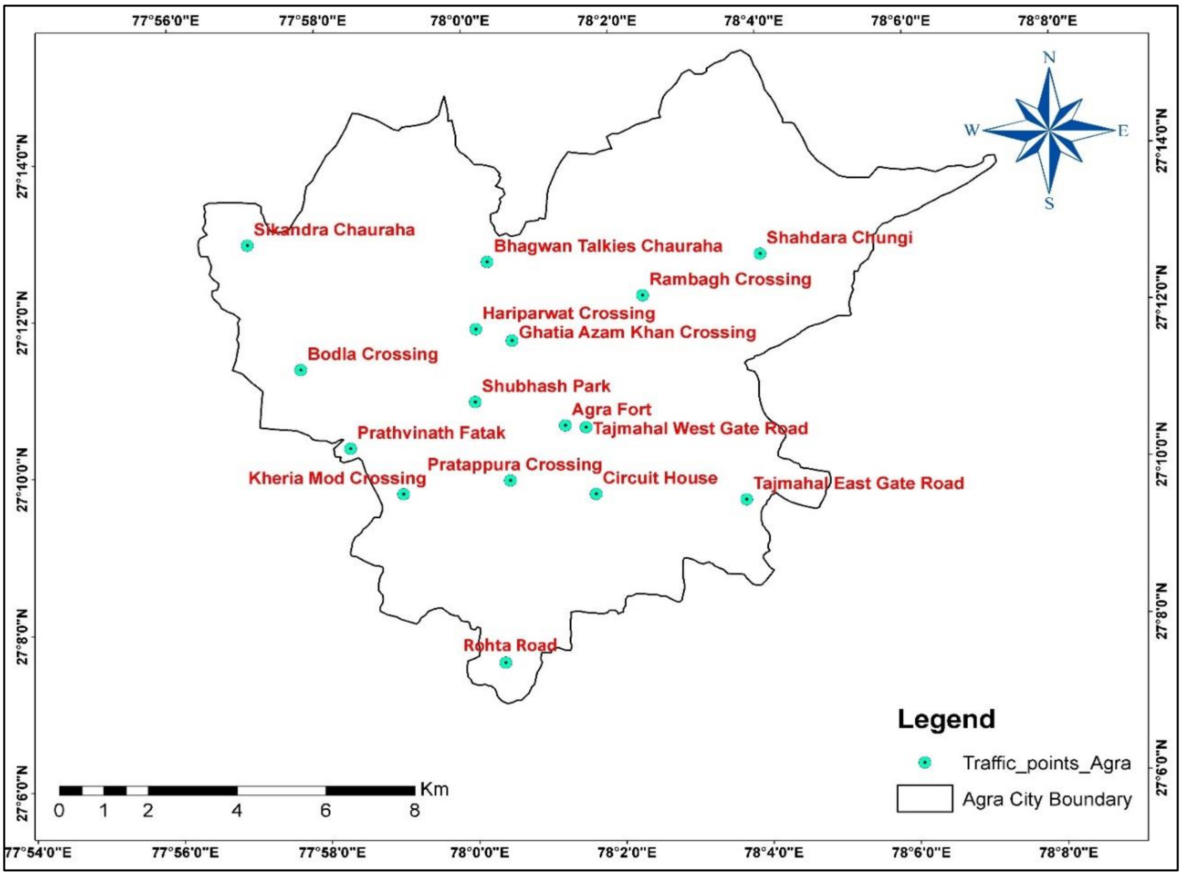


Figure 61: Silt load location considered for Silt Samples in the city of Agra

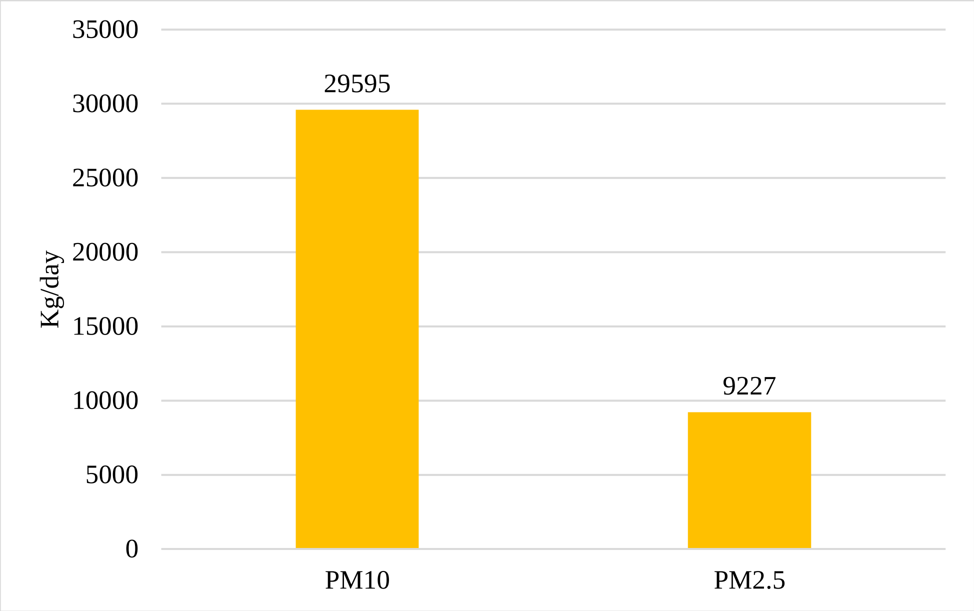


Figure 62: Emission Load from Road Dust (kg/day)

Open Area

The emission load for open area in Agra City was found to be significantly low - nearly 38 kg/day. The only contribution was of PM_{10} in open area source.

3.3.3 City Level Emission Inventory

The overall baseline emission inventory for the entire city is presented in Table 18. The total emission of different pollutants in the Agra City is shown in Figure 63.

Table 18: Agra City Level Inventory (kg/day)

Sources	PM_{10}	$PM_{2.5}$	SO_2	NOx	CO	BC
Domestic	1187	901	235	562	4826	129
MSW	505	343	32	189	2649	43
Hotel	665	341	113	141	3748	44
Construction	844	194	-	-	-	-
DG Sets	30	27	28	424	92	3
Industries	1651	1486	883	516	16043	204
Hospital	47	42	44	661	143	5
Open Area	38	-	-	-	-	-
Vehicle	1832	1649	363	16651	22576	210
Road Dust	29595	9227	-	-	-	-
Total	**36394**	**14210**	**1698**	**19144**	**50077**	**638**

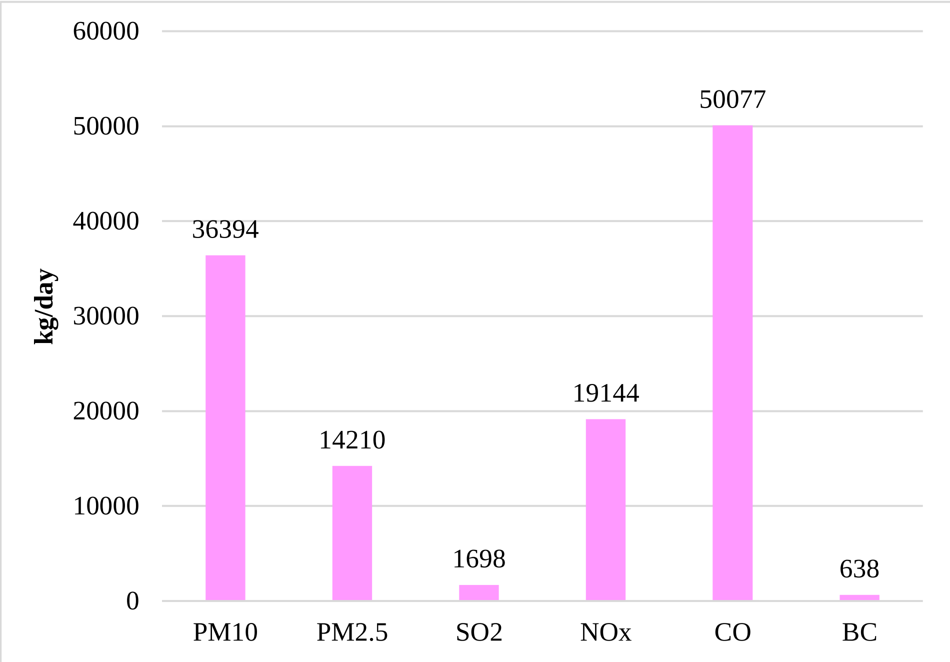


Figure 63: Emissions from various sectors in the Agra City

The total PM_{10} emission load in the city is estimated to be 37 tons/d. Based on annual emissions, the top four contributors to PM_{10} emissions are road dust (80%), industries (5%), vehicles (5%), and construction (2%). Seasonal and daily emissions could be highly variable. The estimated emission suggests that there are many important sources and a composite emission abatement including most of the sources will be required to obtain the desired air quality (Figure 64).

$PM_{2.5}$ emission load in the city is estimated to be 15 tons/d. Based on annual emissions, the top four contributors to $PM_{2.5}$ emissions are road dust (63%), vehicles (11%), industries (10%), and domestic fuel burning (6%). Seasonal and daily emissions could be highly variable (Figure 65).

SO_2 emission load in the city is estimated to be 2 tons/d. Industries account for 53% of the total emission. Vehicles contribute 18% followed by hotels and restaurants (11%) (Figure 66).

NOx emissions load in the city is estimated to be 19 tons/d. Nearly 85% of the emissions are attributable to vehicular emissions followed by DG sets (2%), and industries (5%). Vehicular emission occurs at ground level, making it more lethal . NOx apart from being a pollutant is an important component in the formation of secondary particles (nitrates) and ozone. Controlling

NOx emissions from vehicles and industries can potentially abate overall quantum of NOx emission (Figure 67).

The estimated CO emission is about 54 tons/d. Nearly 42% emission of CO is from vehicles, followed by industries (30%), domestic (9%), and about 5% from MSW burning. Vehicles could be the main target for controlling CO (Figure 68).

The estimated BC emission is about 0.7 tons/d. Nearly 31% of the emission of BC is from vehicles, followed by 29% from industries, 19% from the domestic sector, and about 6% from MSW burning. Vehicles and industries could be the main target for controlling BC. (Figure 69).

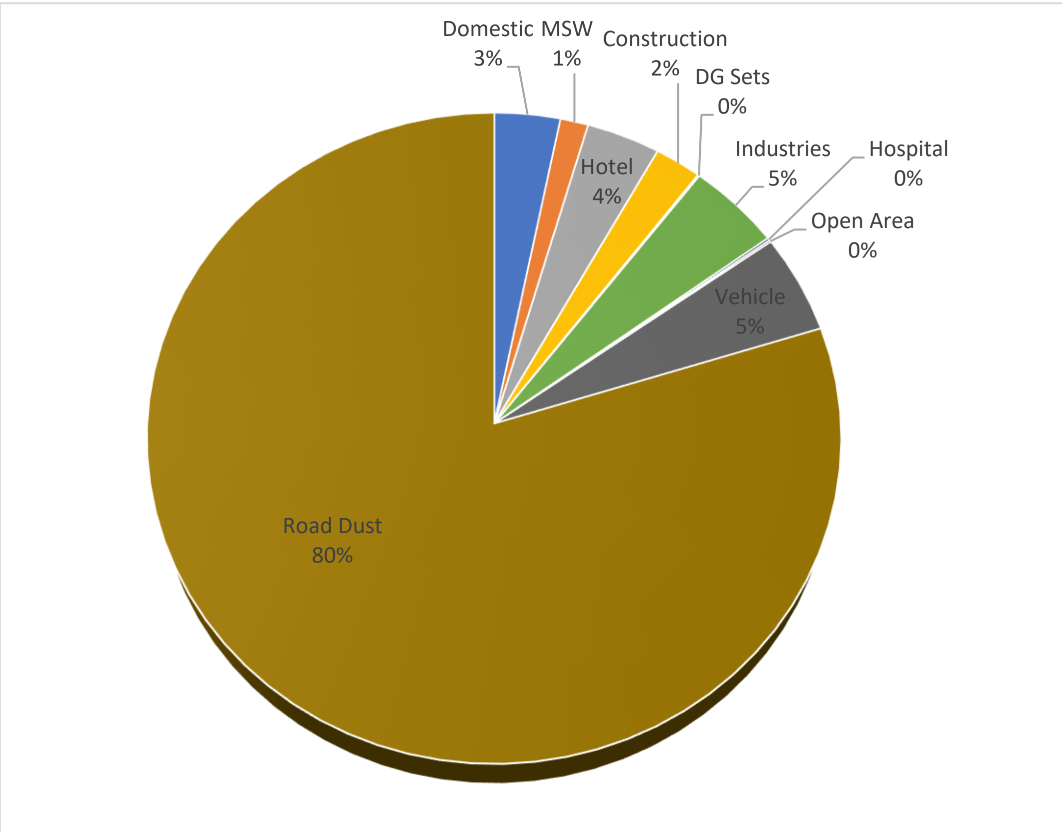


Figure 64: PM_{10} Emission Load of Different Sources (Total: 36394 kg/d)

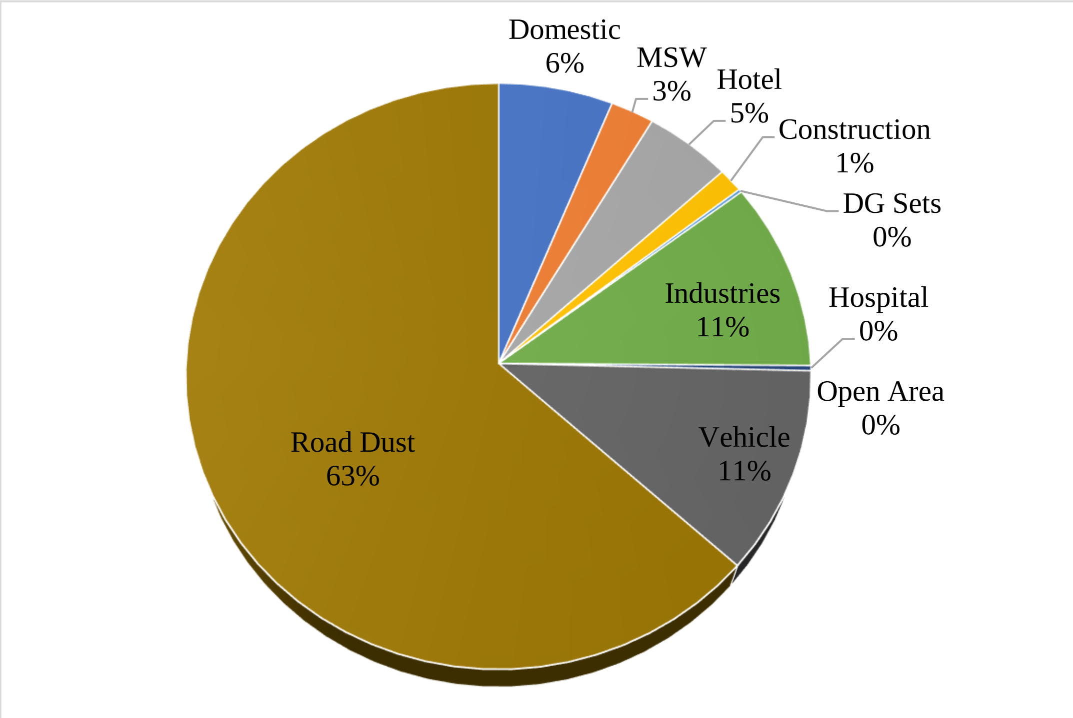


Figure 65: $PM_{2.5}$ Emission Load of Different Sources (Total: 14210 kg/d)

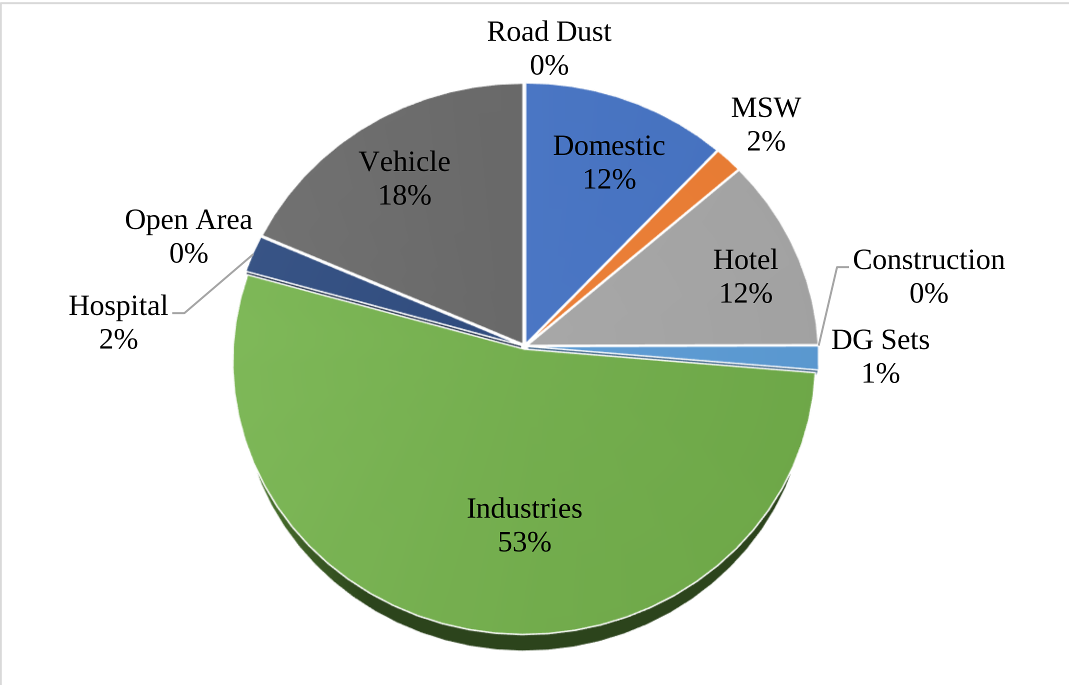


Figure 66: SO_2 Emission Load of Different Sources (Total: 1698 kg/d)

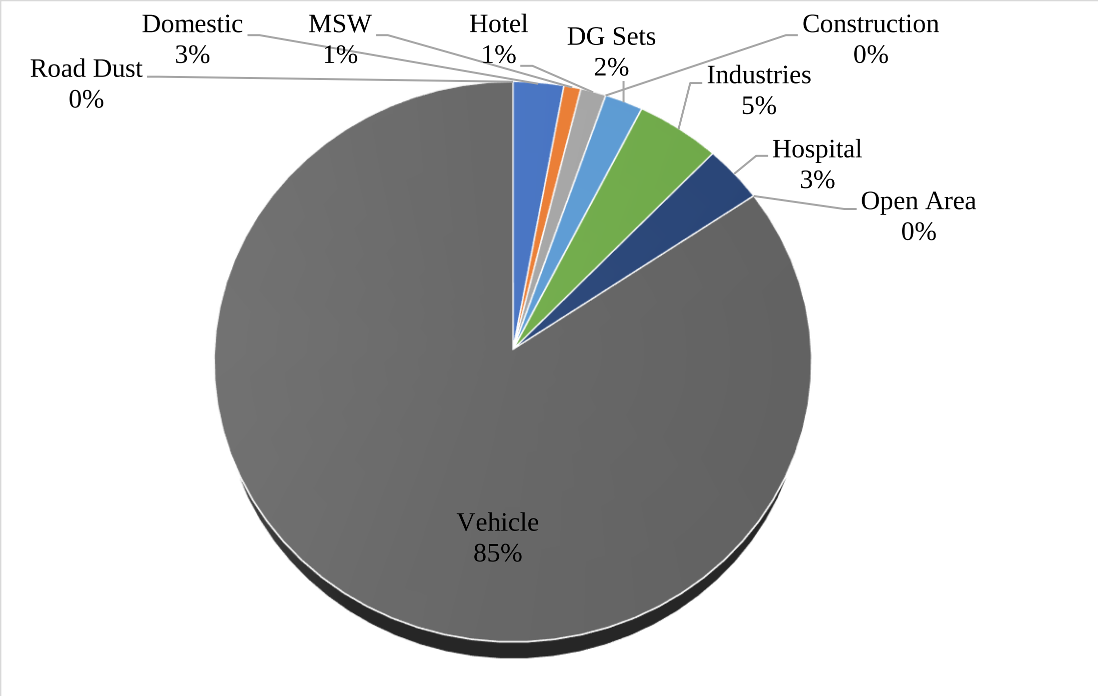


Figure 67: NOx Emission Load of Different Sources (Total: 19144 kg/d)

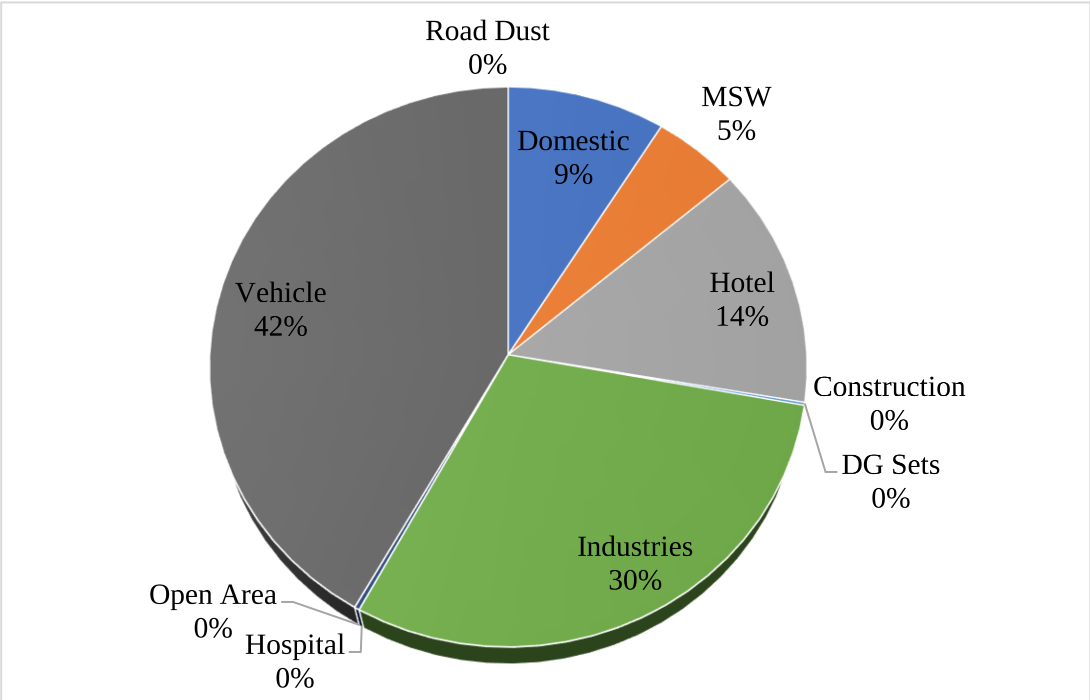


Figure 68: CO Emission Load Contribution of Different Sources (Total: 50077 kg/d)

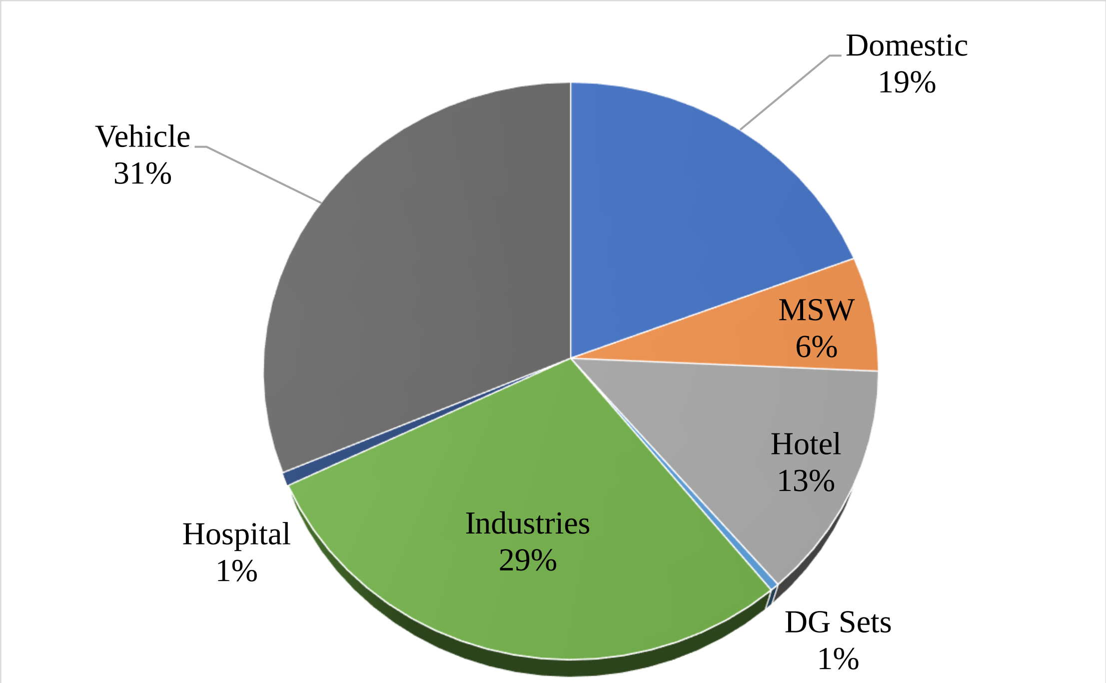


Figure 69: BC Emission Load Contribution of Different Sources (total: 638 kg/d)

3.3.4. Relative Sense of Emission: Agra City Vs. Airshed

It provides a relative sense of emission in the Agra City with respect to the airshed and fraction of the Agra City emission in the entire airshed. Industrial emissions in the Agra City are relatively less compared to emissions in rest of the the airshed. The reason is not the lesser number of industrial units in Agra, but that almost all industries operate on a clean fuel - CNG. It suggests that there could be significant industrial sources outside the Agra City but inside the airshed and can add to the air pollution in Agra. However, when comparing total emissions (including all sources, road dust, transport, household) from the Agra City with the industrial emission in the airshed, the city emissions are much higher (Table 19).

Table 19: Relative Sense of Emissions

Pollutant	Agra (Ind) /Airshed excluding Agra (Ind)	Agra (all) /Airshed excluding Agra (Ind)
PM_{10}	0.17	2.30
$PM_{2.5}$	0.10	1.50
CO	0.09	0.29
SO_2	0.04	0.11
NO_x	0.03	0.72
Ind – Industries		

At the Agra City level, most of the PM_{10} and $PM_{2.5}$ emissions (70 – 50%) are from road dust, NO_X and CO from vehicles, and SO_2 from brick kilns.

Figure 70 shows thatthe maximum contribution is from the Aligarh district for all the pollutants except CO. Figure 71 shows the total emissions and contributions from different sources in the Agra Airshed. Household sources and the combustion manufacturing industries are major contributors to all the pollutants in the Agra Airshed. Figure 72 shows the total emissions and contributions from different sources within the Agra City. Road dust, vehicular and industrial sources are major contributors within the Agra City.

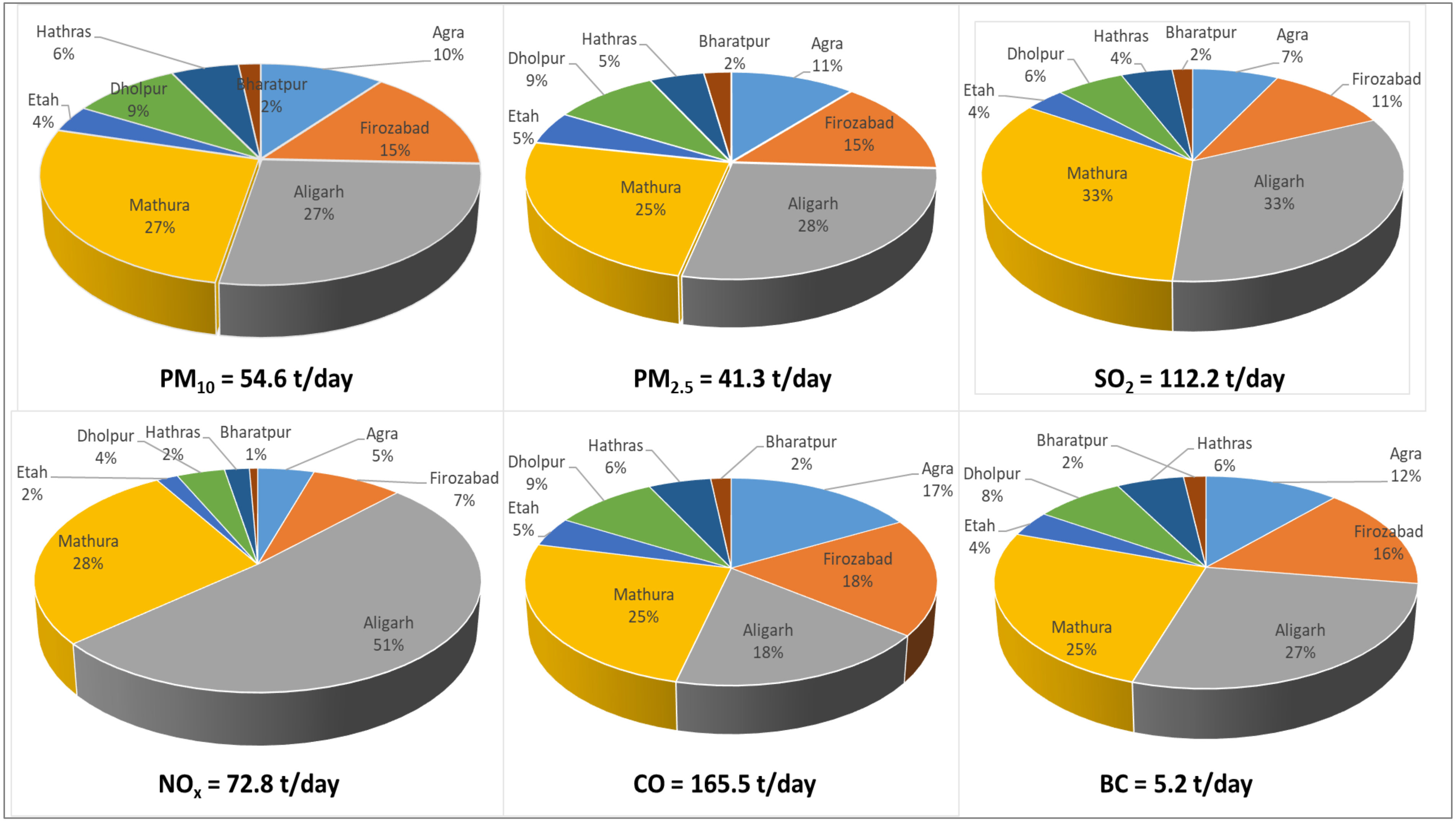


Figure 70: Total Industrial Emissions and Contributions from Different Districts in the Agra Airshed

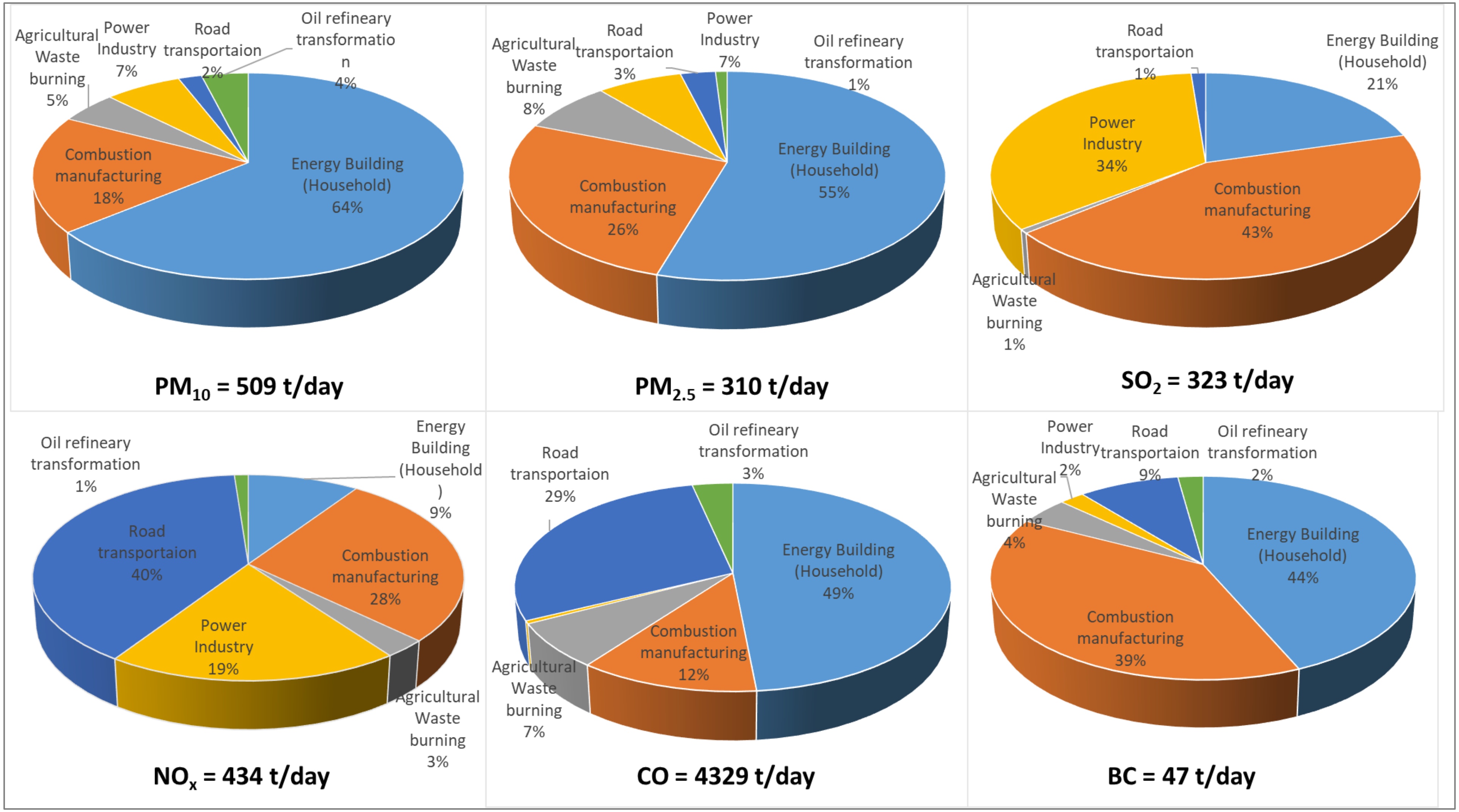


Figure 71: Total Emissions and Contributions from Different Sources in the Agra Airshed (Source: Secondary Data)

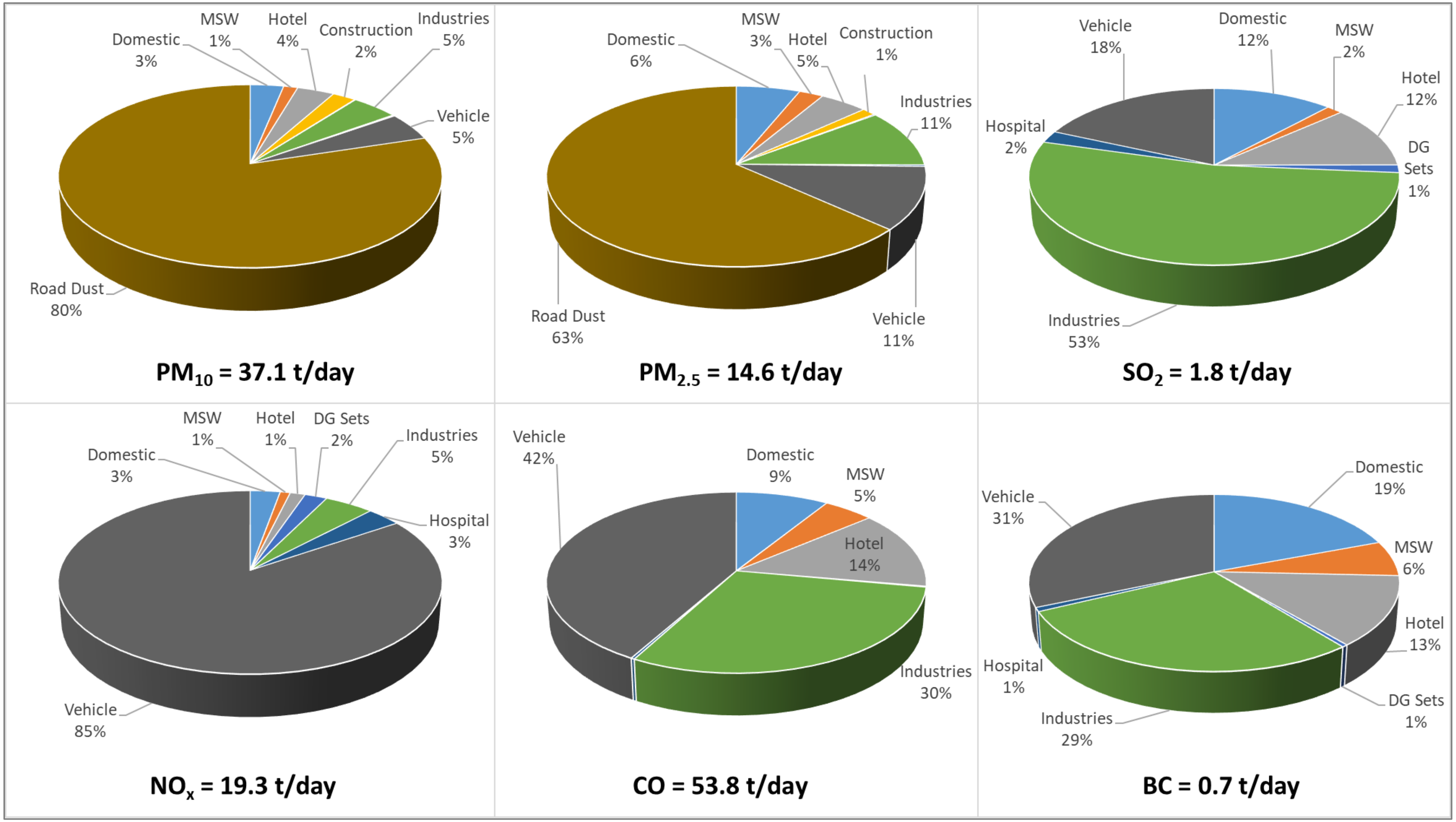


Figure 72: Total Emissions and Contributions from Different Sources within the Agra City

4 Dispersion Modelling

4.1 Introduction

Two current state-of-the-science, comprehensive meteorological and regulatory air dispersion modelling systems have been used in the study to conduct the dispersion modelling. The American Meteorological Society / Environmental Protection Agency Regulatory Model (AERMOD) has been used to assess the impact from short-range transport (<50 km) on $PM_{2.5}$ emitting from the sources within the Agra City, and the Weather Research Forecasting with – Chemistry (WRF-Chem) model has been used to assess the long-range transport (>50 km) on $PM_{2.5}$ emitted from sources in the Agra Airshed.

4.1.1 AERMOD

AERMOD is a dispersion model having the ability to characterize the planetary boundary layer (PBL) through both surface and mixed layer scaling. This model is a complete and powerful air dispersion modelling package that seamlessly incorporates the following popular United States Environmental Protection Agency (EPA) air dispersion models into one integrated interface:

- AERMOD
- ISCST3
- ISC-PRIME

The AERMOD modelling system consists of one main program (AERMOD) and two pre-processors (AERMET and AERMAP). AERMOD uses terrain, boundary layer, and source data to model pollutant transport and dispersion for calculating temporally averaged air pollution concentrations.

The approach for modelling using AERMOD is shown in Figure 73. Onsite hourly meteorological data was generated by WRF model. The model run was performed for a defined study period (year 2018). The output of the WRF model was fed as the input of AERMOD in the pre-processor RAMMET and AERMET of the model. The observed meteorological data was collected from the UPPCB monitoring station located at Sanjay Palace, Agra and compared with the WRF results for validation.

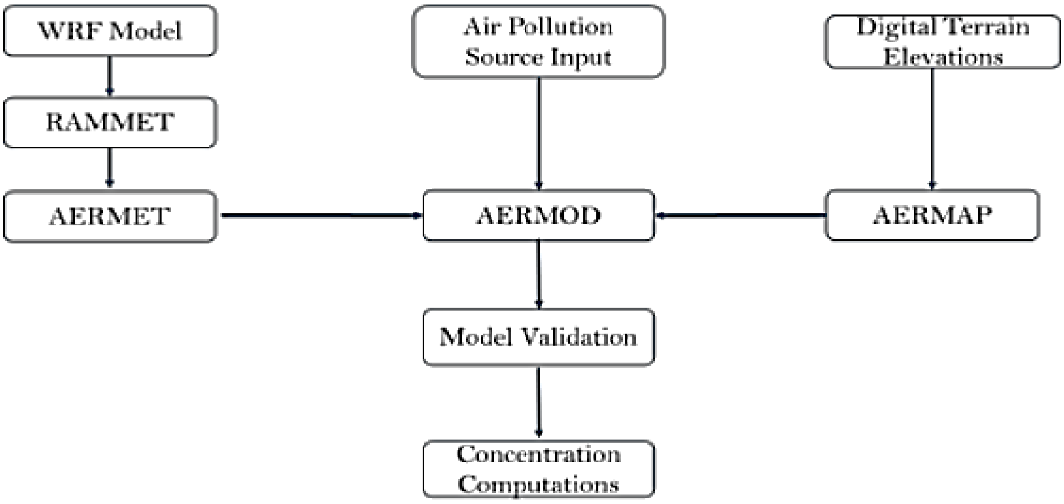


Figure 73: Approach for Dispersion Modelling using AERMOD

The meteorological parameters from WRF model (wind speed, wind direction, rainfall, temperature, humidity, pressure, ceiling height, global horizontal radiation,and cloud cover) with one-hour resolution were organized in a spreadsheet. This spreadsheet was reprocessed in AERMET which is the meteorological pre-processor of AERMOD. The terrain data at 90 m resolution of Shuttle Radar Topography Mission (SRTM) was used in AERMAP which is also the pre-processor of AERMOD. This provided a physical relationship between terrain features and the behaviour of air pollution plumes and generated location and height data for each receptor location. AERMOD was further used to model air quality in the study for the prediction of pollutants concentration from different sources within the Agra City.

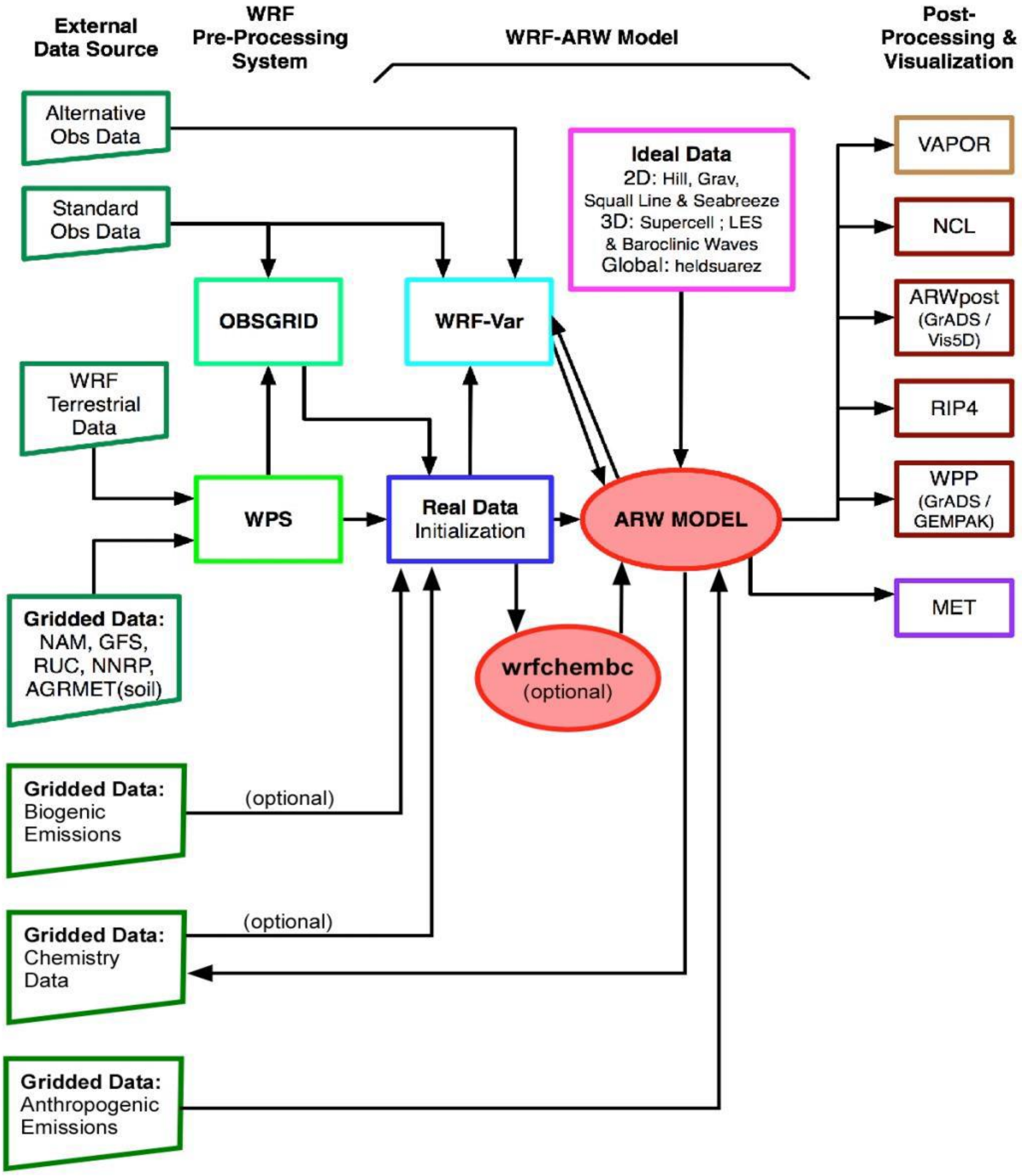
4.1.2 WRF-Chem

WRF-Chem model consists of a portable code that is efficient in running on a range of computational power from massively parallel supercomputers to laptops. It has applications in a large span of scales from large-eddy to global simulations. The applications include regional climate simulations, numerical weather prediction, air-quality monitoring, etc. The WRF software framework includes the dynamics solvers, physics packages, programs for initializations, and WRF-Chem. The model uses Range-Kutta 2^{nd} and 3^{rd} order time integration schemes and 2^{nd} to 6^{th} order advection schemes in both horizontal and vertical directions. The

WRF-Chem model mostly consists of three major programs: (1) WRF-Preprocessing System, (2) Real Data Initialization, and (3) WRF Solver (ARW/NMM) with Chemistry (Figure 74).

Industrial emission inventory of the Agra Airshed was used as an input for running the WRF-Chem model to predict the impacts from surrounding industries to the Agra City.

Figure 74: WRF-Chem Modeling System (Peckham et al., 2015)



4.2 Site Description

A domain of size 100 km x 100 km at the centre of the Agra City was chosen for the modelling study. The outer regions were marked as shown in Figure 75 to assess the efflux of $PM_{2.5}$ from the city to these regions. A gridded emission inventory of $PM_{2.5}$ from all the major sources was taken at a resolution of 2 km x 2 km (Figure 76 and Figure 77).

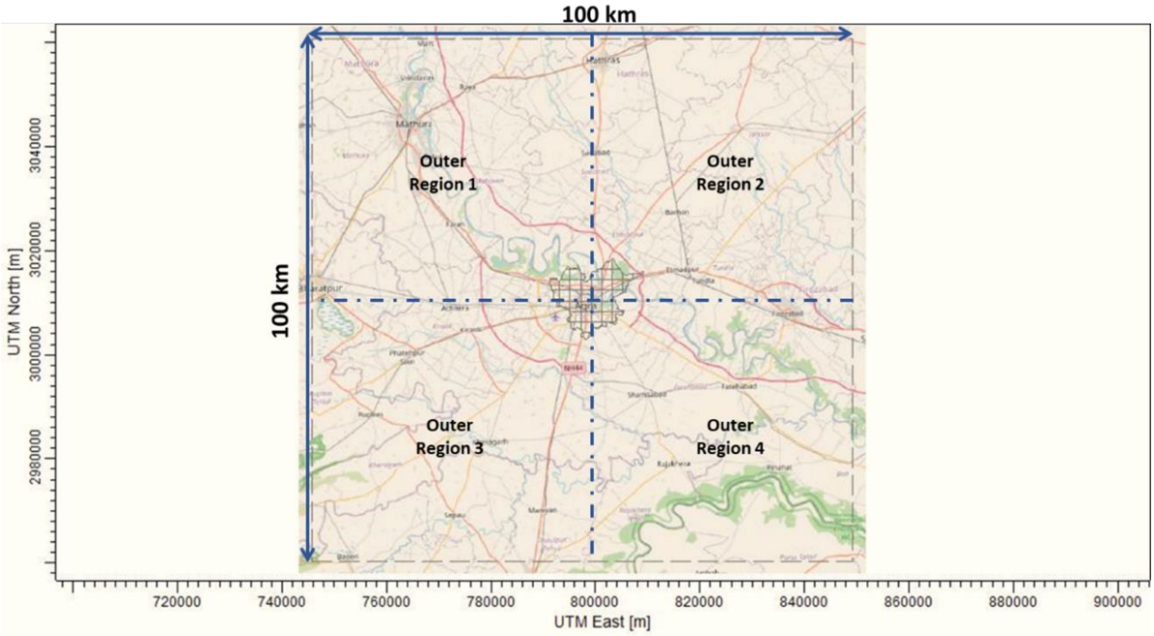


Figure 75: Domain of the Modelling Area for the Impact of Emissions from Agra City to the Outside Regions

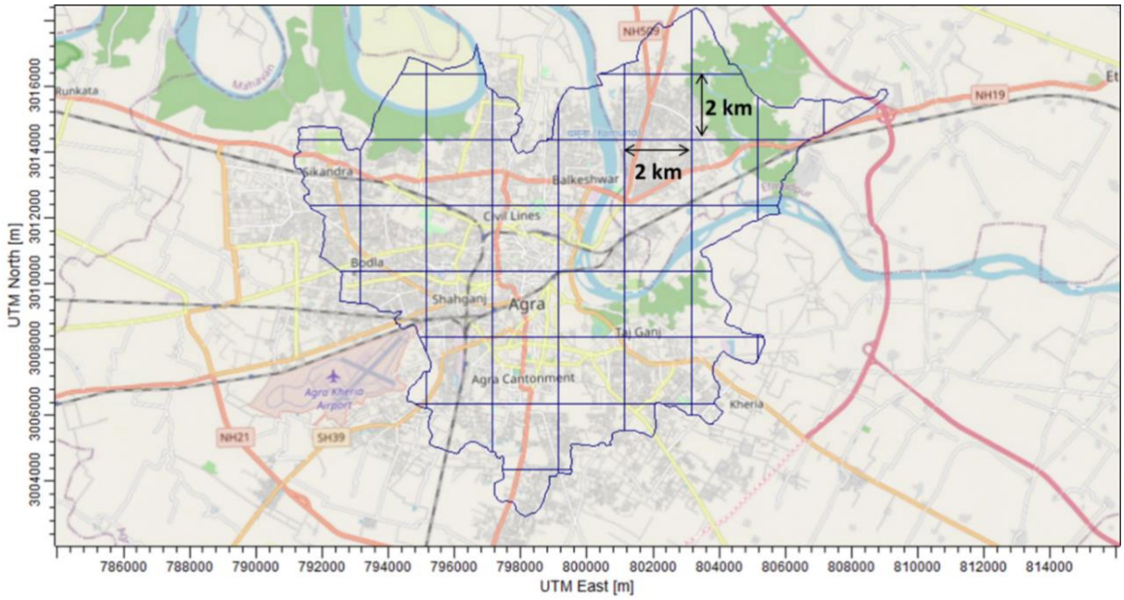


Figure 76: Emission Grid of 2 km x 2 km for the Agra City

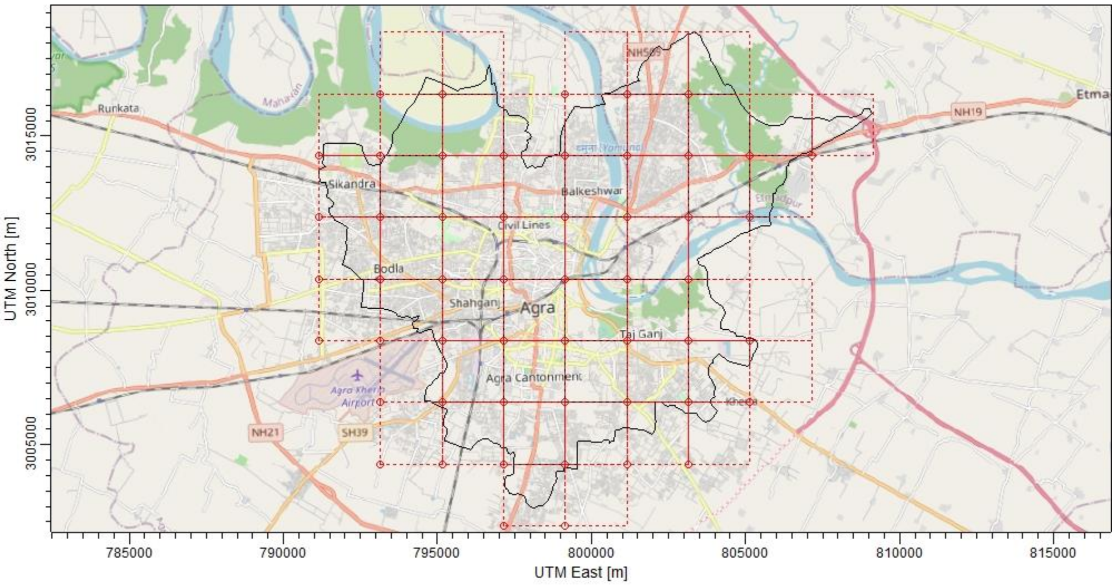


Figure 77: Extent of Emission Grids for Different Sources within the Agra City

4.3 Meteorological Data

(Package 5: Validate the Weather Research and Forecasting (WRF) and Dispersion Model for meteorological parameters and ground-level concentrations against observed data)

In evaluating the emission dispersion using the AERMOD, the meteorological dataset was generated using the WRF model from January 01, 2018 to December 30, 2018. The frequency distribution and frequency count data were obtained by processing the hourly surface file in AERMET. The AERMET program is a meteorological pre-processor that prepares hourly surface data and upper-air data for use in the USEPA air quality dispersion model, AERMOD.

The wind rose plots for the 12 months of 2018 are shown in Figure 78 and Figure 79. The predominant wind blowing direction was observed to be north-west in all the months except July, August, and September. The predominant wind direction was south-east during these months. Also, relatively high wind speed was observed in the summer and monsoon seasons.The modelled wind speed and ambient temperature data were validated using the data obtained from the UPPCB's ambient air quality monitoring station located at Sanjay Palace, Agra. 24-hour moving average from hourly wind speed data for each month of 2018 was also plotted (Figure 80 and Figure 81). The Pearson's correlation coefficient (R), normalised mean square error (NMSE), and fractional bias (FB) were calculated for each month's hourly wind speed data to assess the model performance (Table 20).

Pearson's Correlation Coefficient (R)

Numerical, as well as graphical analyses, are involved in the correlation analysis. A value of correlation coefficient (R) close to unity implies good model performance. The numerical result gives a quantitative relation, while graphical analysis gives a qualitative measure of the observed and predicted parameters. In equation form it is represented as:

$$R = \frac{\overline{(C_o - \overline{C_o})(C_p - \overline{C_p})}}{\sigma_{C_o}\ \sigma_{C_p}}$$

Where C_p = Predicted value; C_o = Observed value

Normalized Mean Square Error (NMSE)

This statistic emphasizes the scatter in the entire data set and is known as Normalized Mean Square Error (NMSE). The normalization by the product of $C_{p*}C_o$ assures that the NMSE will not be biased towards models that over-predict or under-predict. Smaller values of NMSE denote better model performance. The expression for the NMSE is given by:

$$NMSE = \frac{\overline{(C_o - C_p)^2}}{\overline{C_o C_p}}$$

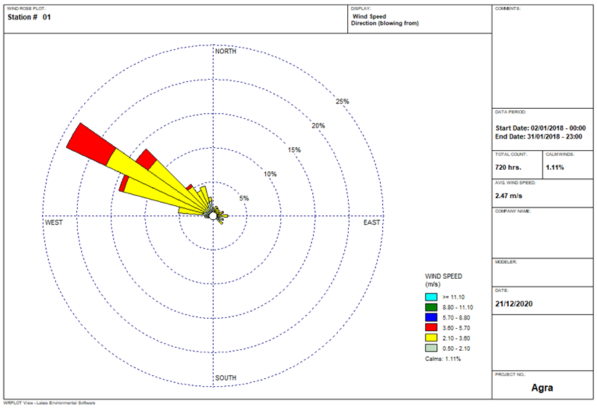
Fractional Bias (FB)

Model Bias is the mean error that is defined as the observed value of concentration (C_o) less than the predicted value (C_p). This bias is normalized to make it non-dimensionless fractional bias. Its value varies between +2 and -2 and has an ideal value of zero for an ideal model. It is written in symbolic form as:

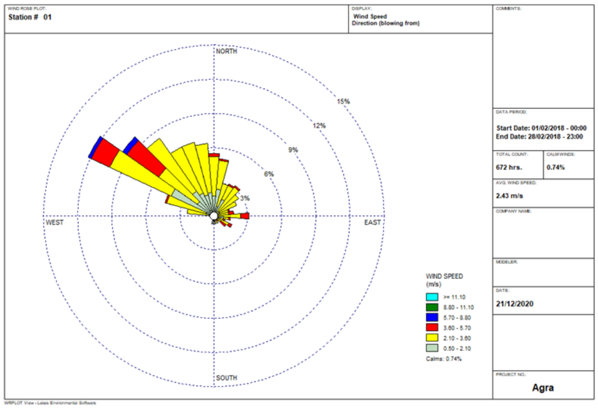
$$FB = 2 \times \frac{\overline{C_o} - \overline{C_p}}{\overline{C_o} + \overline{C_p}}$$

The quality of an ideal and perfect model is to have both the fractional bias and normalized mean square error equal to zero. The performance of a model can be deemed as acceptable if, NMSE ≤ 0.5, and -0.5 ≤ FB ≤ +0.5.

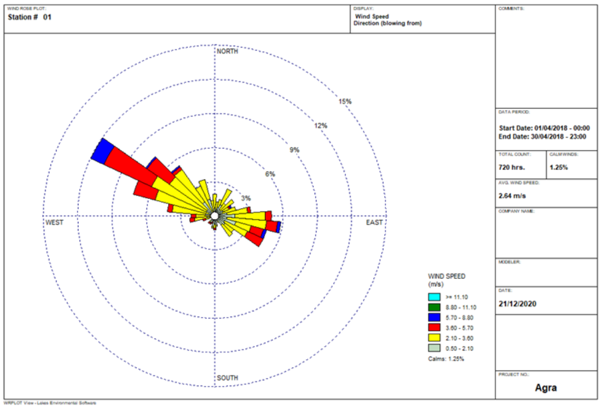
January



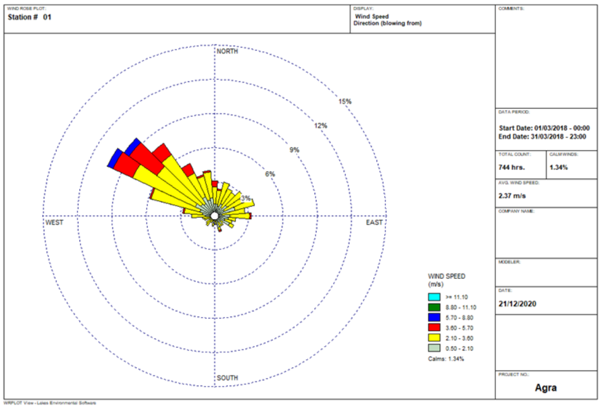
February



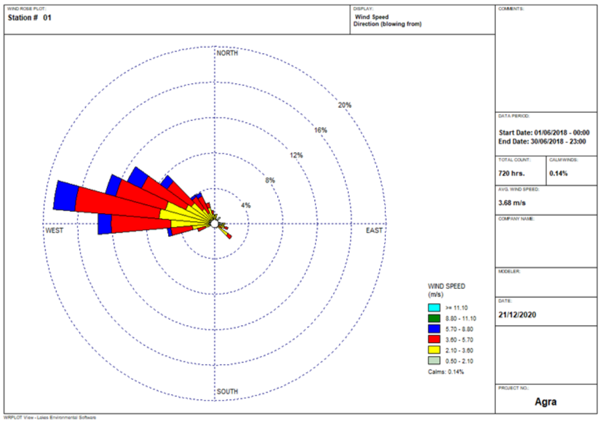
March



April



May



June

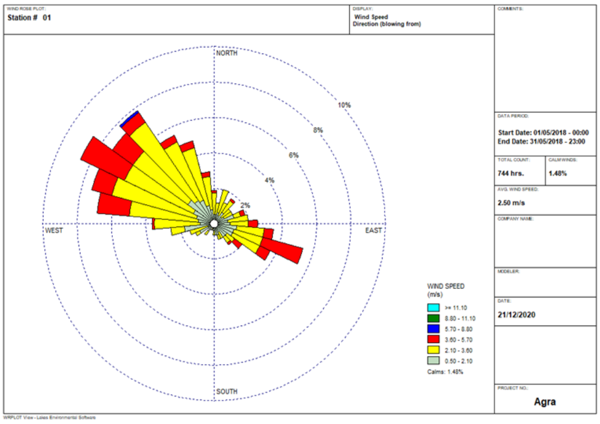
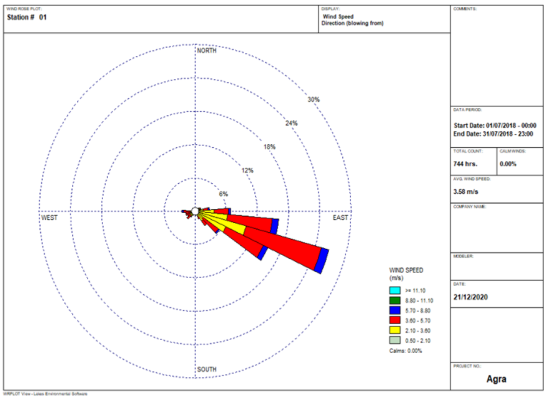
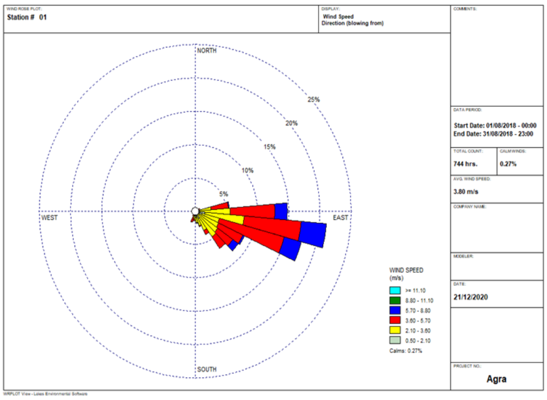


Figure 78: Wind Rose Plots for the First Six Months of 2018 from WRF Output Data

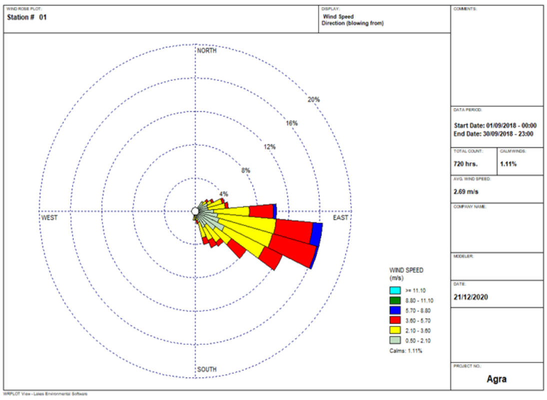
July



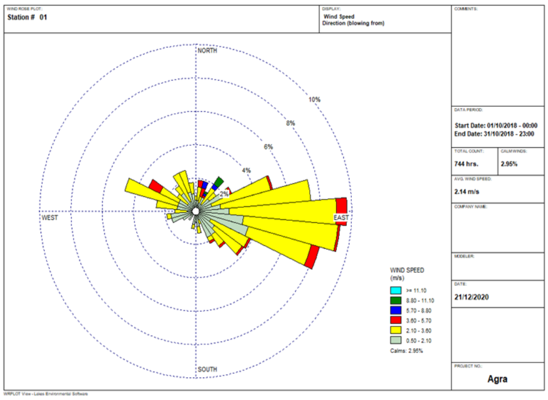
August



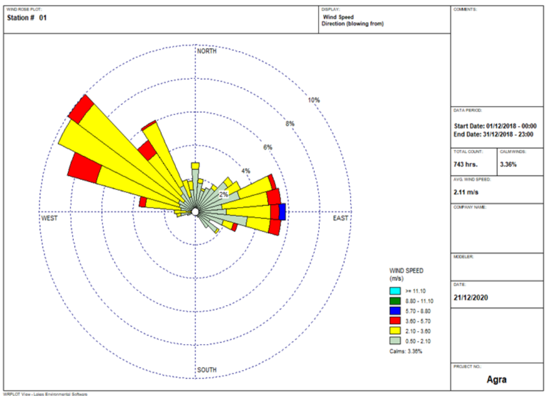
September



October



November



December

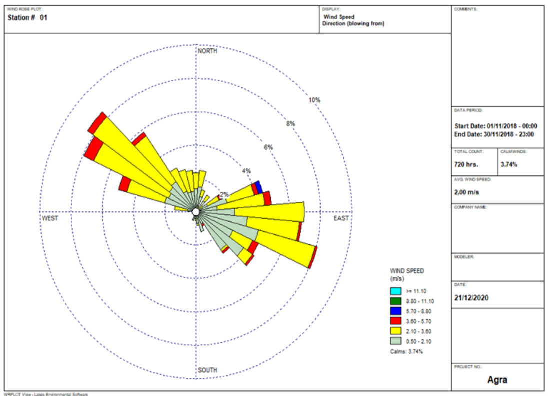


Figure 79: Wind Rose Plots for the Last Six Month of 2018 from WRF Output Data

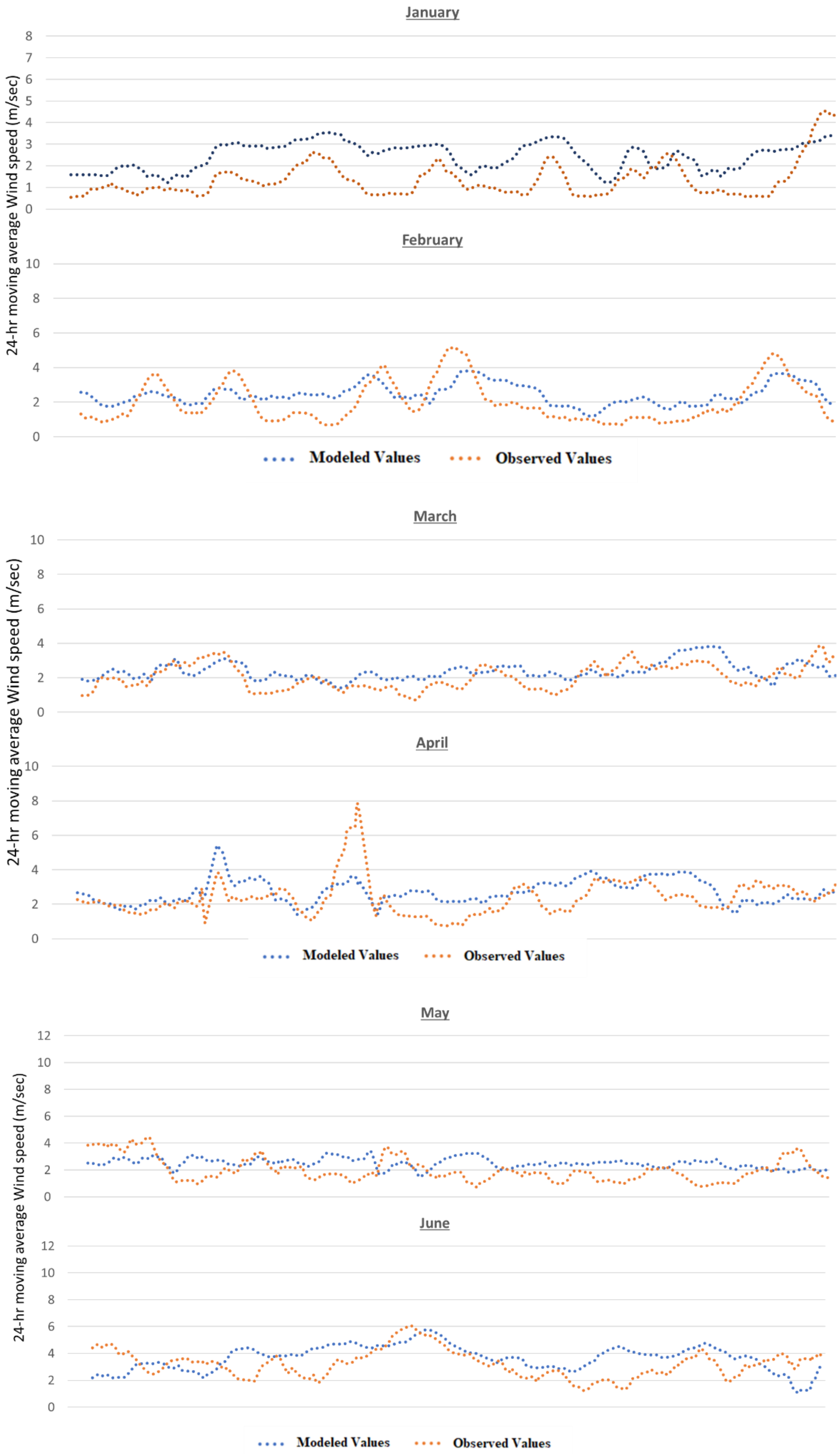


Figure 80: Time-Series Plot of 24-hour Moving Average Wind Speed (Model vs. Observed) for 2018

Figure 81: Time-Series Plot of 24-hourr Moving Average Wind Speed for Last Six Months of 2018

Table 20: Statistical Parameters for validating Wind Speed Data

	NMSE	FB	R
January	0.79	0.57	0.48
February	0.51	-0.20	0.51
March	0.55	0.14	0.29
April	0.42	0.16	0.36
May	0.68	0.22	0.11
June	0.32	0.14	0.24
July	0.72	0.51	0.01
August	0.87	0.63	0.07
September	0.40	0.06	0.41
October	1.10	0.52	0.16
November	0.71	0.37	0.33
December	1.09	0.62	0.24

The model performed satisfactorily for predicting wind speeds in the months of February, March, April, June, and September, while overestimating the wind speeds in general. Furthermore, the time-series plot of observed hourly ambient temperature values with modeled values shows a good agreement for all the months of 2018, four of which are shown in Figure 82. The statistical parameters assessing the performance of the model are listed in Table 21.

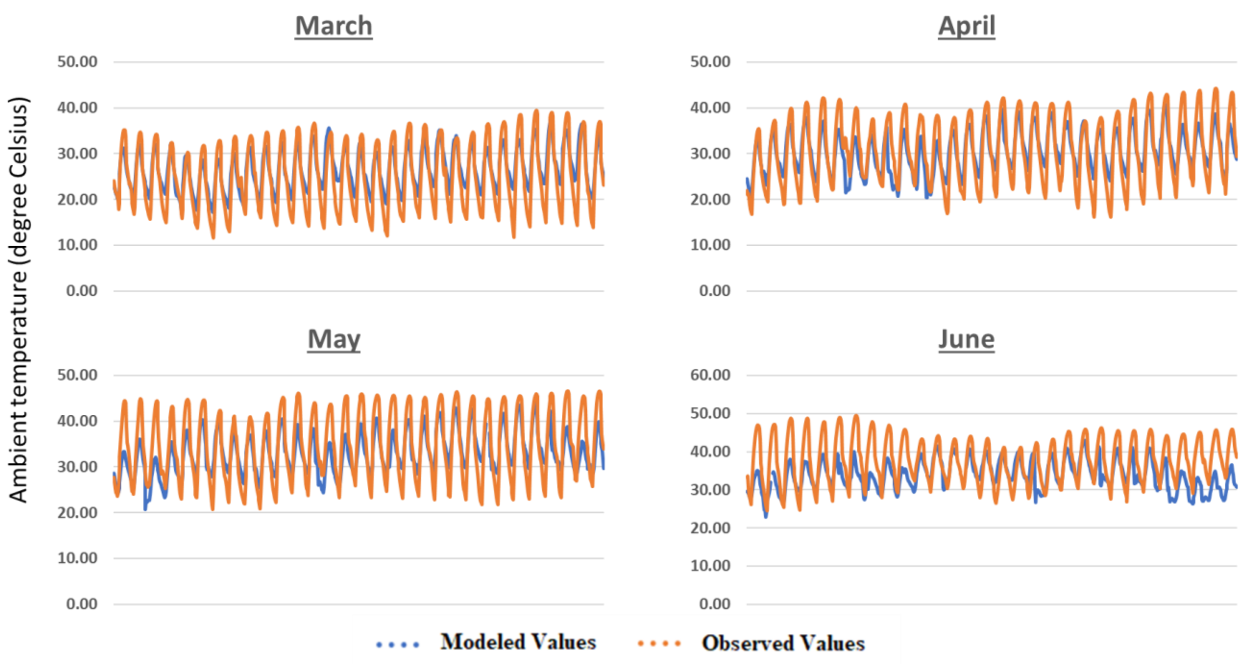


Figure 82: Time-Series Plot of Ambient Temperature Data for Four Months of 2018

Table 21: Statistical Parameters for validating Ambient Temperature Data

	RMSE (°C)	NMSE	FB	R
March	0.14	0.02	0.05	0.90
April	0.15	0.02	-0.01	0.85
May	0.22	0.03	-0.05	0.82
June	0.30	0.05	-0.11	0.61

It is concluded that except for the monsoon months of May to August, model performance to predict windspeed is acceptable. As for the rest of the months, the correlation coefficient is statistically significant. Other performance parameters – FB and NMSE - are acceptable for the months having acceptable coefficient of correlation.

The model performance for prediction of temperature is also acceptable with coefficient of correlation in the range of 0.61 to 0.90 (Table 21).

4.4 Digital Elevation Model (DEM) and receptor grid network

The Digital Terrain Elevation Model (DEM) is the most critical information required for complex terrain. The terrain affects the dispersion significantly. DEM is required to predict wind flow pattern and dispersion.AERMOD processes DEM data and creates an elevation and height scale (the terrain height and location that has the greatest influence on dispersion) for each receptor in the domain.The terrain is the vertical dimension of the land surface. Gridded terrain elevations for the proposed modelling domain were derived from 3 arc-second digital elevation models (DEMs) produced by the United States Geological Survey (USGS). The processed terrain elevation data is shown in Figure 83 and Figure 84.

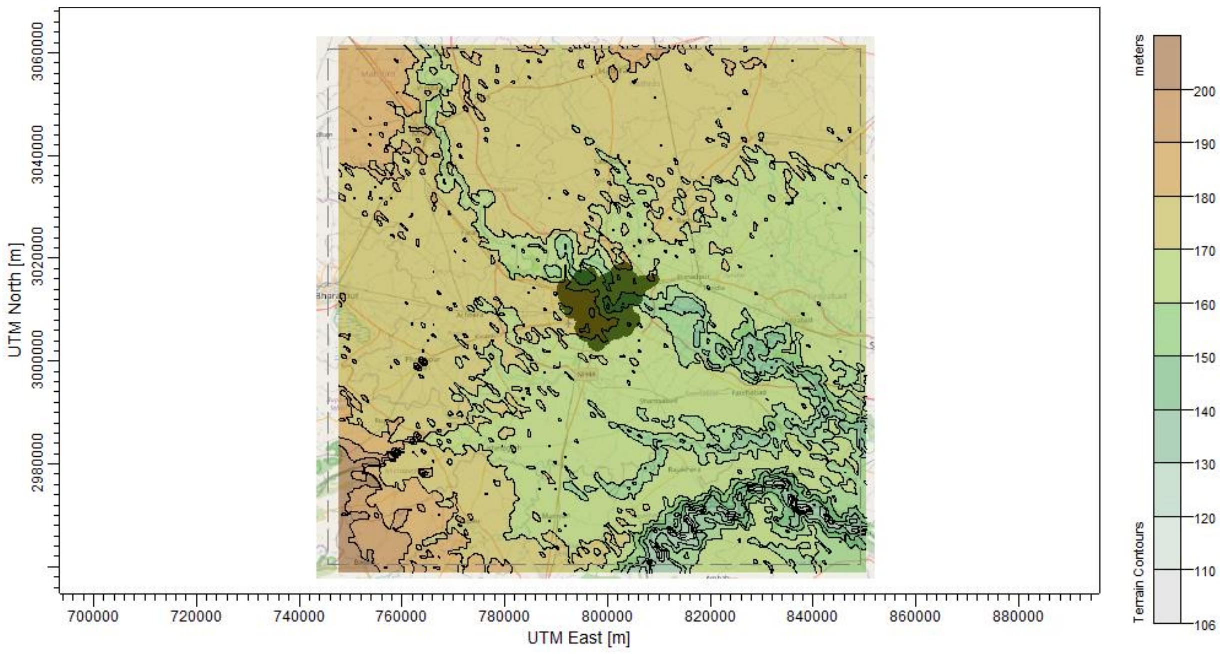


Figure 83: Terrain Contour Map of the Agra Airshed (Shaded region is the Agra City)

Receptor locations were defined using a set of non-uniform cartesian grid networks, uniform polar grid networks, and discrete cartesian grid networks. Five non-uniform cartesian grid networks (Figure 85) were employed to assess the impact within the Agra City boundary. Four uniform polar grid networks (

Figure 86) were used to quantify the impact on the region outside the city boundary. And six discrete cartesian receptors (Figure 87) were used to assess the impact at the locations where the manual ground observations were being recorded. A total of 739 receptors were defined for the analysis of ground-level $PM_{2.5}$ concentrations.

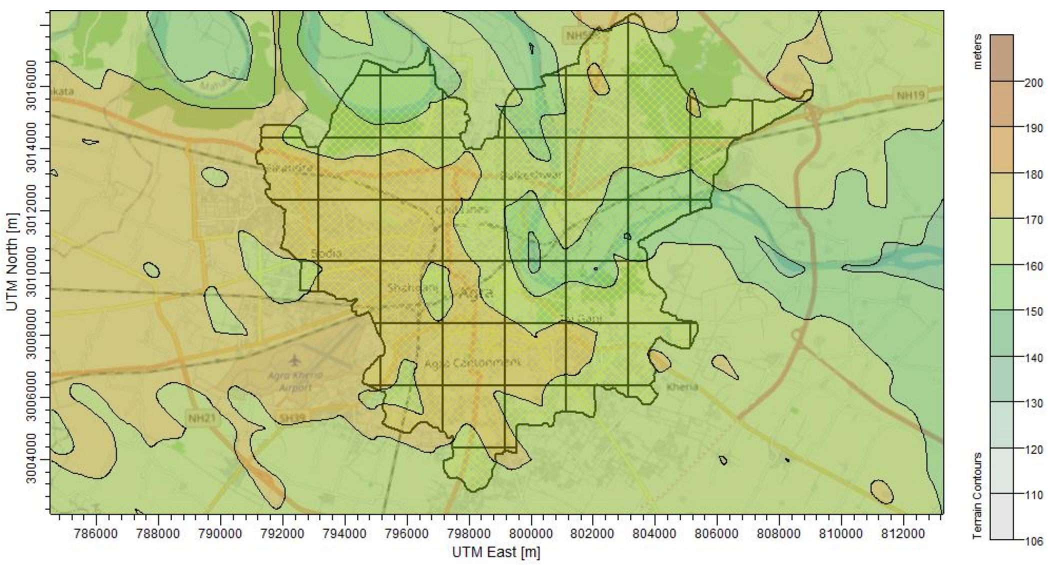


Figure 84: Terrain Contour Map of the Agra City

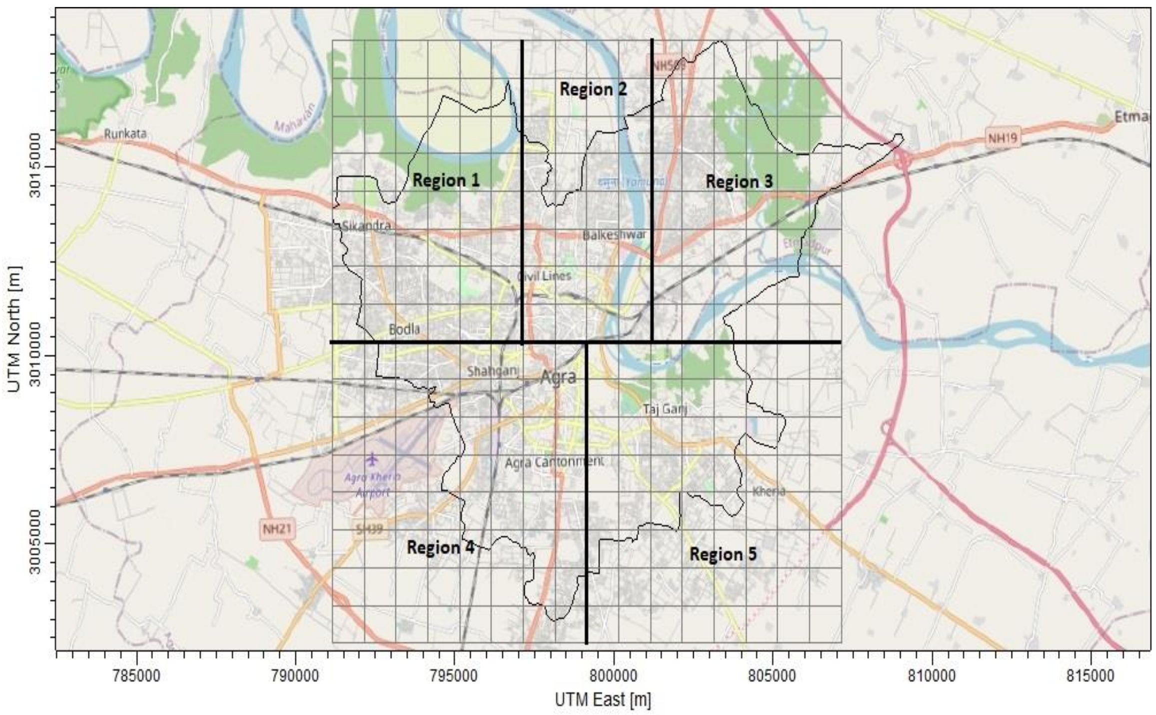


Figure 85: Non-Uniform Cartesian Grid Receptor Network

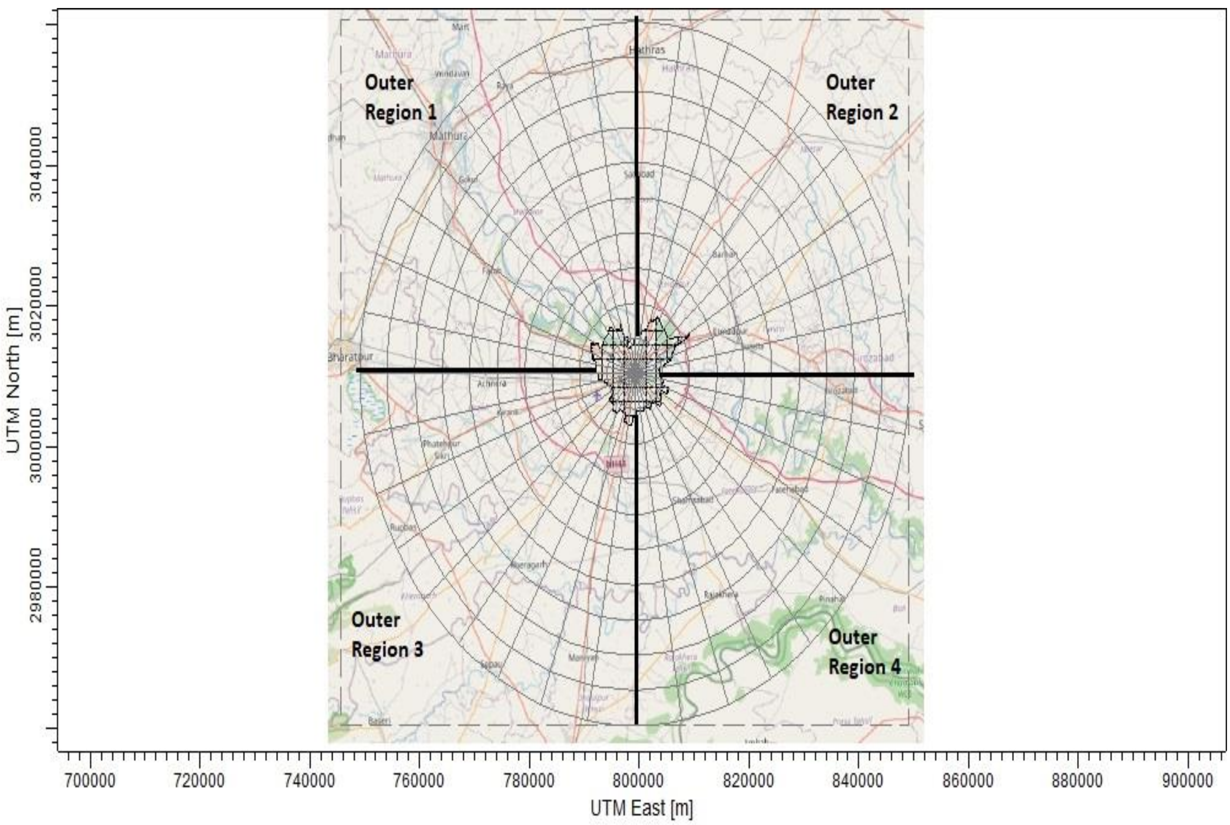


Figure 86: Uniform Polar Grid Receptor Network

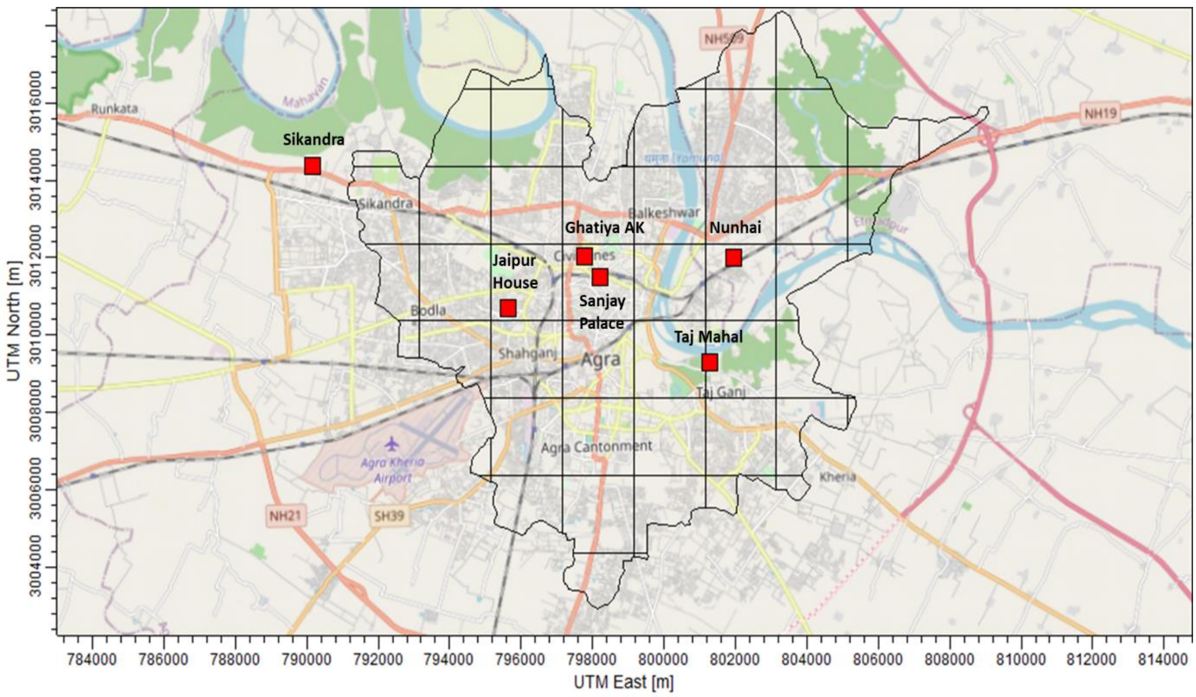


Figure 87: Discrete Cartesian Receptor (red squares show where air quality is monitored)

Table 22: Receptor Networks defined for Impact Assessment

Receptor Type	No. of Networks	No. of Receptors
Uniform Cartesian Grid	0	-
Non-Uniform Cartesian Grid	5	-
REGION 1	-	63
REGION 2	-	45
REGION 3	-	63
REGION 4	-	81
REGION 5	-	81
Uniform Polar Grid	4	-
OREGION 1	-	100
OREGION 2	-	100
OREGION 3	-	100
OREGION 4	-	100
Non-Uniform Polar Grid	0	-
Multi-Tier Grid (Risk Grid)	-	0
Nested Grid	0	0
Discrete Cartesian	-	6
Discrete Polar	-	0

4.5 Evaluation of Dispersion Modelling Results (Package 5)

The air dispersion modelling was done with complex terrain (using the elevation heights in the Agra City). By this approach, all the elevations of terrain were accounted, and the air dispersion reflected more accurate results as compared to flat terrain. The model was run considering only the sources within the Agra City.

The time-series and scatter plot of 24-hour average $PM_{2.5}$ concentration observed at the UPPCB's continuous ambient monitoring station located at Sanjay Palace, Agra and the modeled $PM_{2.5}$ concentrations considering all the major sources of $PM_{2.5}$ was plotted (Figure 88 and Figure 89) and it was observed that the model predicted well with a root mean square error of 79.51 µg/m^3 (Table 23). During winters high concentrations of $PM_{2.5}$ were observed which the model could not account for. It appeared there was a significant contribution of sources located outside the Agra City including the formation of secondary aerosols from distantly located emission sources.

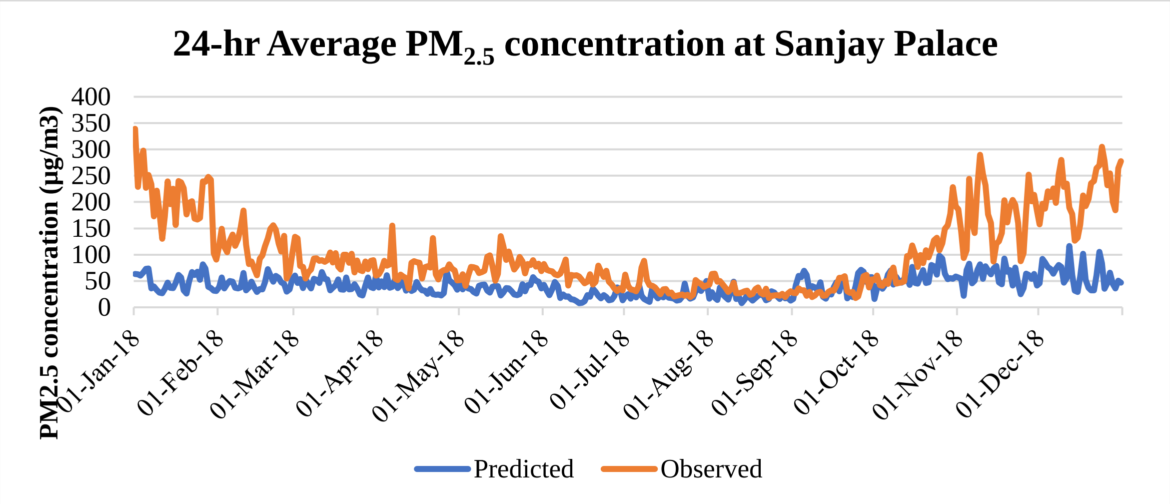


Figure 88:Observed vs. Predicted $PM_{2.5}$ Concentrations at Sanjay Palace

Table 23: Statistical Parameters for validating the Model

Root Mean Square Error (RMSE), µg/m^3	79.51
Normalised Mean Square Error (NMSE)	1.54
Fractional Bias (FB)	0.78
Pearson Correlation Coefficient (R)	0.64

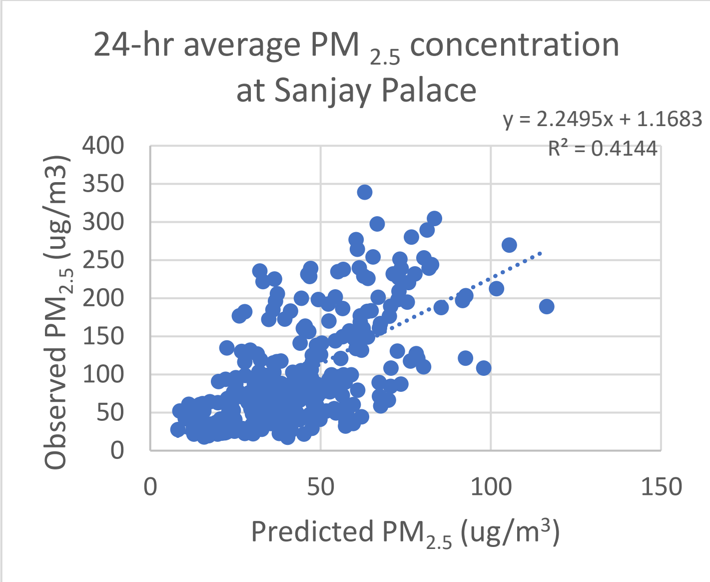


Figure 89: Scatter Plot for the 24-hour Average Observed and Predicted $PM_{2.5}$ Concentration at Sanjay Palace in 2018 (ug/m^3)

It is seen (Figure 89) that the modelled and observed $PM_{2.5}$ concentrations show a good association R^2 0.414 (for over 350 data points). However, the noteworthy point is that the model under-predicts the concentration by a factor of more than 2. The probable reasons for underestimation by the model is because of (i) over-prediction of wind speed by the WRF model, (ii) inventory may be incomplete and some source may be missing, and (iii) there is a substantial contribution of sources present outside the Agra City. Since the linear association in the model-computed and observed levels is very good, the model could be used for decision-making and useful insights.

The deficit in the model and measured data (referred to as unidentified) of $PM_{2.5}$ levels were highest during the January-February and November- December periods (Figure 90). Also, it is worth noting that there was a sudden spike in these unidentified concentrations of $PM_{2.5}$ during the first week of November which then increased gradually to a maximum value of 267 ug/m^3 in the first week of January and then decreased to a minimum value of 3 ug/m^3 in the first week of March. This episodic spike in the unidentified $PM_{2.5}$ concentrations, whose average value was 119 ug/m^3 (Table 24) in the city can be attributed to the influx from the surrounding regions outside of the city.

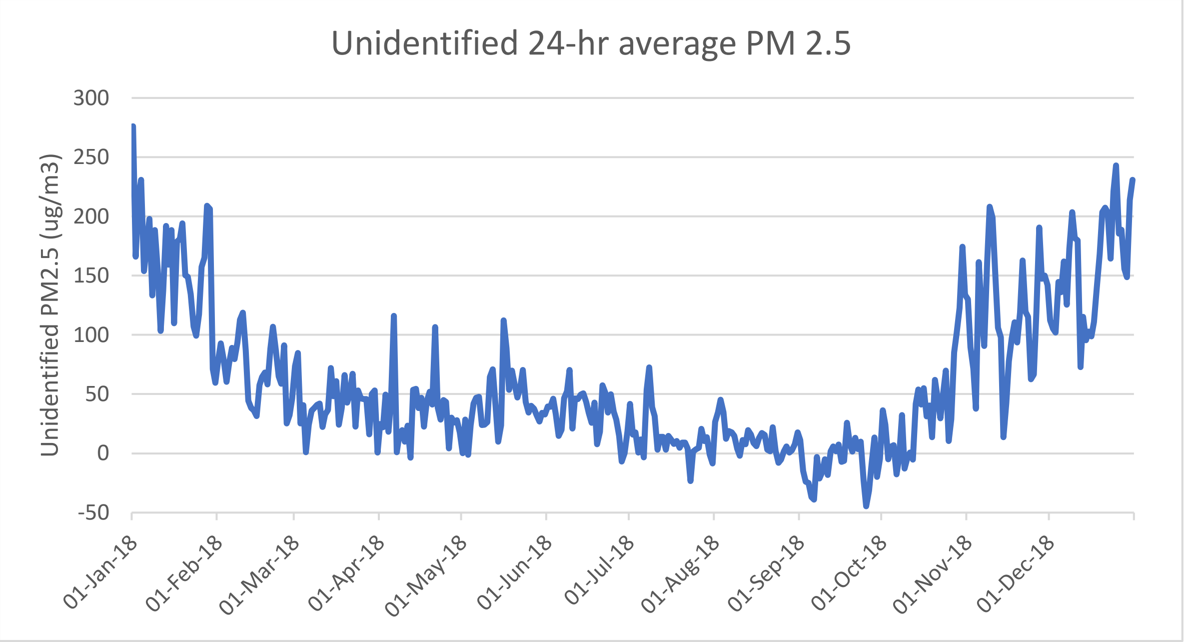


Figure 90: Unidentified 24-hour Average $PM_{2.5}$ Concentrations at Sanjay Palace

Table 24:Statistics for Unidentified 24-hour Average $PM_{2.5}$ Concentrations at Sanjay Palace (ug/m^3)

	Winter	**Summer**
Max	267	174
Min	3	-45
Average	119	26
Std. Dev.	55	30

On further plotting the 24-hour average $PM_{2.5}$ concentrations at Sanjay Palace with the modeled $PM_{2.5}$ concentrations for each month (Figure 91 and Figure 92), the monthly unidentified $PM_{2.5}$ concentrations were noted and are tabulated below (Table 25). The highest values were observed in December and January. Months of March and April did not show good model performance as these two months are characterized by high winds and dust storm that cannot be accounted for by the model.

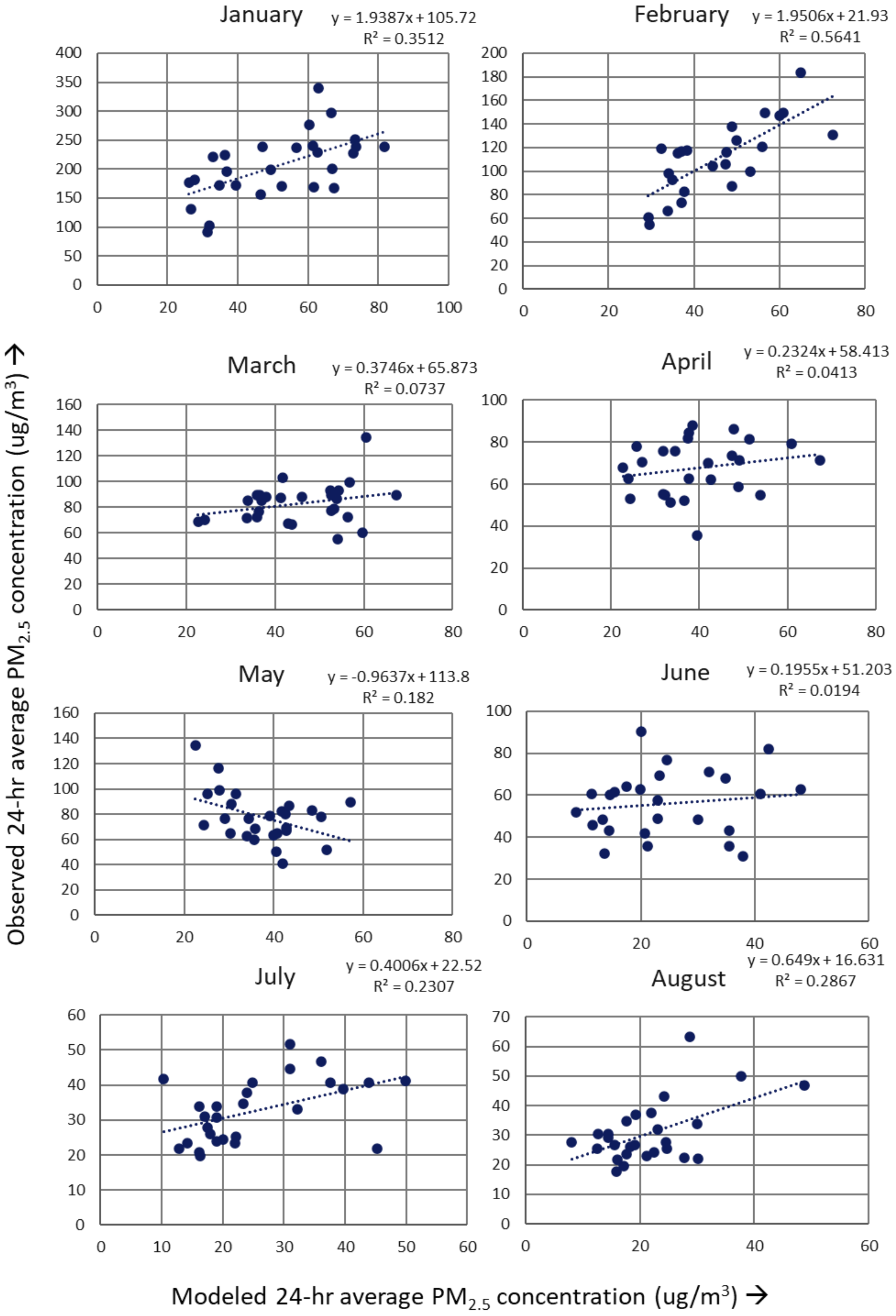


Figure 91: Scatter Plots for 24-hour Average $PM_{2.5}$ Concentration for Different Months (1)

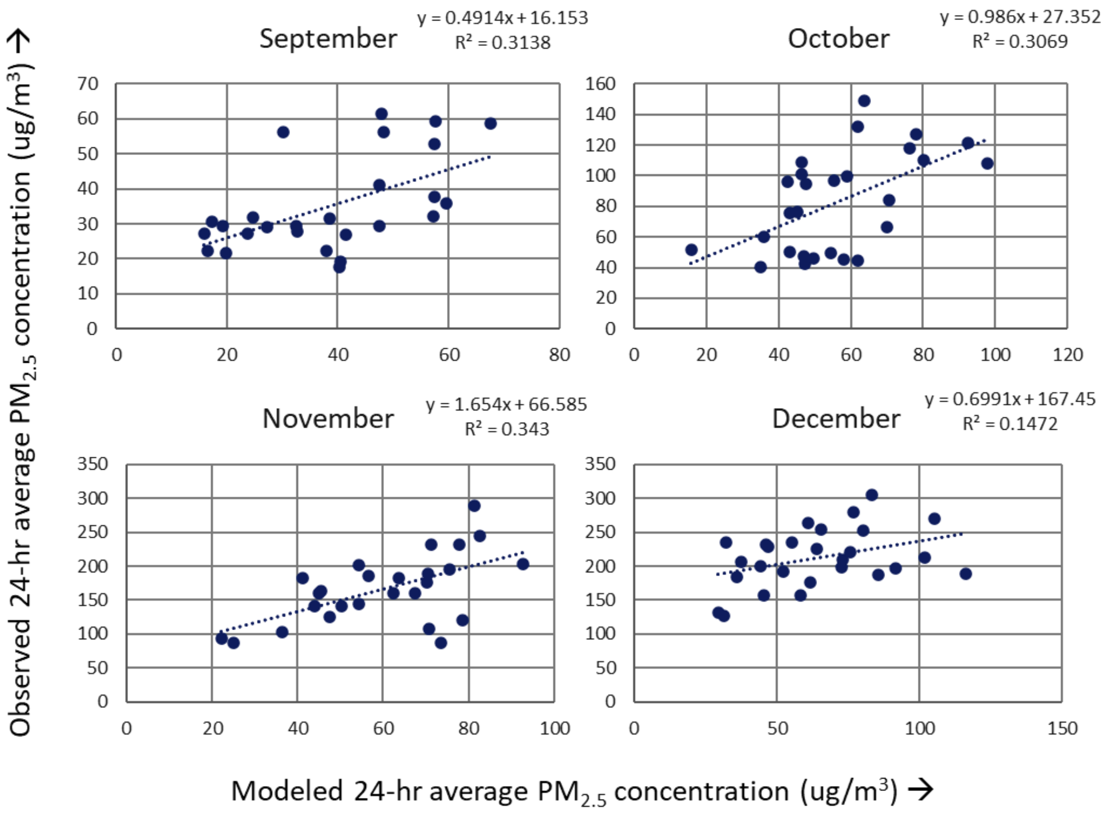


Figure 92: Scatter Plots for 24-hour Average $PM_{2.5}$ Concentration for Different Months (2)

Table 25: Background 24-hour Average $PM_{2.5}$ Concentration in Each Month of 2018

Month	R (Correlation coefficient)	Background Concentration (Intercept), $\mu g/m^3$
January	0.593	105.7
February	0.751	21.9
March	0.271	65.9
April	0.203	58.4
May	0.427	113.8
June	0.139	51.2
July	0.480	22.5
August	0.535	16.6
September	0.560	16.2
October	0.554	27.4
November	0.586	66.6
December	0.384	167.5

4.6 Region-wise impact assessment

(Package 6: Carry out dispersion modeling using state-of-the-art models to apportion contribution of sources (sector-wise; industries, power plants, brick kilns, vehicles, open fires, dust, domestic, etc.) to air pollution in the Agra City and its airshed)

Agra City was divided into 5 regions (Figure 93) for a better assessment of the impacts from different sources which could enable efficient planning of mitigation strategies in these regions. Major localities in these regions are given in Table 26.

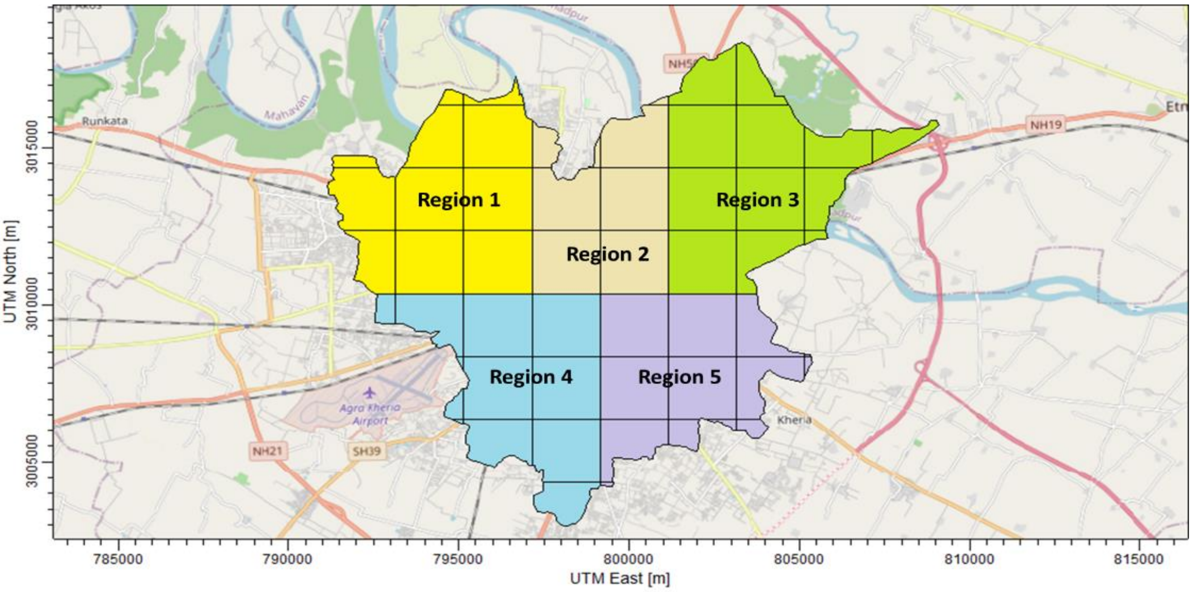


Figure 93: Demarcation of Five Regions for Impact Assessment

Table 26: Major Localities in Different Regions of Agra

Region 1	Region 2	Region 3	Region 4	Region 5
Transport Nagar	Jeoni Mandi	Tedhi Bagiya	Shahganj	Bijli Ghar
Sikandra	Langde ki Chowki	Nunhai	Bhogipura	Tajganj
Loha Mandi	Ghatia Azam Khan	Trans Yamuna	Chipi Tola	Shaheed Nagar
Awas Vikas	Mantola	Foundary Nagar	Pachkuiyan	Shamsabad Road

The highest 24-hour average $PM_{2.5}$ concentrations were plotted and tabulated for these regions in all the 12 months of the year 2018 (Figure 94 and Table 27). It was observed that region 3 has the highest 24-hour average $PM_{2.5}$ concentration among all with an average value of 298 ±

62 µg/m³ followed by region 2 with 175 ± 63 µg/m³and region 1 with 140 ± 44 µg/m³. Region 5 has the least 24-hour average $PM_{2.5}$ concentration among all with an average value of 76 ± 24 µg/m³.

The highest 24-hour average $PM_{2.5}$ concentrations were observed during the winters (November to February) while the lowest during the peak summers (May to July).

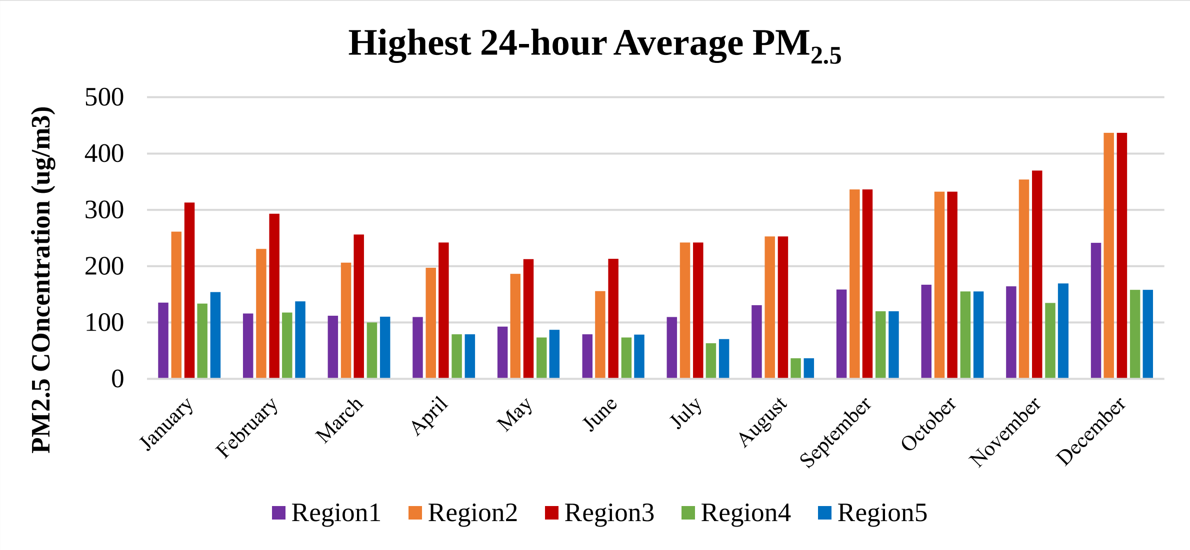


Figure 94: Region-Wise Highest 24-hour Average $PM_{2.5}$ Concentrations in 2018

Table 27: Region-Wise Highest 24-hour Average $PM_{2.5}$ Concentrations in 2018

	Region 1	Region 2	Region 3	Region 4	Region 5
January	135.23	261.17	312.78	133.89	153.91
February	115.98	230.67	293.37	117.57	137.35
March	112.24	206.16	256.41	100.22	110.27
April	109.74	197.45	242.27	79.14	79.14
May	92.59	186.49	212.31	73.67	86.99
June	79.28	155.47	212.85	73.43	78.36
July	109.93	242	241.99	62.97	70.33
August	130.85	252.56	252.56	36.8	36.8
September	158.64	336.4	336.41	119.72	119.72
October	167.38	332.35	332.35	155.1	155.1
November	164.25	354	370	134.92	169.17
December	241.43	436.79	436.79	157.91	157.91

Region 1

The major contributors in this region were road dust (67.87%), vehicular emissions (9.87%) and domestic sources (5.68%) accounting for around 83% of the total $PM_{2.5}$ concentration followed by industries (5.86%), hotels (4.27%), MSW burning (2.5%) and other sources (4%). The other sources included the DG sets, open areas, and hospital sources. The maximum of the highest 24-hour average $PM_{2.5}$ concentrations was observed during December while the minimum during June (Figure 95).

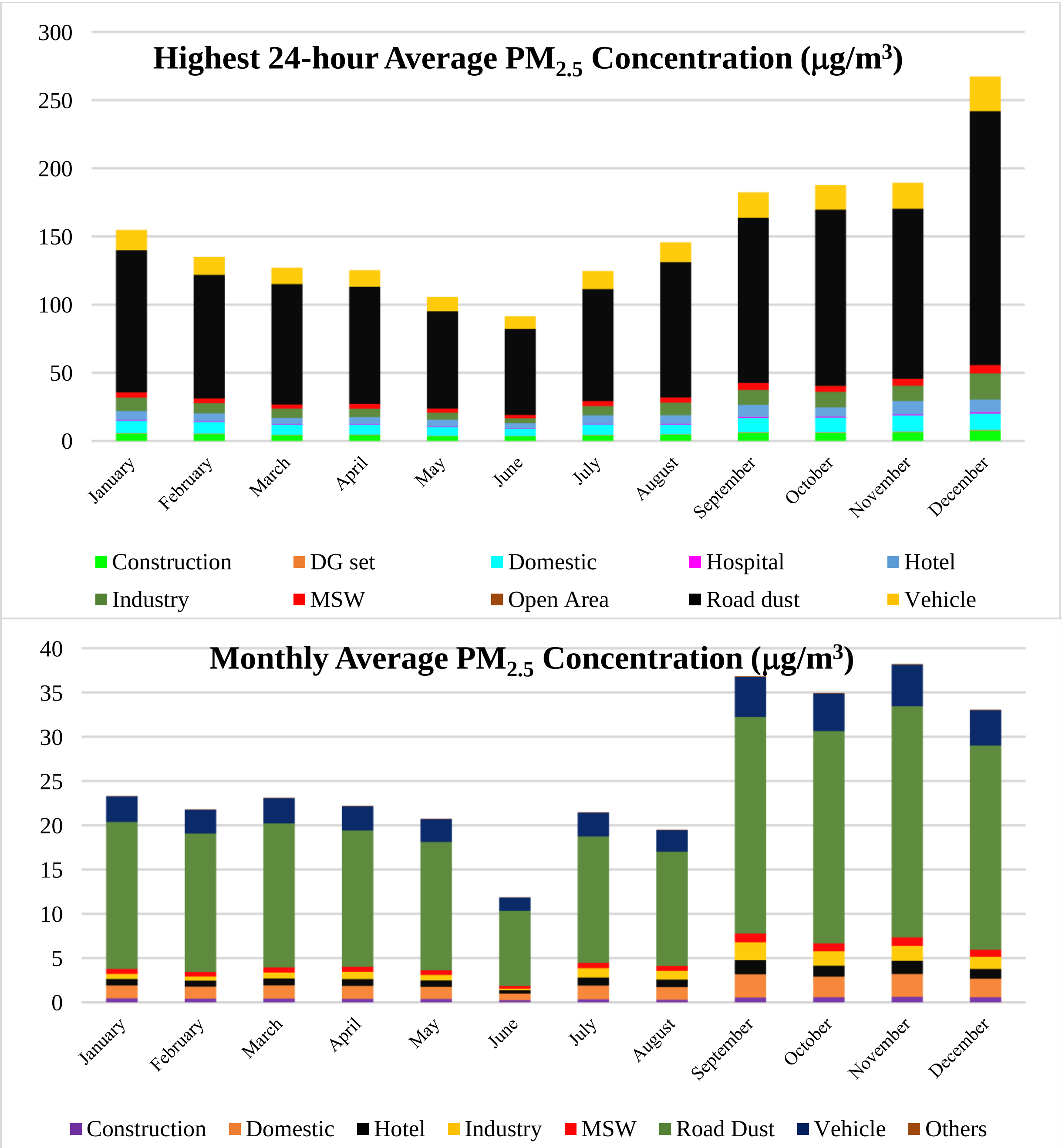
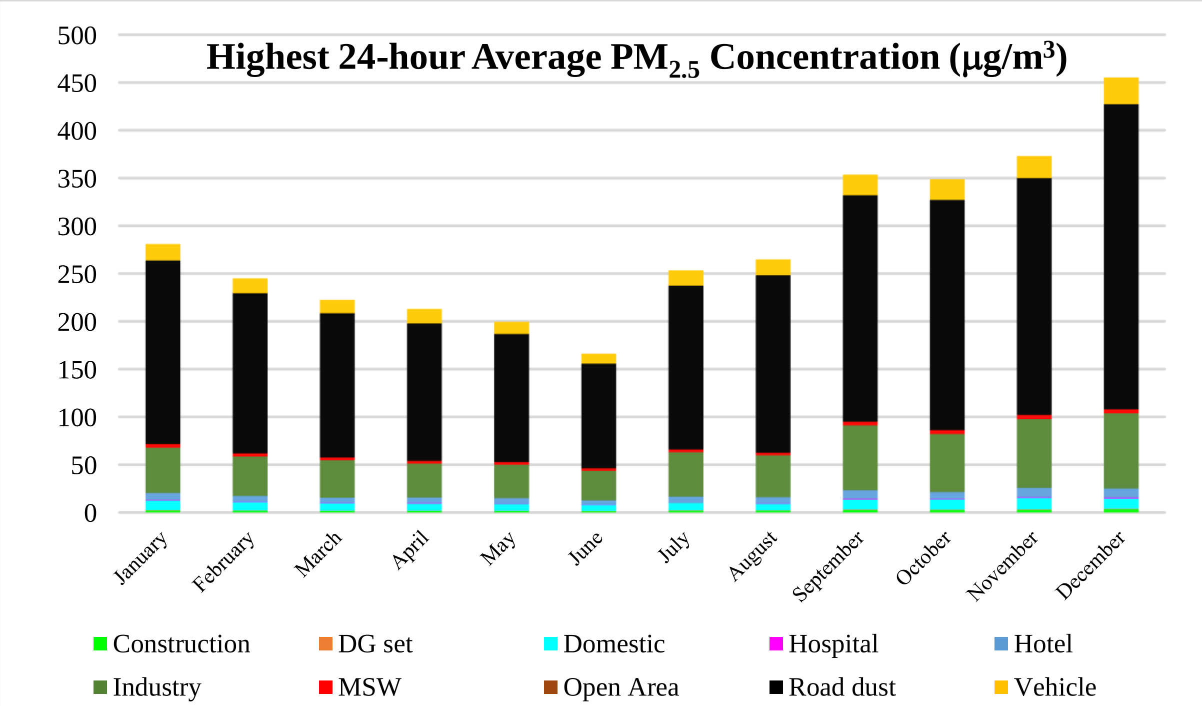


Figure 95:Highest 24-hour Average and Monthly Average $PM_{2.5}$ Concentration in Region 1

Region 2

The major contributors in this region were road dust (68.14%), industries (17.76%), and vehicular emissions (6.29%) accounting for around 92% of the total $PM_{2.5}$ concentration followed by domestic sources (3.15%), hotels (2.43%), MSW burning (1.17%), and other sources (1%). The other sources included construction, DG sets, open areas, and hospital sources. The maximum of the highest 24-hour average $PM_{2.5}$ concentrations was observed during December while the minimum during June (Figure 96).



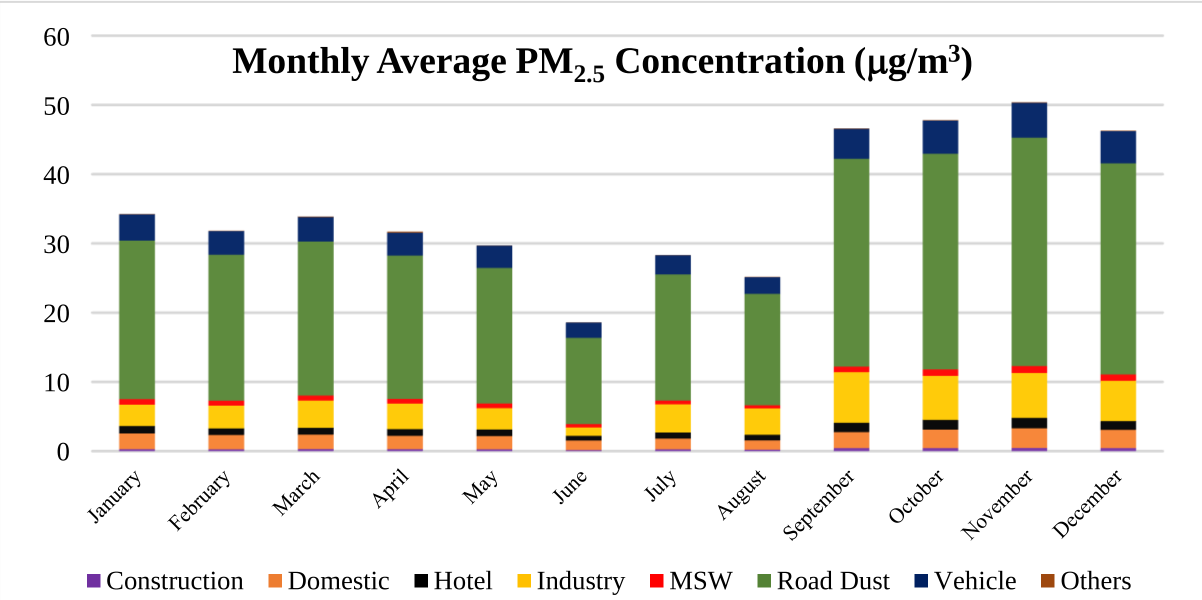


Figure 96:Highest 24-hour Average and Monthly Average $PM_{2.5}$ Concentration in Region 2

Region 3

The major contributors in this region were road dust (70.05%), industries (18.15%), and vehicular emissions (6.5%) accounting for around 94% of the total $PM_{2.5}$ concentration followed by domestic sources (1.83%), hotels (1.65%), MSW burning (0.65%), and other sources (1.1%). The other sources includes construction, DG sets, open areas, and hospital sources. The maximum of the highest 24-hour average $PM_{2.5}$ concentrations was observed during December while the minimum during July (Figure 97).

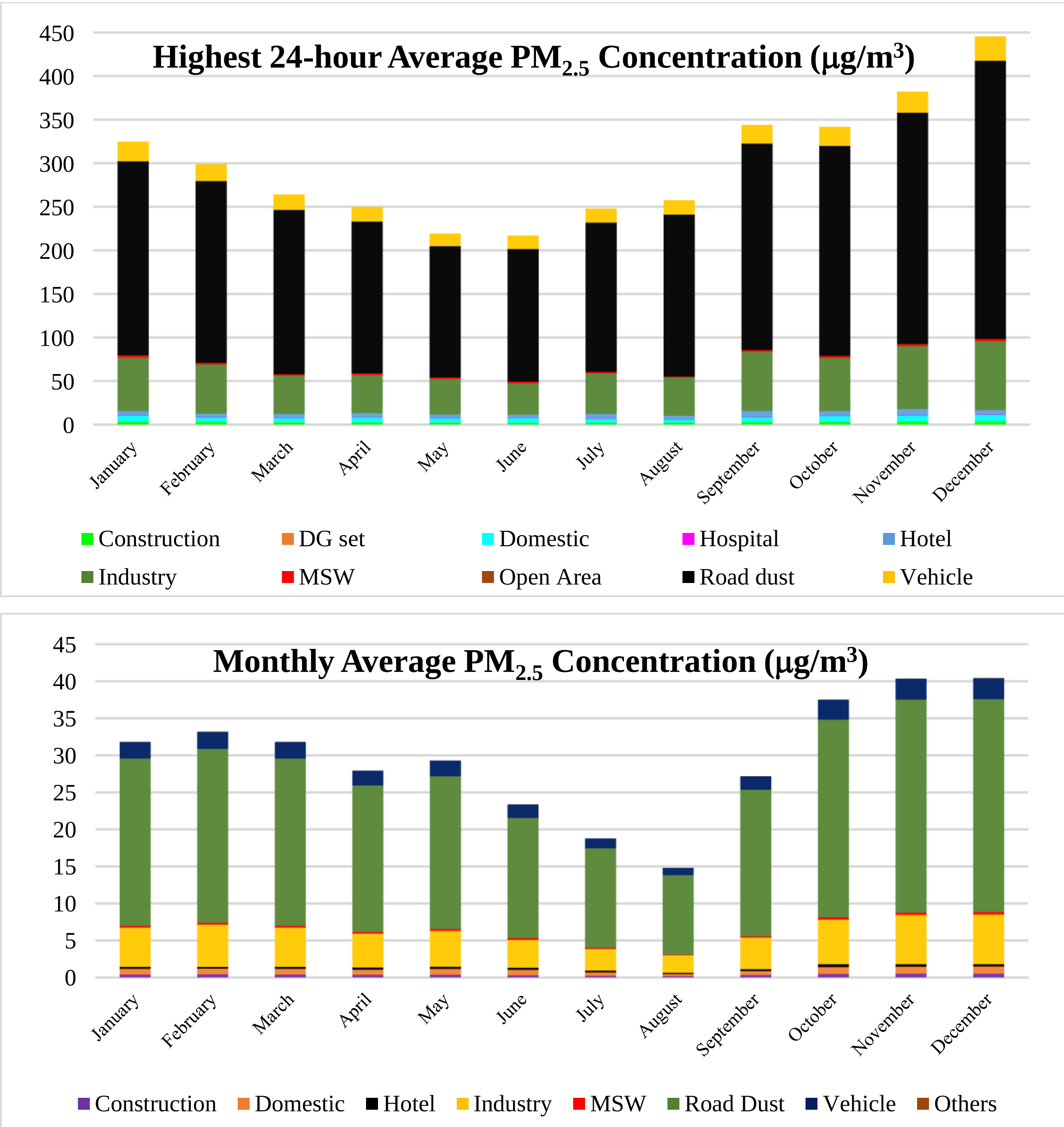
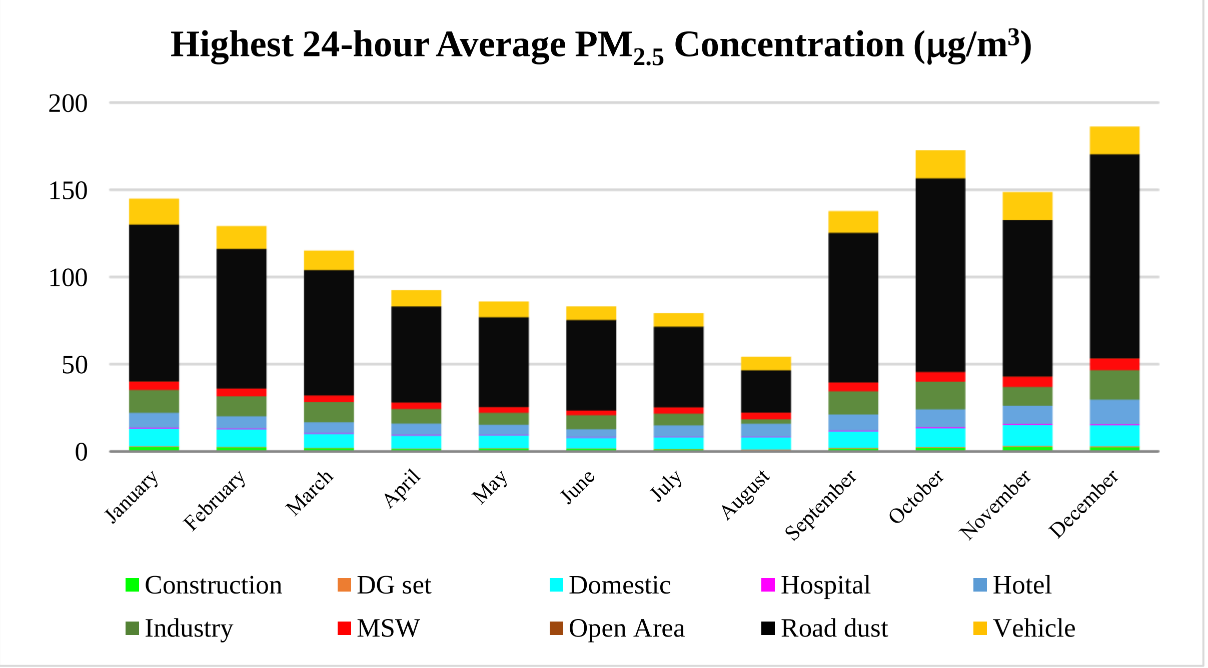


Figure 97:Highest 24-hour Average and Monthly Average $PM_{2.5}$ Concentration in Region 3

Region 4

The major contributors in this region were road dust (61%), vehicular emissions (9.9%), and industries (8.79%) accounting for around 80% of the total $PM_{2.5}$ concentration, followed by domestic sources (7.5%), hotels (6.74%), MSW burning (3.69%), and other sources (2%). The other sources included construction, DG sets, open areas, and hospital sources. The maximum of the highest 24-hour average $PM_{2.5}$ concentration was observed during December while the minimum during August (Figure 98).



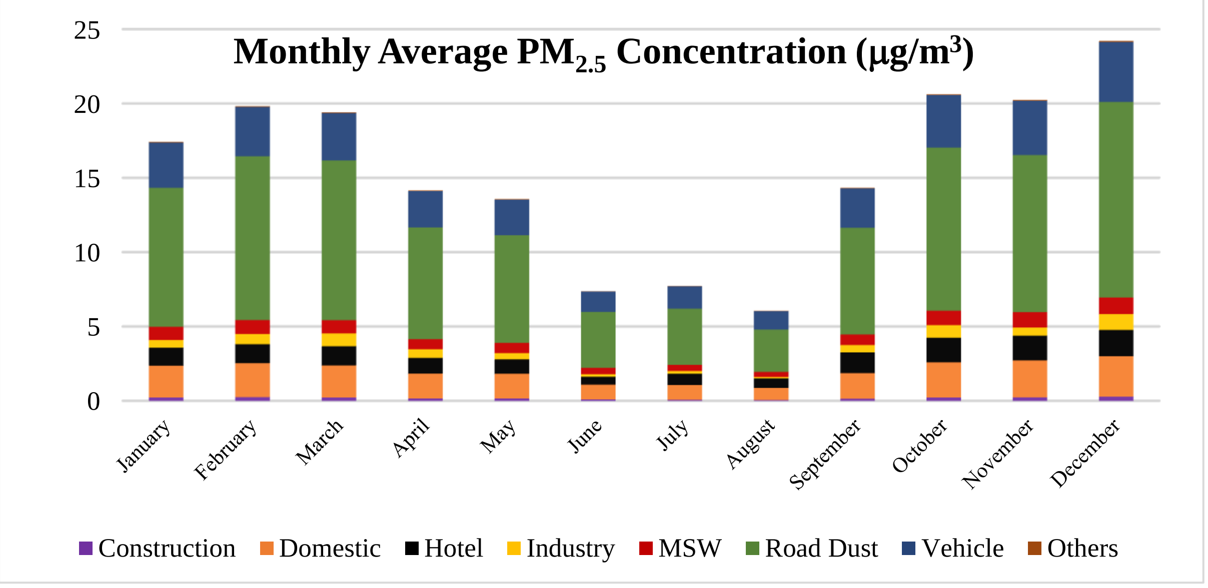
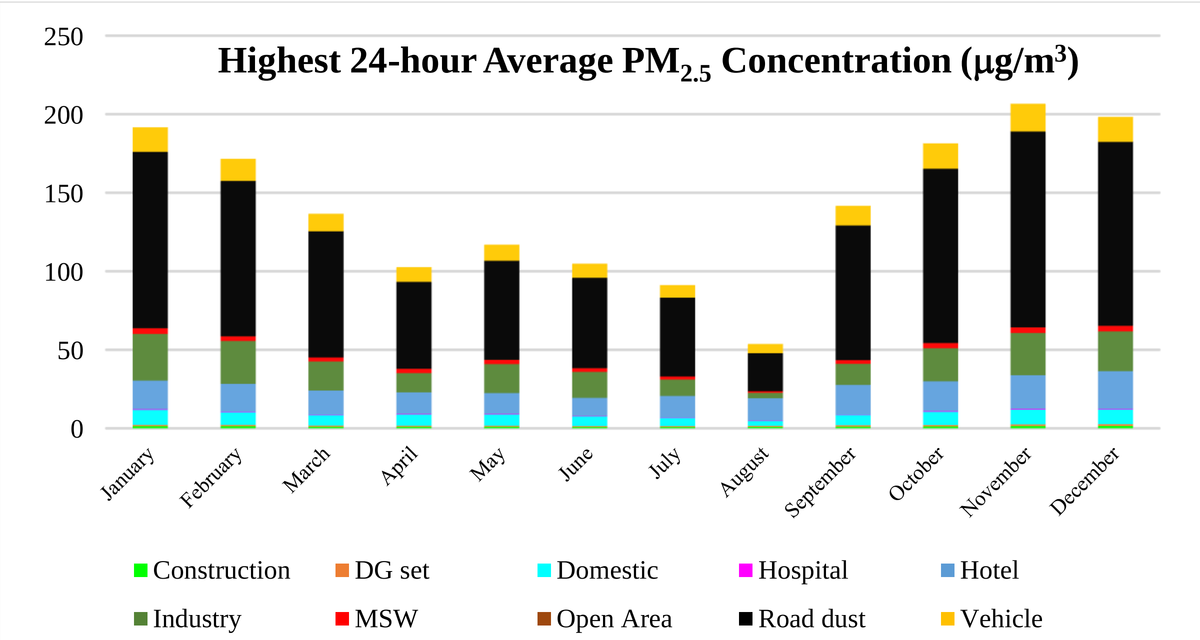


Figure 98:Highest 24-hour Average and Monthly Average $PM_{2.5}$ Concentration in Region 4

Region 5

The major contributors in this region were road dust (57.8%), industries (13.2%), and hotels (11.9%) accounting for around 83% of the total $PM_{2.5}$ concentration followed by vehicular emissions (8.6%), domestic sources (5%), MSW burning (1.9%), and other sources (1.6%). The other sources included construction, DG sets, open areas, and hospital sources. The maximum of the highest 24-hour average $PM_{2.5}$ concentrations were observed during November while the minimum during August (Figure 99).



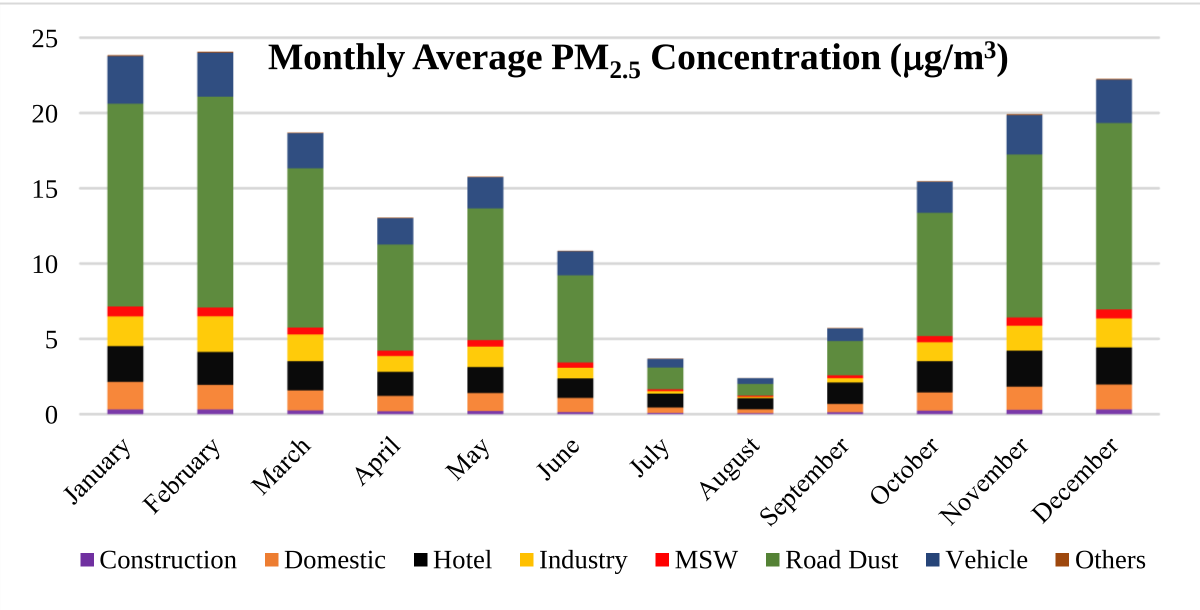


Figure 99: Highest 24-hr Average and Monthly Average $PM_{2.5}$ Concentration in Region 5

Summary

The highest contributing source among all was road dust in all the regions followed by vehicular emissions in regions 1, 4 and 5. Industries were the second-highest contributors in regions 2 and 3.

Domestic sources were the third-highest contributors in regions 3 and 4, where the residential population is concentrated. Hotel sources were the third-highest contributors in region 5, where the tourist hotspots are located. MSW burning and construction sources contributed least in all the regions (Table 28). The rank of different sources based on their $PM_{2.5}$ contribution in all the regions is given in Table 29.

Overall, top contributors to $PM_{2.5}$ were road dust (64%), vehicles (13%), industry (9%), domestic sources (7%), and hotels (3%).

Table 28: $PM_{2.5}$ Contribution from Different Sources (%)

Contribution of total $PM_{2.5}$ from various sources in different regions (%)						
Sources	**Region 1**	**Region 2**	**Region 3**	**Region 4**	**Region 5**	**Overall**
Construction	1.7	0.9	1.3	1.2	1.5	1.3
Domestic	6.8	5.9	2.4	12.3	8.1	7.1
Hotel	1.8	1.5	0.5	4.0	6.4	2.9
Industry	4.0	12.4	16.4	3.7	8.9	9.1
MSW	2.6	2.0	0.8	5.1	2.9	2.7
Road Dust	70.3	66.6	71.3	55.2	57.8	64.2
Vehicle	12.6	10.4	7.1	18.2	14.0	12.5
Others	0.2	0.2	0.1	0.3	0.3	0.2

Table 29: Rank Assigned to Sources in Different Regions based on their $PM_{2.5}$ Contribution

Rank	**Region 1**	**Region 2**	**Region 3**	**Region 4**	**Region 5**	**Overall**
1	Road Dust	Road Dust	Road Dust	Road Dust	Road Dust	Road Dust
2	Vehicle	Industry	Industry	Vehicle	Vehicle	Vehicle
3	Domestic	Vehicle	Vehicle	Domestic	Industry	Industry
4	Industry	Domestic	Domestic	MSW	Domestic	Domestic
5	MSW	MSW	Construction	Hotel	Hotel	Hotel
6	Hotel	Hotel	MSW	Industry	MSW	MSW
7	Construction	Construction	Hotel	Construction	Construction	Construction

4.7 Temporal Impact Assessment in Agra Region

January

The highest 24-hour average $PM_{2.5}$ concentration in January was observed to be 312µg/m^3. Road dust, vehicular, and industrial sources were the main contributors followed by MSW burning, hotels, and domestic sources. The construction, hospital areas, DG sets, and open area sources contributed the least. The plots for the highest 24-hour average $PM_{2.5}$ concentration for the Agra Airshed and the city region are shown in Figure 100 and Figure 101, respectively.

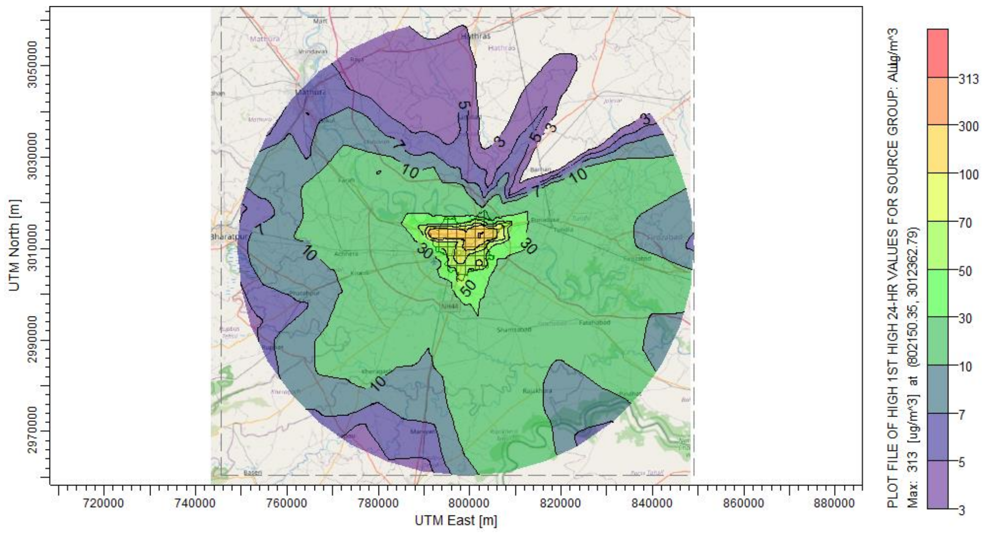


Figure 100: Contour Plot for the highest 24-hour Average $PM_{2.5}$ Concentration in the Agra Airshed (up to 50 km from the city centre) (January)

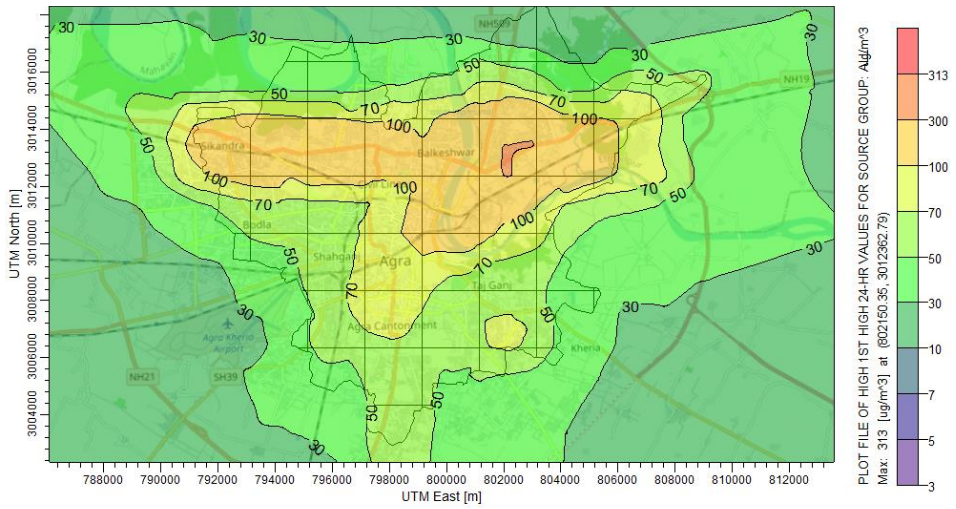


Figure 101: Contour Plot for the highest 24-hour Average $PM_{2.5}$ Concentration in the Agra City (January)

Table 30: Highest 24-hour Average $PM_{2.5}$ Concentration (ug/m^3) in the Agra City (January)

	Region 1	Region 2	Region 3	Region 4	Region 5
Construction	5.27	2.08	3.04	2.44	1.32
DG set	0.43	0.36	0.28	0.43	0.88
Domestic	9.11	9.85	7.23	10.15	9.51
Hospital	0.57	0.62	0.53	0.56	0.45
Hotel	6.55	7.49	4.33	8.48	18.24
Industry	9.81	47.35	61.31	13.17	29.69
MSW	3.78	3.76	2.64	4.74	3.55
Open Area	0.08	0.05	0.07	0.09	0.08
Road dust	104.21	192.15	222.7	90.01	112.33
Vehicle	14.97	17.22	22.67	14.88	15.56
All Sources	**135.23**	**261.17**	**312.78**	**133.89**	**153.91**

The highest monthly average $PM_{2.5}$ concentration in January was observed to be 186 µg/m^3. The contour plots for monthly average $PM_{2.5}$ concentration for the Agra Airshed and the city region are shown in Figure 102 and Figure 103, respectively. Thehighest 24-hour average $PM_{2.5}$ concentration and the monthly average $PM_{2.5}$ concentrations for different regions in the Agra City are given in Table 30 and Table 31, respectively.

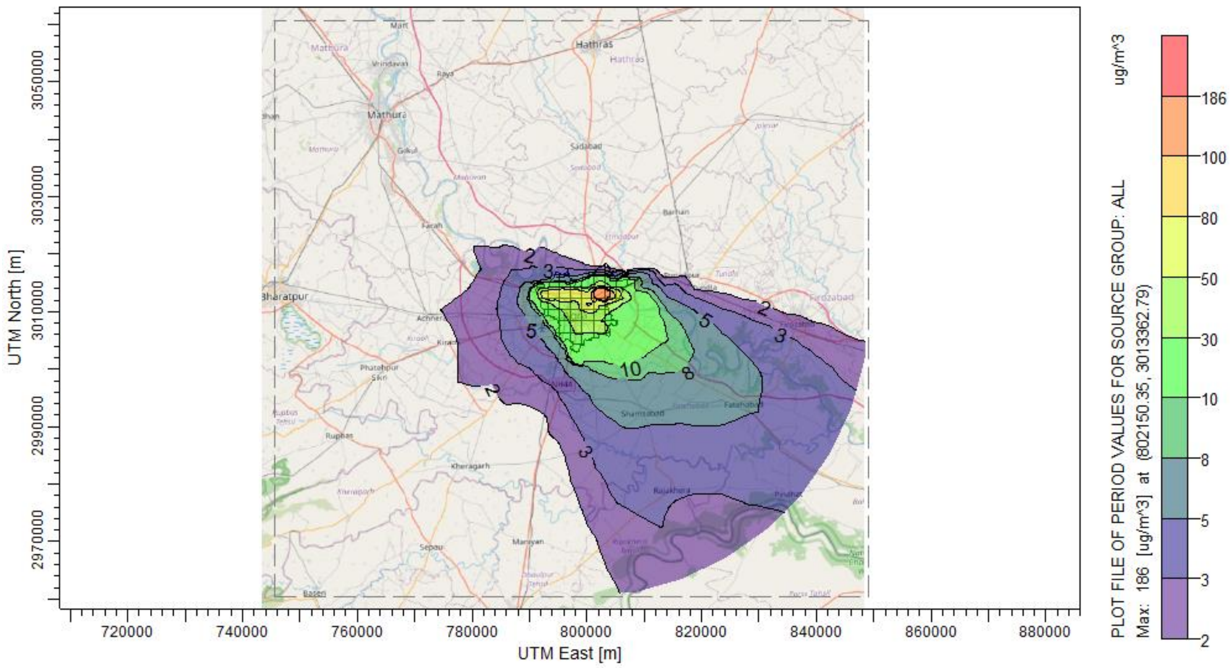


Figure 102: Contour Plot for Average Monthly $PM_{2.5}$ Concentration in the Agra Airshed (January)

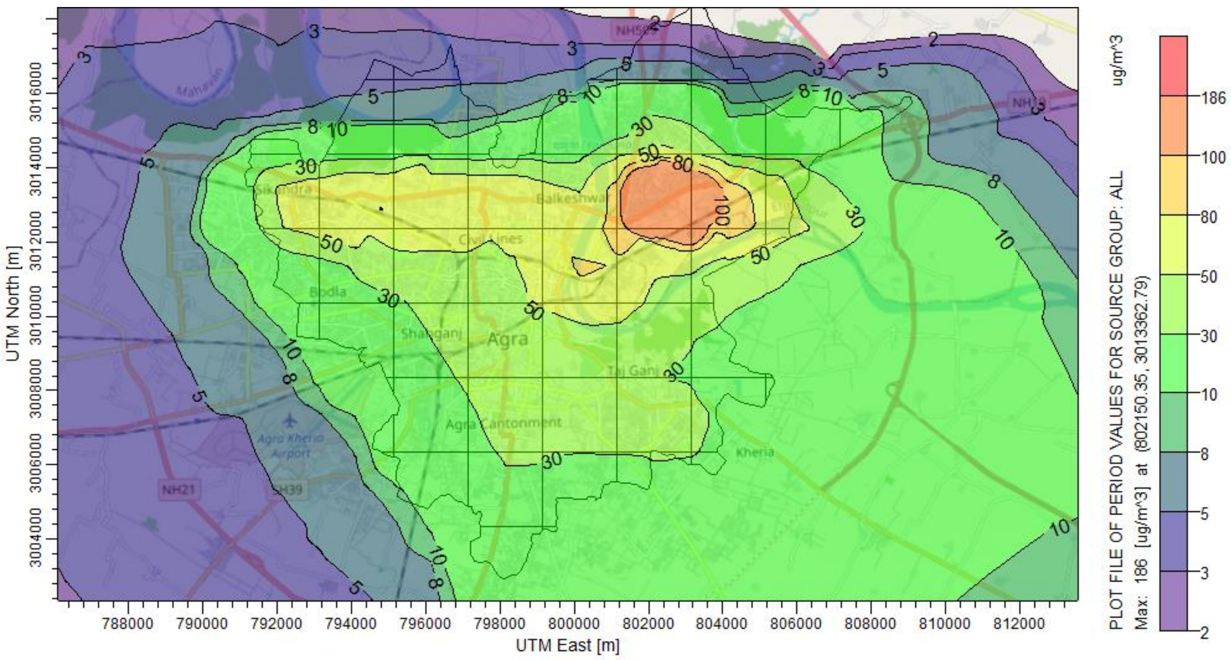


Figure 103: Contour Plot for Average Monthly $PM_{2.5}$ Concentration in the Agra City (January)

Table 31: Monthly Average $PM_{2.5}$ Concentration (μg/m³) in the Agra City (January)

	Region 1	Region 2	Region 3	Region 4	Region 5
Construction	0.45	0.29	0.41	0.22	0.31
Domestic	1.45	2.26	0.76	2.14	1.83
Hotel	0.73	1.08	0.27	1.21	2.38
Industry	0.58	3.08	5.29	0.52	1.97
MSW	0.55	0.79	0.26	0.89	0.66
Road Dust	16.61	22.91	22.57	9.35	13.46
Vehicle	2.89	3.78	2.25	3.04	3.17
Others	0.05	0.06	0.02	0.05	0.06
All Sources	**23.42**	**34.37**	**31.87**	**17.52**	**23.98**

February

The highest 24-hour average $PM_{2.5}$ concentration in February was observed to be 293 μg/m³. Road dust, vehicular, and industrial sources were the main contributors followed by MSW burning, hotels, and domestic sources. The constructions, hospital areas, DG sets, and open areas sources contributed the least. The plots for the highest 24-hour average $PM_{2.5}$ concentration for the Agra Airshed and the city region are given in Figure 104 and Figure 105, respectively.

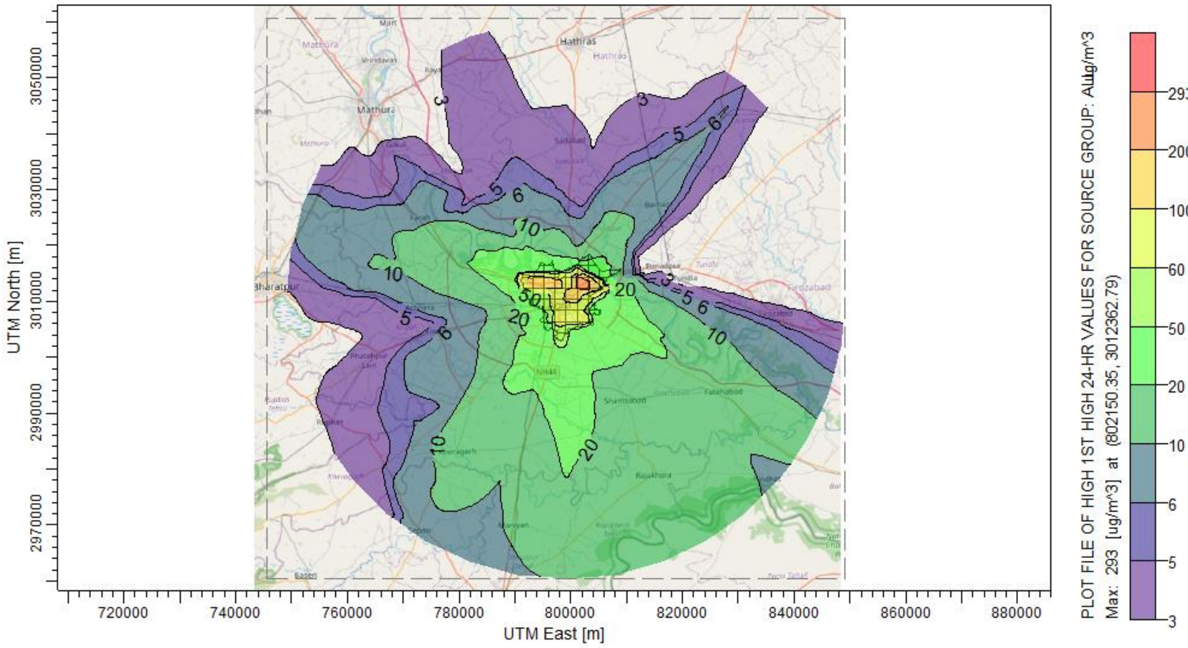


Figure 104: Contour Plot for Highest 24-hour Average $PM_{2.5}$ Concentration in the Agra Airshed (February)

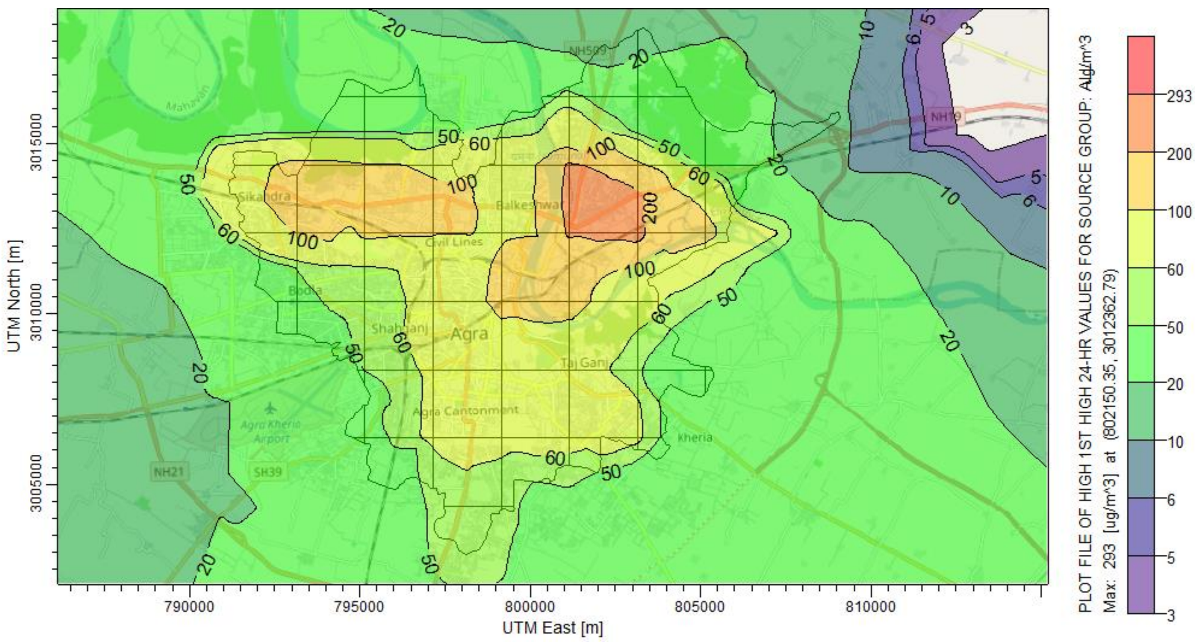


Figure 105: Contour Plot for Highest 24-hour Average $PM_{2.5}$ Concentration in the Agra City (February)

Table 32: The Highest 24-hour Average $PM_{2.5}$ Concentration (µg/m^3) in the Agra City (February)

	Region 1	Region 2	Region 3	Region 4	Region 5
Construction	4.97	1.74	2.84	2.14	1.33
DG set	0.4	0.35	0.24	0.4	0.86
Domestic	8.56	8.84	5.15	10.03	8.04
Hospital	0.52	0.56	0.4	0.51	0.43
Hotel	5.79	5.78	3.88	6.99	17.63
Industry	7.5	41.19	56.55	11.51	27.27
MSW	3.35	3.27	1.78	4.34	2.96
Open Area	0.06	0.04	0.06	0.08	0.07
Road dust	90.67	167.73	208.58	80.09	98.88
Vehicle	13.21	15.57	19.54	13.11	14.123
All Sources	**115.98**	**230.67**	**293.37**	**117.57**	**137.35**

The highest monthly average $PM_{2.5}$ concentration in the month of February was observed to be 177 µg/m^3. The contour plots for monthly average $PM_{2.5}$ concentration for the Agra Airshed and the city region are shown in Figure 106 and Figure 107, respectively.The highest 24-hour average $PM_{2.5}$ concentration and the monthly average $PM_{2.5}$ concentrations for different regions in the Agra City are given in Table 32 and Table 33, respectively.

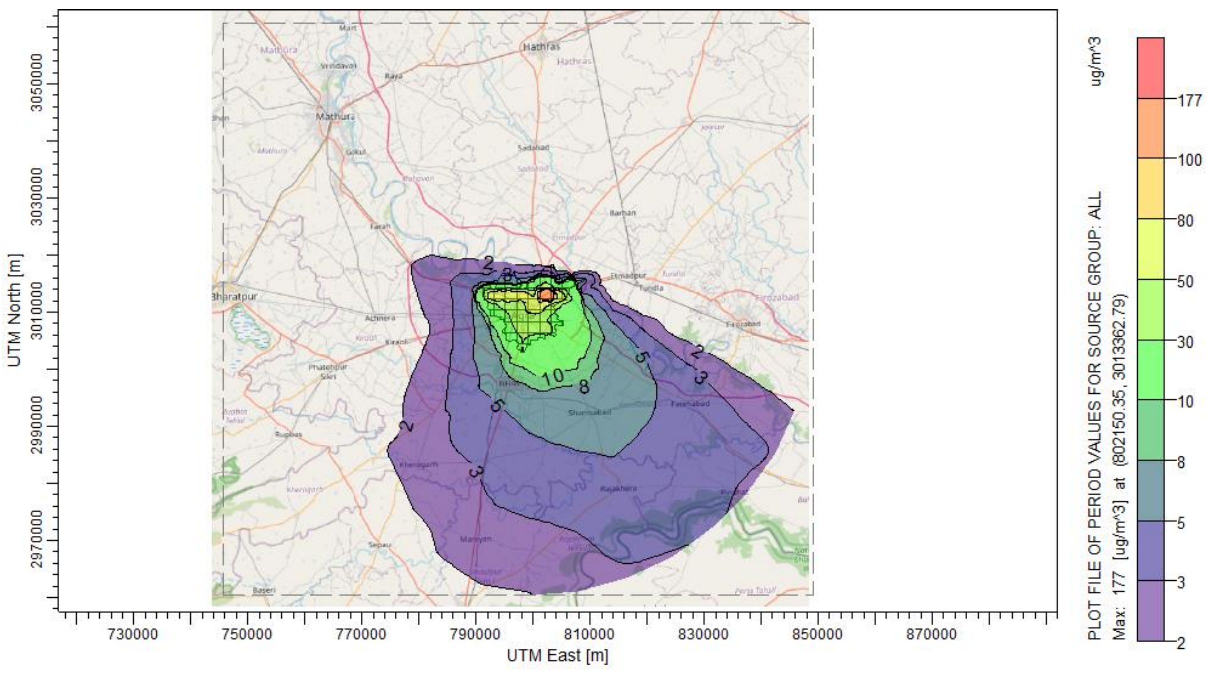


Figure 106: Contour Plot for Average Monthly $PM_{2.5}$ Concentration in the Agra Airshed (February)

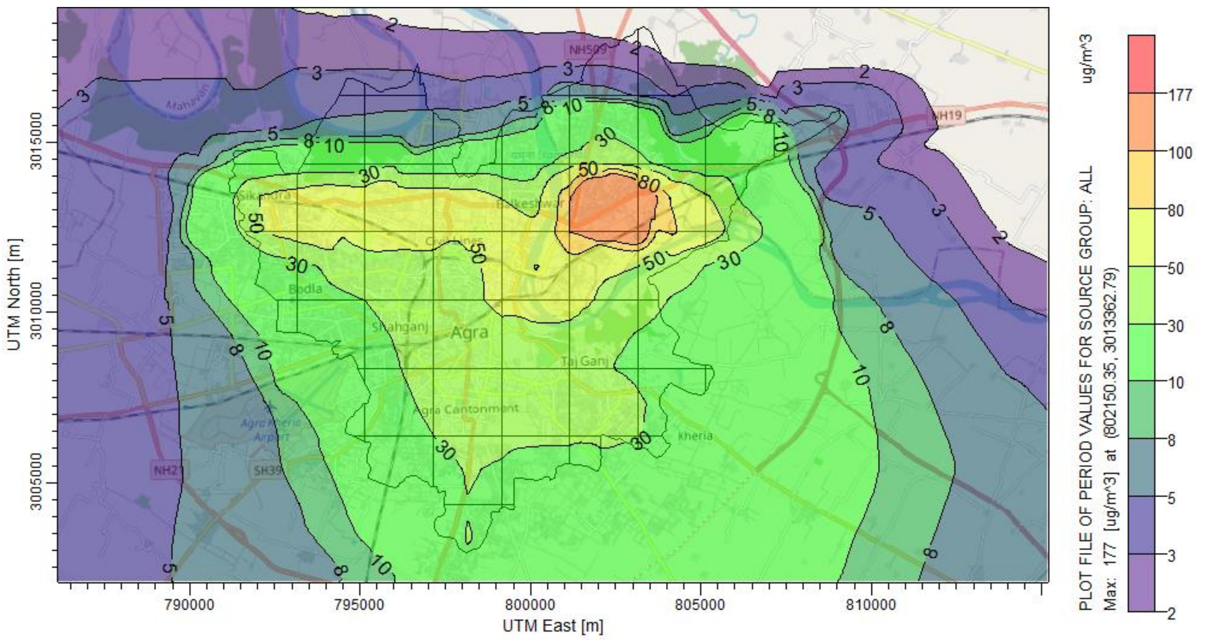


Figure 107: Contour Plot for Average Monthly $PM_{2.5}$ Concentration in the Agra City (February)

Table 33: Monthly Average $PM_{2.5}$ Concentration ($\mu g/m^3$) in the Agra City (February)

	Region 1	Region 2	Region 3	Region 4	Region 5
Construction	0.42	0.27	0.43	0.25	0.31
Domestic	1.35	2.05	0.76	2.28	1.63
Hotel	0.67	0.96	0.23	1.28	2.19
Industry	0.48	3.29	5.71	0.68	2.37
MSW	0.51	0.71	0.26	0.94	0.58
Road Dust	15.63	21.08	23.48	11.02	14
Vehicle	2.69	3.42	2.3	3.32	2.93
Others	0.05	0.05	0.02	0.05	0.06
All Sources	**21.91**	**31.96**	**33.24**	**19.94**	**24.17**

March

The highest 24-hour average $PM_{2.5}$ concentration in March was observed to be 256 $\mu g/m^3$. Road dust, vehicular, and industrial sources were the main contributors followed by MSW burning, hotels, and domestic sources. The constructions, hospital areas, DG sets, and open area sources contributed the

least. The plots for the highest 24-hour average $PM_{2.5}$ concentration for the Agra Airshed and the city region are given in Figure 108 and Figure 109, respectively.

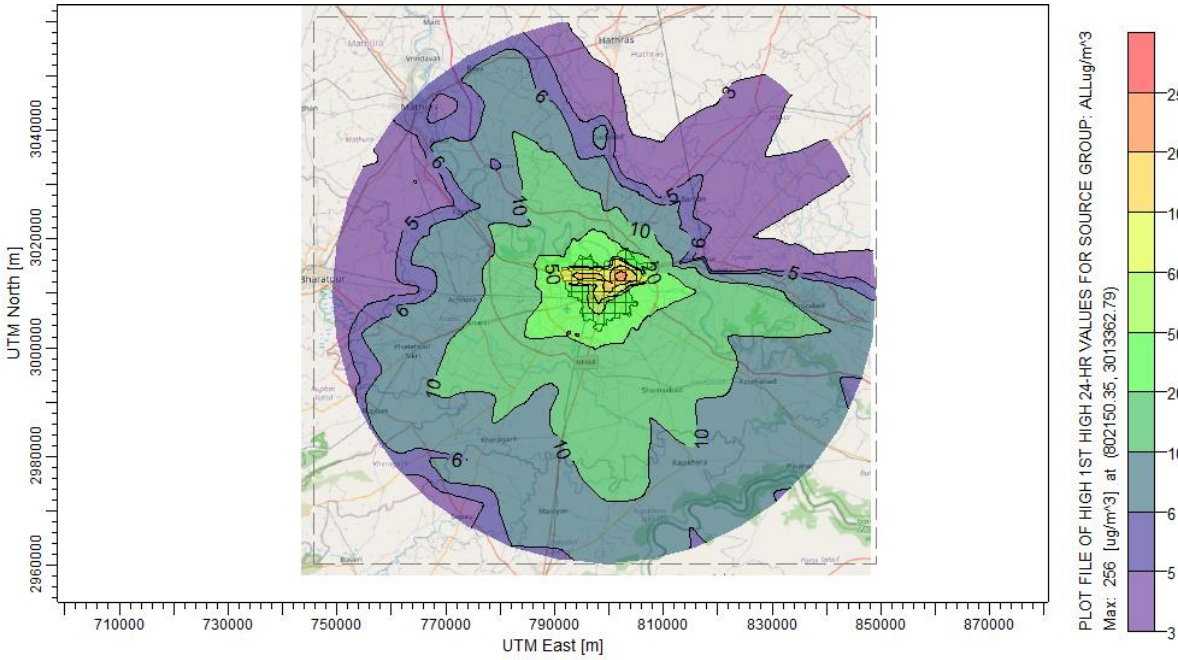


Figure 108: Contour Plot for Highest 24-hour Average $PM_{2.5}$ Concentration in the Agra Airshed (March)

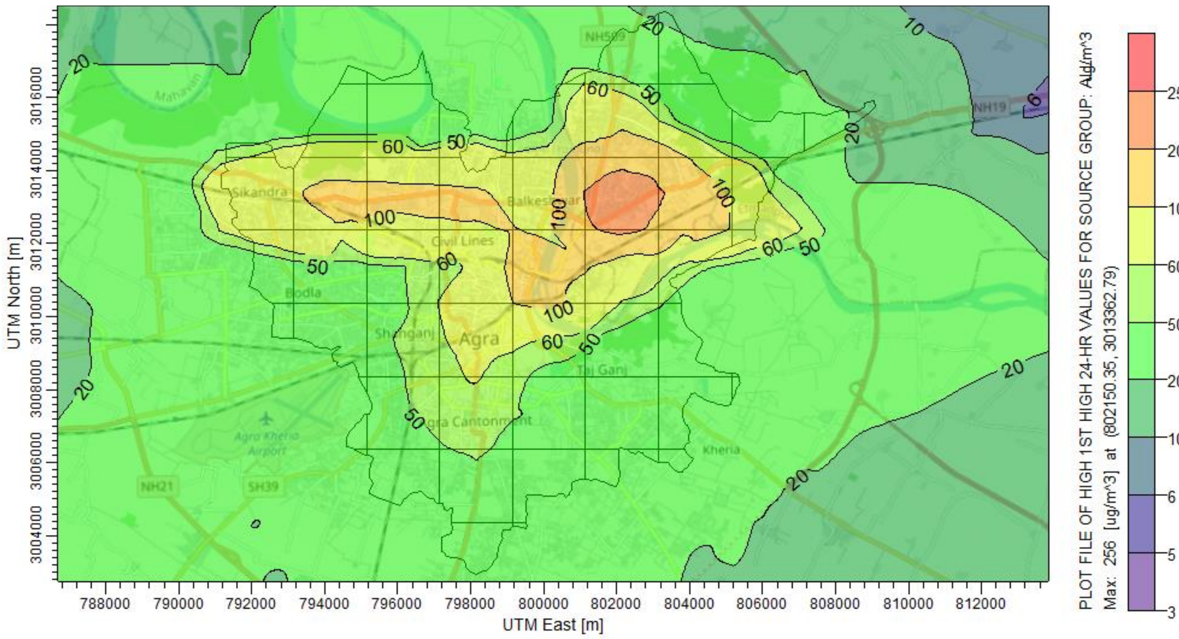


Figure 109: Contour Plot for Highest 24-hour Average $PM_{2.5}$ Concentration in the Agra City (March)

Table 34: Highest 24-hour Average $PM_{2.5}$ Concentration ($\mu g/m^3$) in the Agra City (March)

	Region 1	Region 2	Region 3	Region 4	Region 5
Construction	4.11	1.57	2.42	1.68	0.97
DG set	0.34	0.27	0.23	0.29	0.72
Domestic	7.43	7.92	4.67	8.03	6.73
Hospital	0.45	0.51	0.37	0.43	0.32
Hotel	4.56	5.24	4.48	6.21	15.3
Industry	6.82	39.07	43.95	11.63	18.52
MSW	2.93	2.94	1.61	3.71	2.48
Open Area	0.06	0.04	0.06	0.07	0.06
Road dust	88.32	150.88	188.57	71.89	80.31
Vehicle	12.13	13.99	17.81	11.21	11.22
All Sources	**112.24**	**206.16**	**256.41**	**100.22**	**110.27**

The highest monthly average $PM_{2.5}$ concentration in March was observed to be 173 $\mu g/m^3$. The contour plots for monthly average $PM_{2.5}$ concentration for the Agra Airshed and the city region are shown in Figure 110 and Figure 111, respectively. The highest 24-hour average $PM_{2.5}$ concentration and the monthly average $PM_{2.5}$ concentrations for different regions in the Agra City are given in Table 34 and Table 35, respectively.

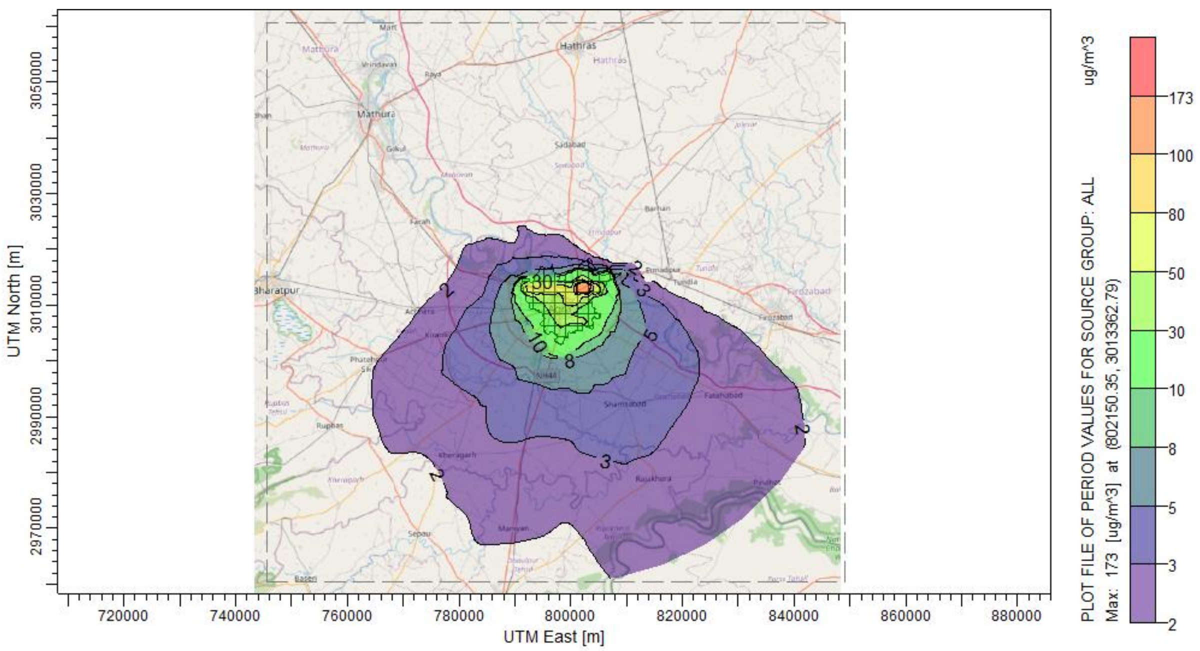


Figure 110: Contour Plot for Average Monthly $PM_{2.5}$ Concentration in the Agra Airshed (March)

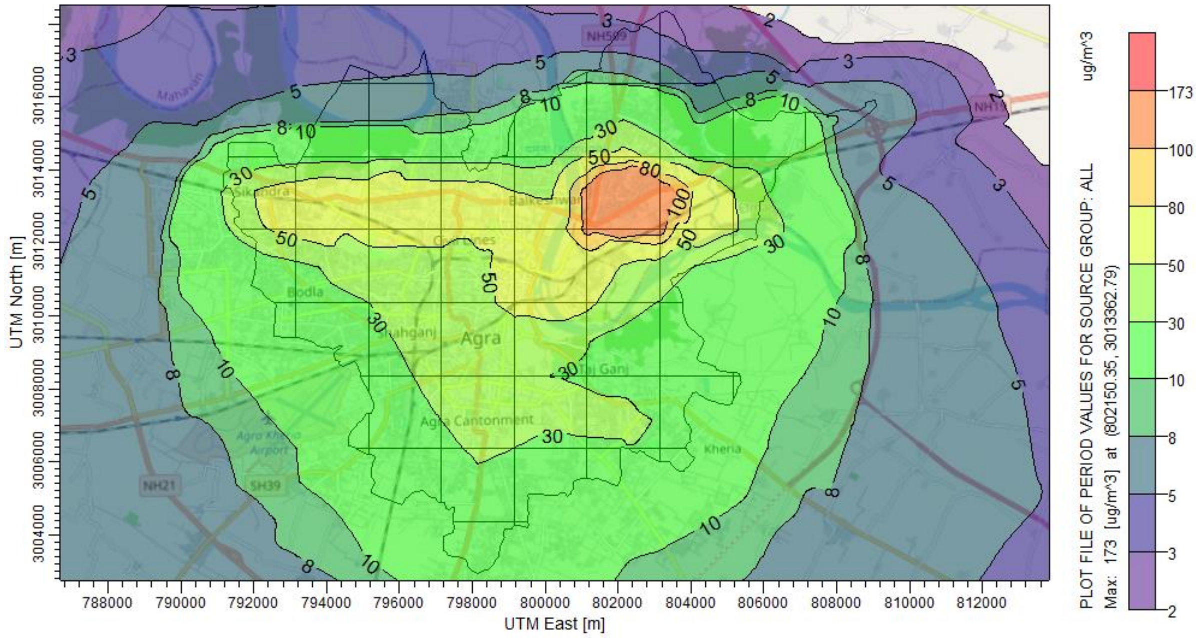


Figure 111: Contour Plot for average Monthly $PM_{2.5}$ Concentration in the Agra City (March)

Table 35: Monthly Average $PM_{2.5}$ Concentration (µg/m^3) in the Agra City (March)

	Region 1	Region 2	Region 3	Region 4	Region 5
Construction	0.43	0.3	0.41	0.22	0.25
Domestic	1.49	2.07	0.76	2.16	1.33
Hotel	0.77	1	0.27	1.29	1.94
Industry	0.68	3.92	5.29	0.86	1.77
MSW	0.57	0.73	0.26	0.89	0.46
Road Dust	16.26	22.24	22.57	10.75	10.58
Vehicle	2.86	3.54	2.25	3.19	2.33
Others	0.05	0.08	0.02	0.05	0.04
All Sources	**23.21**	**33.98**	**31.07**	**19.51**	**18.78**

April

The highest 24-hour average $PM_{2.5}$ concentration in April was observed to be 242 µg/m^3. Road dust, vehicular, and industrial sources were the main contributors followed by MSW burning, hotels, and domestic sources. The constructions, hospital areas, DG sets, and open area sources contributed the

least. The plots for the highest 24-hour average $PM_{2.5}$ concentration for the Agra Airshed and the city region are given in Figure 112 and Figure 113, respectively.

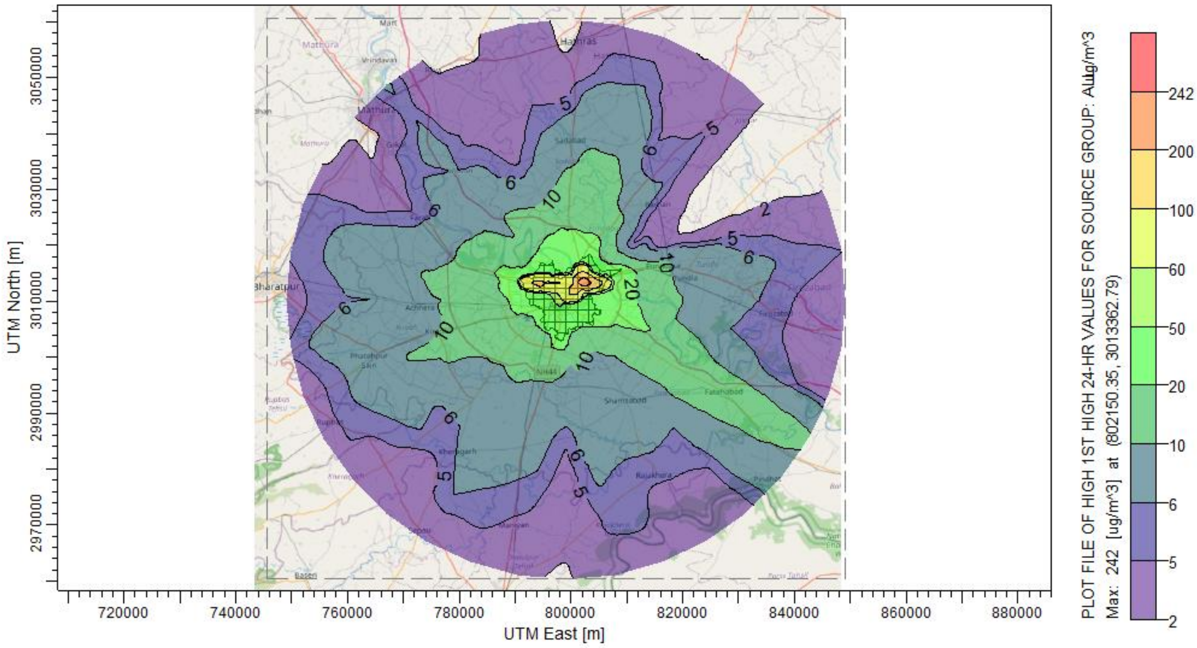


Figure 112: Contour Plot for theHighest 24-hour Average $PM_{2.5}$ Concentration in the Agra Airshed (April)

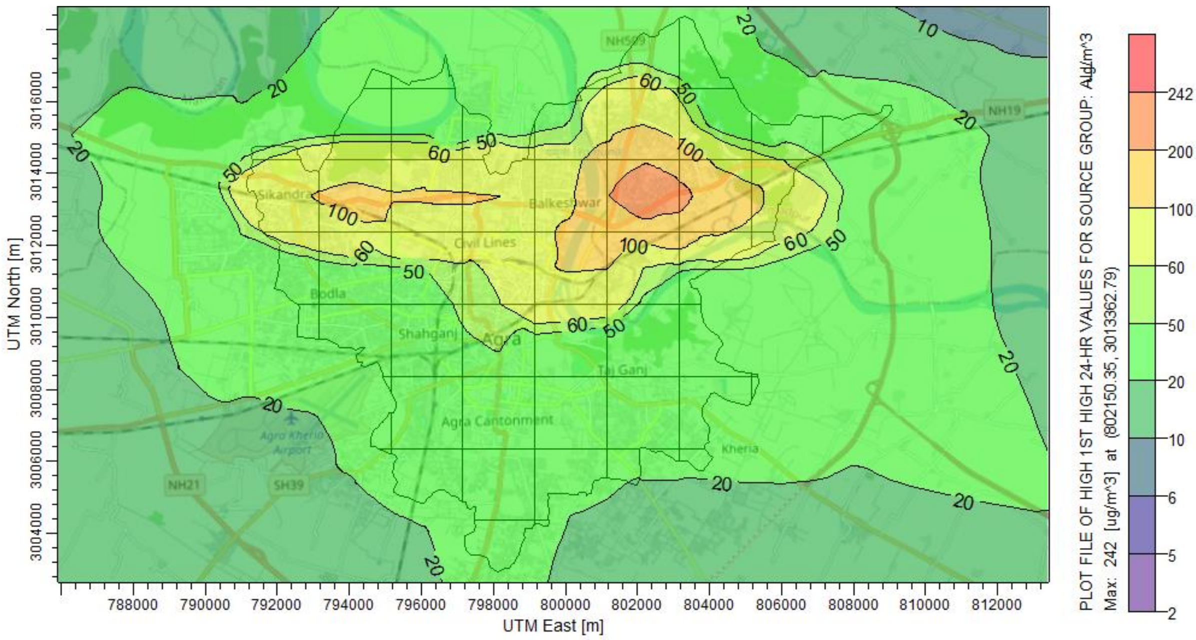


Figure 113: Contour Plot for the highest 24-hour average $PM_{2.5}$ Concentration in the Agra City (April)

Table 36: Highest 24-hour Average $PM_{2.5}$ Concentration ($\mu g/m^3$) in the Agra City (April)

	Region 1	Region 2	Region 3	Region 4	Region 5
Construction	4.25	1.49	2.38	1.27	0.97
DG set	0.32	0.29	0.25	0.28	0.68
Domestic	7.35	7.44	5.44	7.44	7.07
Hospital	0.49	0.56	0.38	0.39	0.36
Hotel	5.05	5.75	4.7	6.52	13.8
Industry	6.19	35.61	43.58	8.38	12.31
MSW	3.46	2.79	1.9	3.65	2.66
Open Area	0.06	0.05	0.06	0.06	0.06
Road dust	85.9	143.89	174.27	55.1	55.33
Vehicle	12.17	15.15	16.99	9.37	9.36
All Sources	**109.74**	**197.45**	**242.27**	**79.14**	**79.14**

The highest monthly average $PM_{2.5}$ concentration in April was observed to be 155 $\mu g/m^3$. The contour plots for monthly average $PM_{2.5}$ concentration for the Agra Airshed and the city region are shown in Figure 114 and Figure 115, respectively. The highest 24-hour average $PM_{2.5}$ concentration and the monthly average $PM_{2.5}$ concentrations for different regions in the Agra City are given in Table 36 and Table 37, respectively.

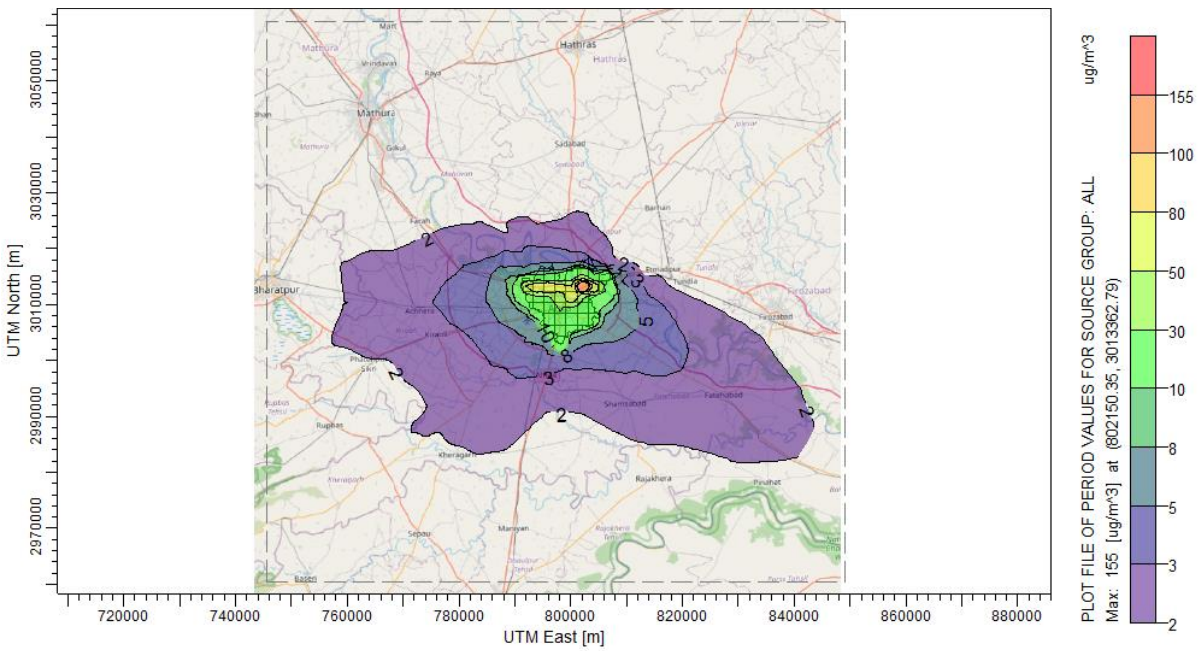


Figure 114: Contour Plot for Average Monthly $PM_{2.5}$ Concentration in the Agra Airshed (April)

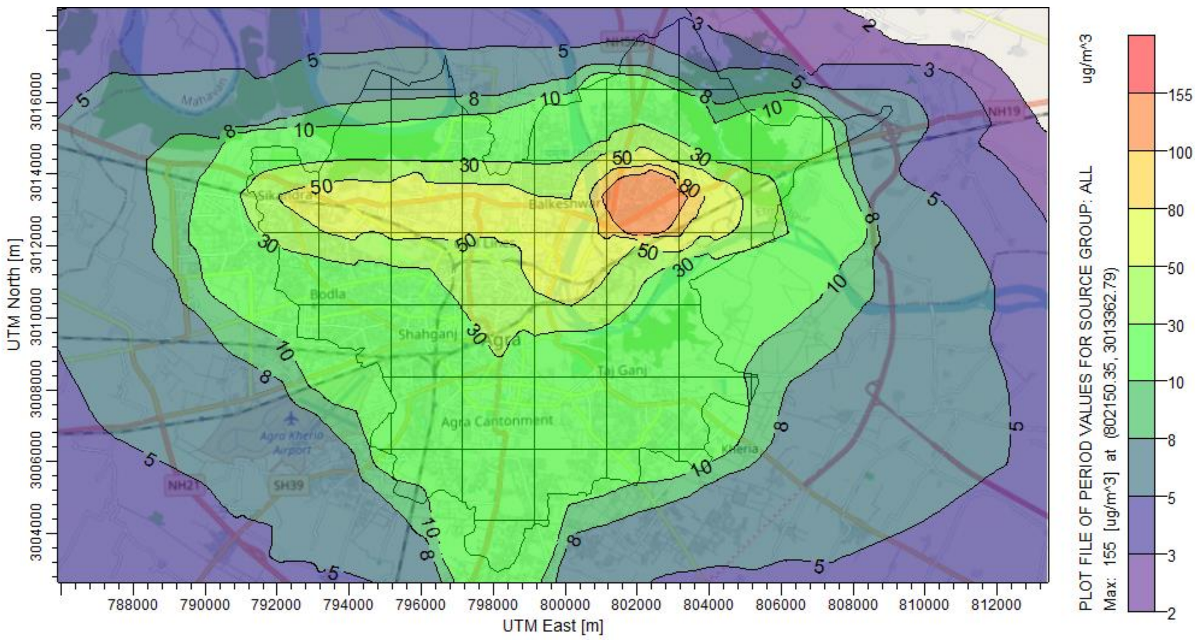


Figure 115: Contour Plot for Average Monthly $PM_{2.5}$ Concentration in the Agra City (April)

Table 37: Monthly Average $PM_{2.5}$ Concentration (µg/m^3) in the Agra City (April)

	Region 1	**Region 2**	**Region 3**	**Region 4**	**Region 5**
Construction	0.39	0.28	0.36	0.16	0.19
Domestic	1.47	1.92	0.69	1.67	1.02
Hotel	0.76	0.97	0.3	1.06	1.6
Industry	0.83	3.7	4.56	0.58	1.05
MSW	0.56	0.67	0.24	0.68	0.36
Road Dust	15.4	20.7	19.77	7.51	7.04
Vehicle	2.74	3.31	2.01	2.45	1.75
Others	0.05	0.15	0.02	0.04	0.04
All Sources	**22.3**	**31.71**	**28**	**14.23**	**13.12**

May

The highest 24-hour average $PM_{2.5}$ concentration in May was observed to be 212 µg/m^3. Road dust, vehicular, and industrial sources were the main contributors followed by MSW burning, hotels, and domestic sources. The constructions, hospital areas, DG sets, and open area sources contributed the

least. The plots for the highest 24-hour average $PM_{2.5}$ concentration for the Agra Airshed and the city region are given in Figure 116 and Figure 117, respectively.

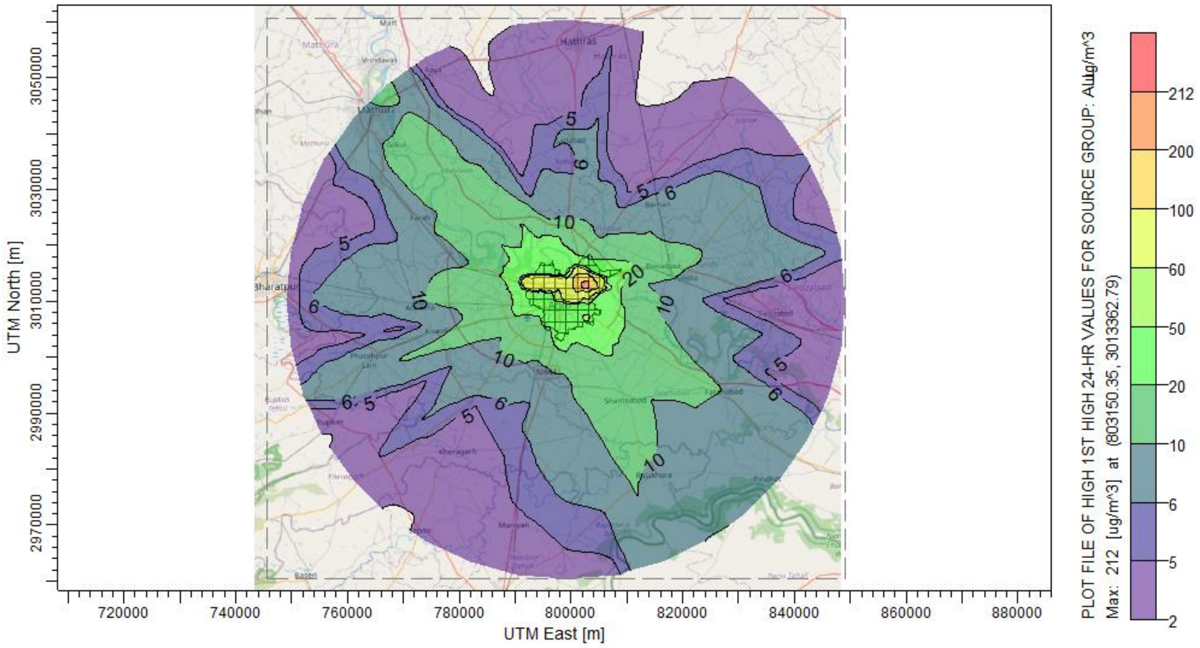


Figure 116: Contour Plot for highest 24-hour average $PM_{2.5}$ Concentration in the Agra Airshed (May)

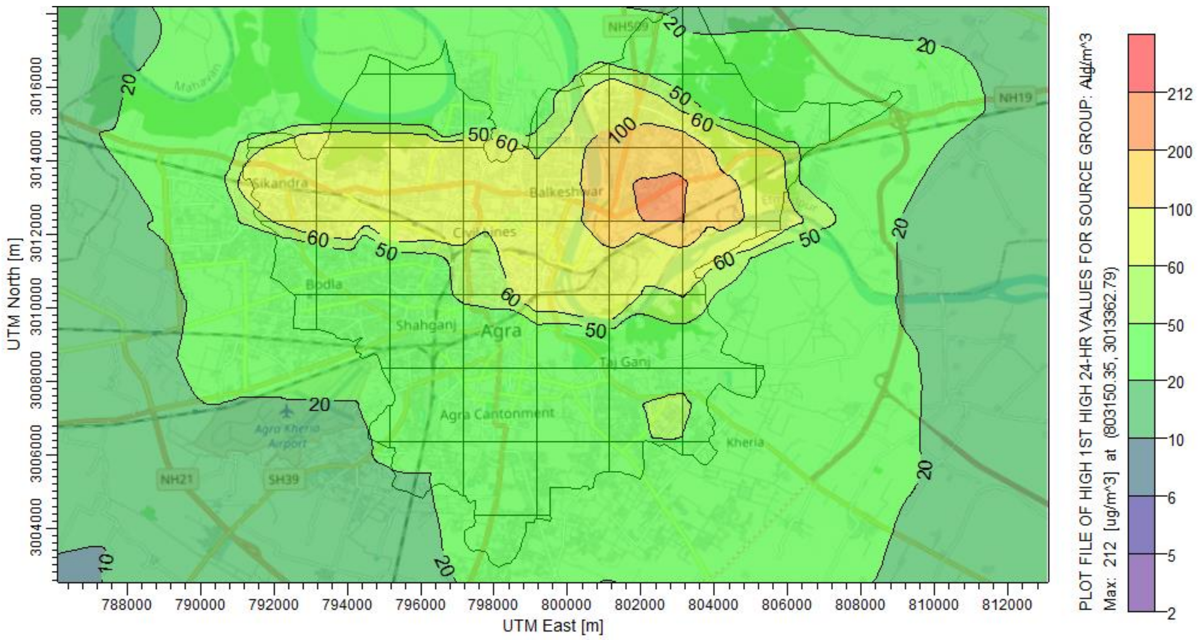


Figure 117: Contour Plot for Highest 24-hour Average $PM_{2.5}$ Concentration in the Agra City (May)

Table 38: Highest 24-hour average $PM_{2.5}$ Concentration (μg/m^3) in the Agra City (May)

	Region 1	Region 2	Region 3	Region 4	Region 5
Construction	3.48	1.44	2.15	1.47	0.98
DG set	0.29	0.27	0.19	0.26	0.63

Domestic	6.36	7.11	4.8	7.35	7.11
Hospital	0.39	0.43	0.33	0.38	0.38
Hotel	5.08	5.69	4.14	5.75	13.33
Industry	5.17	35.08	40.64	6.86	18.48
MSW	2.9	2.66	1.66	3.27	2.66
Open Area	0.06	0.04	0.05	0.06	0.06
Road dust	71.32	134.13	150.74	51.49	63.01
Vehicle	10.62	12.7	14.63	9.08	10.31
All Sources	**92.59**	**186.49**	**212.31**	**73.67**	**86.99**

The highest monthly average $PM_{2.5}$ concentration in May was observed to be 156 µg/m^3. The contour plots for monthly average $PM_{2.5}$ concentration for the Agra Airshed and the city region are shown in Figure 118 and Figure 119, respectively. The highest 24-hour average $PM_{2.5}$ concentration and the monthly average $PM_{2.5}$ concentrations for different regions in the Agra City are given in Table 38 and Table 39, respectively.

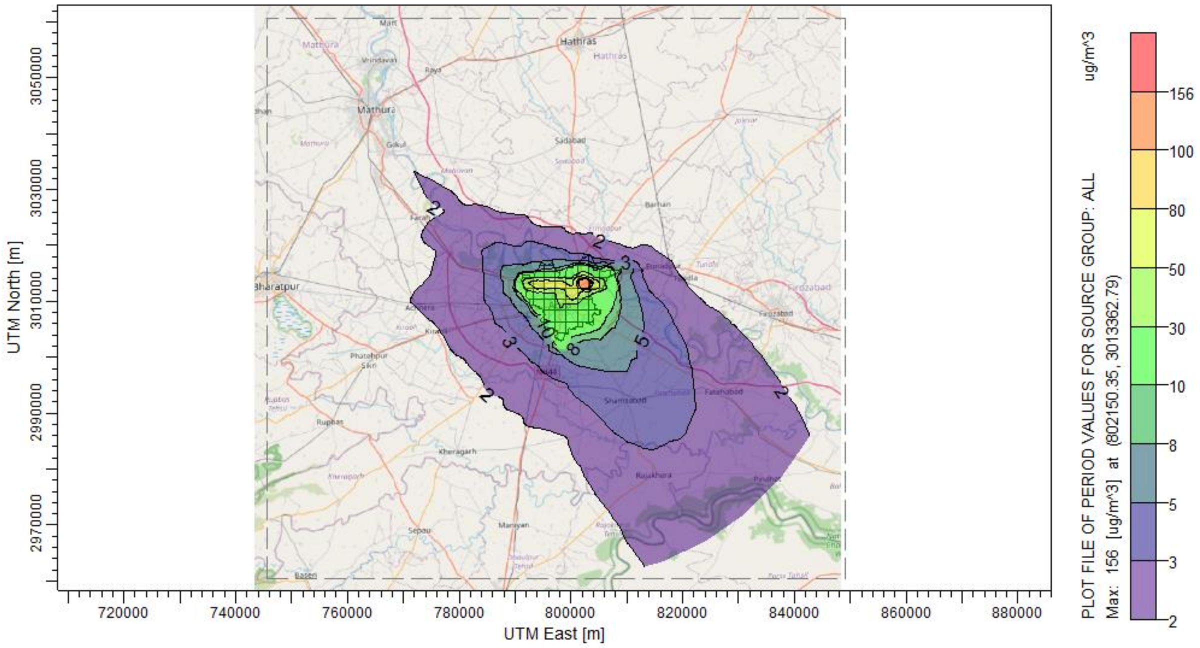


Figure 118: Contour Plot for Average Monthly $PM_{2.5}$ Concentration in the Agra Airshed (May)

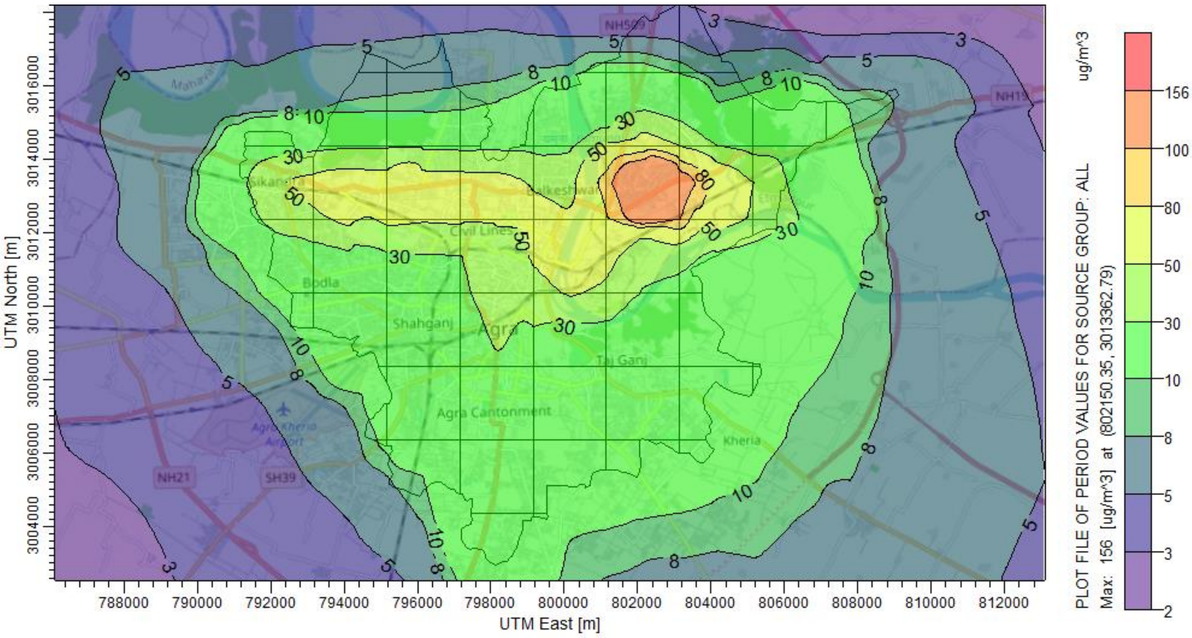


Figure 119: Contour Plot for Average Monthly $PM_{2.5}$ Concentration in the Agra City (May)

Table 39: Monthly Average $PM_{2.5}$ Concentration ($\mu g/m^3$) in the Agra City (May)

	Region 1	Region 2	Region 3	Region 4	Region 5
Construction	0.38	0.26	0.38	0.16	0.21
Domestic	1.37	1.91	0.77	1.66	1.19
Hotel	0.72	0.96	0.3	0.97	1.73
Industry	0.62	3.08	4.84	0.42	1.36
MSW	0.52	0.67	0.26	0.69	0.43
Road Dust	14.49	19.58	20.61	7.24	8.74
Vehicle	2.59	3.21	2.13	2.39	2.07
Others	0.05	0.05	0.02	0.04	0.04
All Sources	**20.85**	**29.83**	**29.37**	**13.65**	**15.87**

June

The highest 24-hour average $PM_{2.5}$ concentration in June was observed to be 215 $\mu g/m^3$. Road dust, vehicular, and industrial sources were the main contributors followed by MSW burning, hotels, and domestic sources. The constructions, hospital areas, DG sets, and open area sources contributed the

least. The plots for the highest 24-hour average $PM_{2.5}$ concentration for the Agra Airshed and the city region are given in Figure 120 and Figure 121, respectively.

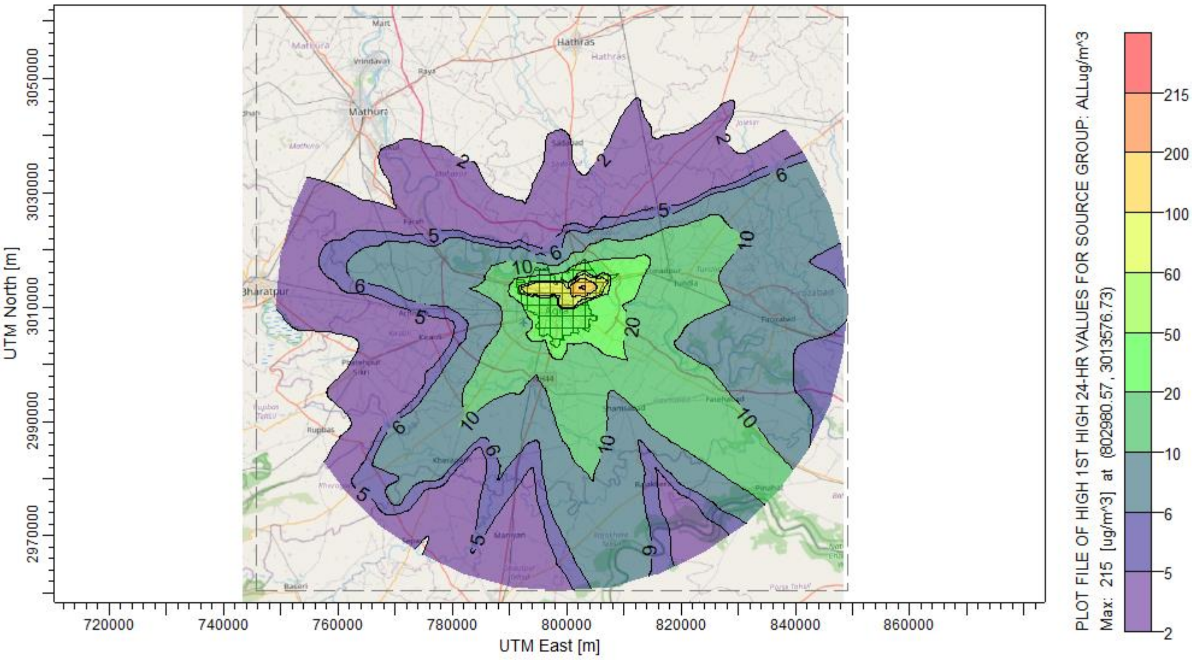


Figure 120: Contour Plot for highest 24-hour Average $PM_{2.5}$ Concentration in the Agra Airshed (June)

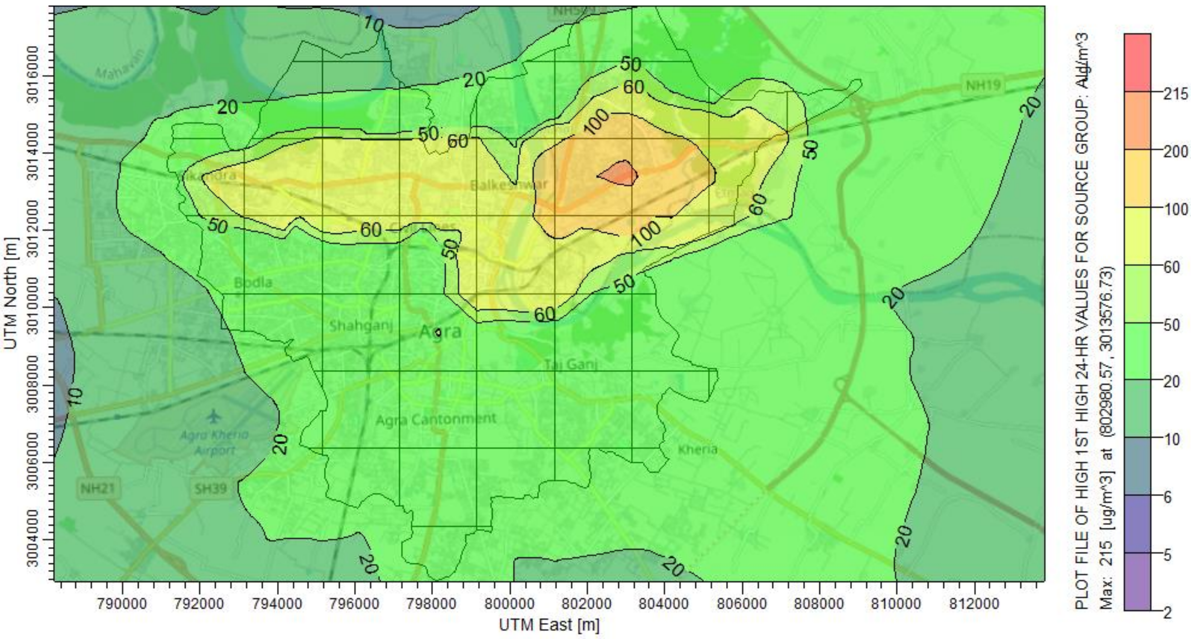


Figure 121: Contour Plot for Highest 24-hour Average $PM_{2.5}$ Concentration in the Agra City (June)

Table 40: Highest 24-hour Average $PM_{2.5}$ Concentration (µg/m^3) in the Agra City (June)

	Region 1	Region 2	Region 3	Region 4	Region 5
Construction	3.35	1.24	1.96	1.38	0.82
DG set	0.26	0.25	0.2	0.24	0.56

Domestic	5.46	6.51	5.21	6.13	6.08
Hospital	0.33	0.43	0.37	0.33	0.295
Hotel	3.66	4.11	3.65	4.62	11.65
Industry	3.57	31.07	35.88	7.98	16.54
MSW	2.38	2.53	1.86	2.68	2.27
Open Area	0.04	0.04	0.05	0.05	0.05
Road dust	63.15	109.64	152.25	51.89	57.59
Vehicle	9.17	10.42	15.62	7.83	8.94
All Sources	**79.28**	**155.47**	**212.85**	**73.43**	**78.36**

The highest monthly average $PM_{2.5}$ concentration in June was observed to be 110 μg/m^3. The contour plots for monthly average $PM_{2.5}$ concentration for the Agra Airshed and the city region are shown in Figure 122 and Figure 123, respectively. The highest 24-hour average $PM_{2.5}$ concentration and the monthly average $PM_{2.5}$ concentrations for different regions in the Agra City are given in Table 40 and Table 41, respectively.

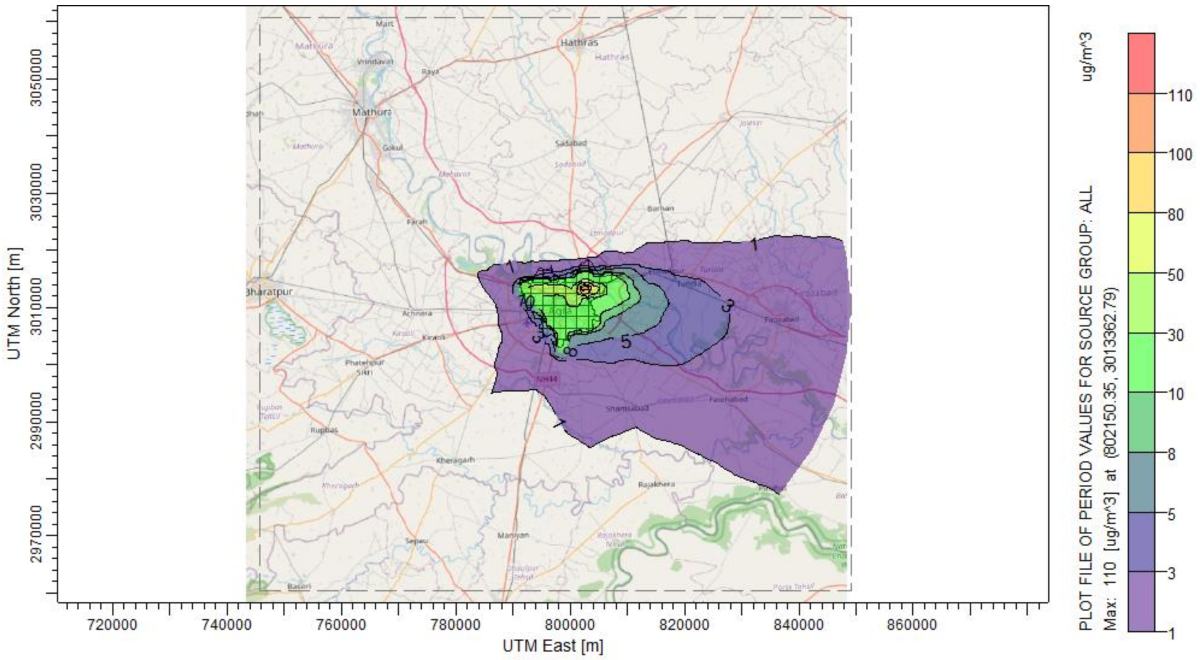


Figure 122: Contour Plot for Average Monthly $PM_{2.5}$ Concentration in the Agra Airshed (June)

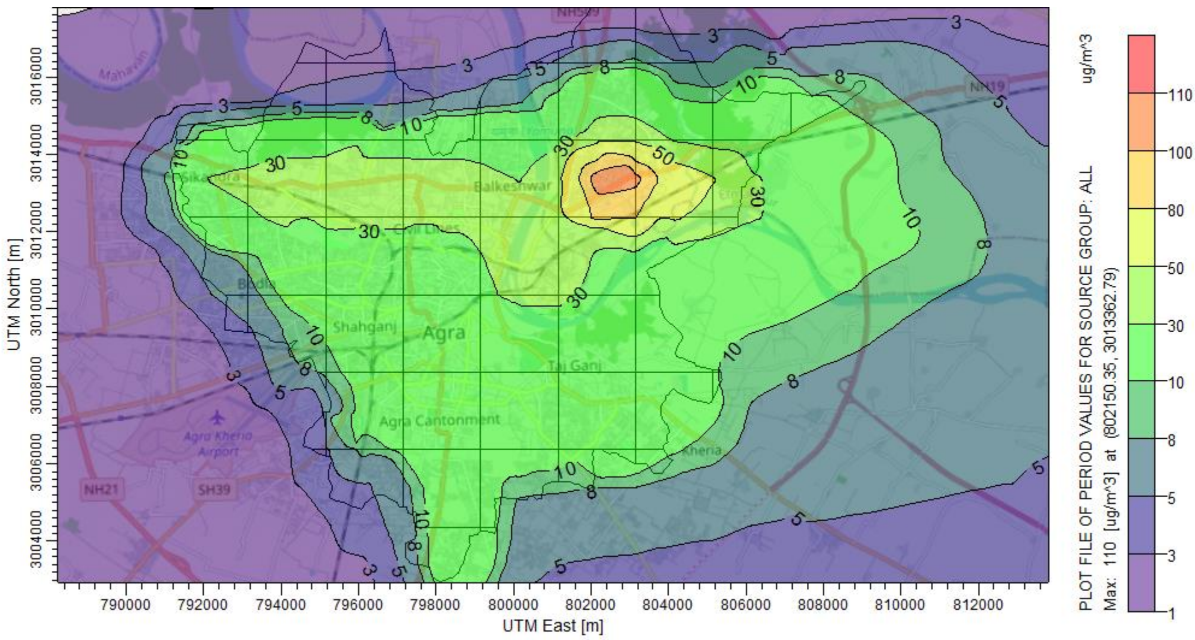


Figure 123: Contour Plot for Aaverage Monthly $PM_{2.5}$ Concentration in the Agra City (June)

Table 41: Monthly Average $PM_{2.5}$ Concentration (µg/m^3) in the Agra City (June)

	Region 1	Region 2	Region 3	Region 4	Region 5
Construction	0.24	0.16	0.3	0.09	0.14
Domestic	0.76	1.37	0.74	1	0.94
Hotel	0.36	0.67	0.28	0.53	1.29
Industry	0.18	1.22	3.75	0.17	0.71
MSW	0.3	0.49	0.26	0.43	0.35
Road Dust	8.49	12.45	16.21	3.76	5.79
Vehicle	1.51	2.21	1.82	1.37	1.6
Others	0.03	0.04	0.02	0.02	0.03
All Sources	**11.92**	**18.69**	**23.42**	**7.39**	**10.91**

July

The highest 24-hour average $PM_{2.5}$ concentration in July was observed to be 242 µg/m^3. Road dust, vehicular, and industrial sources were the main contributors followed by MSW burning, hotels, and domestic sources. The constructions, hospital areas, DG sets, and open area sources contributed the least. The plots for the highest 24-hour average $PM_{2.5}$ concentration for the Agra Airshed and thecity region are given in Figure 124 and Figure 125, respectively.

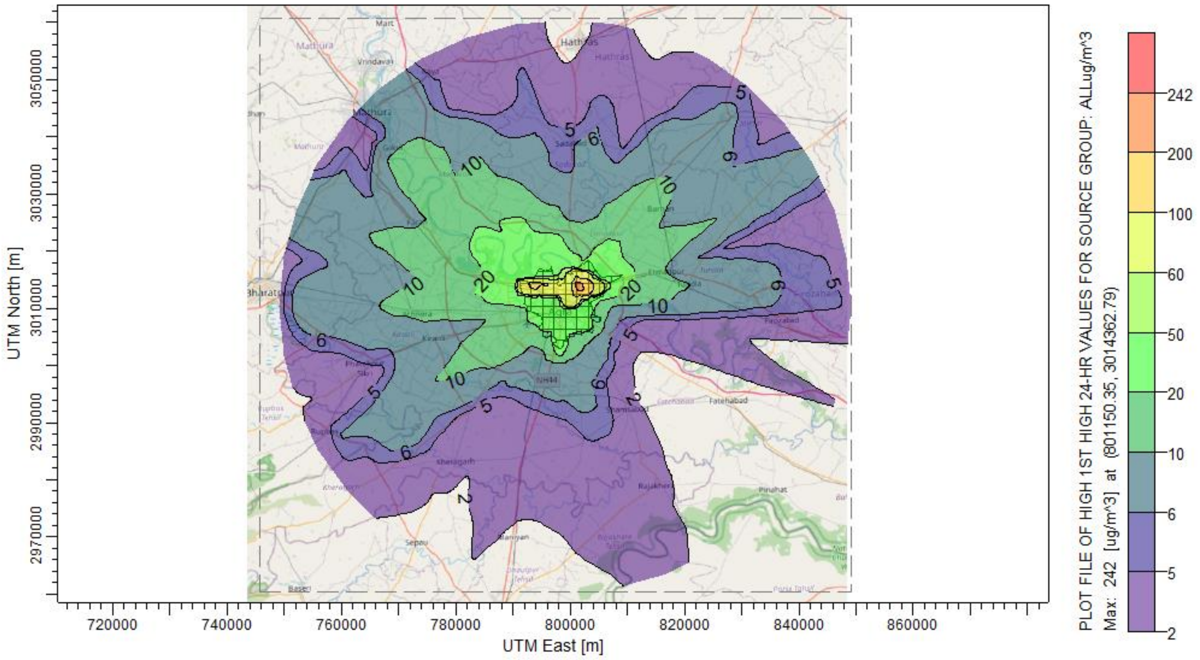


Figure 124: Contour Plot for Highest 24-hour average $PM_{2.5}$ Concentration in the Agra Airshed (July)

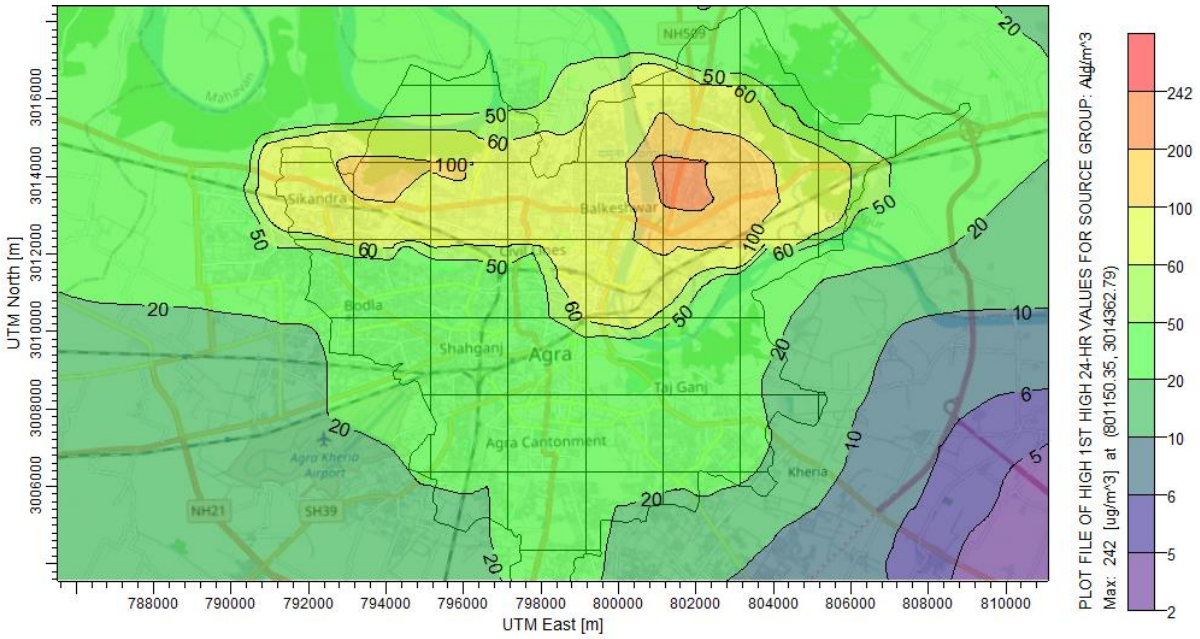


Figure 125: Contour Plot for Highest 24-hour Average $PM_{2.5}$ Concentration in the Agra City (July)

Table 42: Highest 24-hour average $PM_{2.5}$ Concentration ($\mu g/m^3$) in the Agra City (July)

	Region 1	Region 2	Region 3	Region 4	Region 5
Construction	4.03	1.77	1.88	1.07	0.77
DG set	0.34	0.33	0.23	0.3	0.66

Domestic	7.7	7.7	4.41	6.62	5.14
Hospital	0.51	0.05	0.3	0.32	0.23
Hotel	6.28	6.56	5.38	6.56	13.81
Industry	6.7	46.66	46.65	6.74	10.45
MSW	3.59	2.86	1.56	3.59	1.86
Open Area	0.07	0.04	0.05	0.05	0.05
Road dust	82.18	171.35	171.33	46.2	50.19
Vehicle	13.22	16.17	16.17	7.86	8.05
All Sources	**109.93**	**242**	**241.99**	**62.97**	**70.33**

The highest monthly average $PM_{2.5}$ concentration in July was observed to be 116 µg/m^3. The contour plots for monthly average $PM_{2.5}$ concentration for the Agra Airshed and the city region are shown in Figure 126 and Figure 127, respectively.The highest 24-hour average $PM_{2.5}$ concentration and the monthly average $PM_{2.5}$ concentrations for different regions in the Agra City are given in Table 42 and Table 43, respectively.

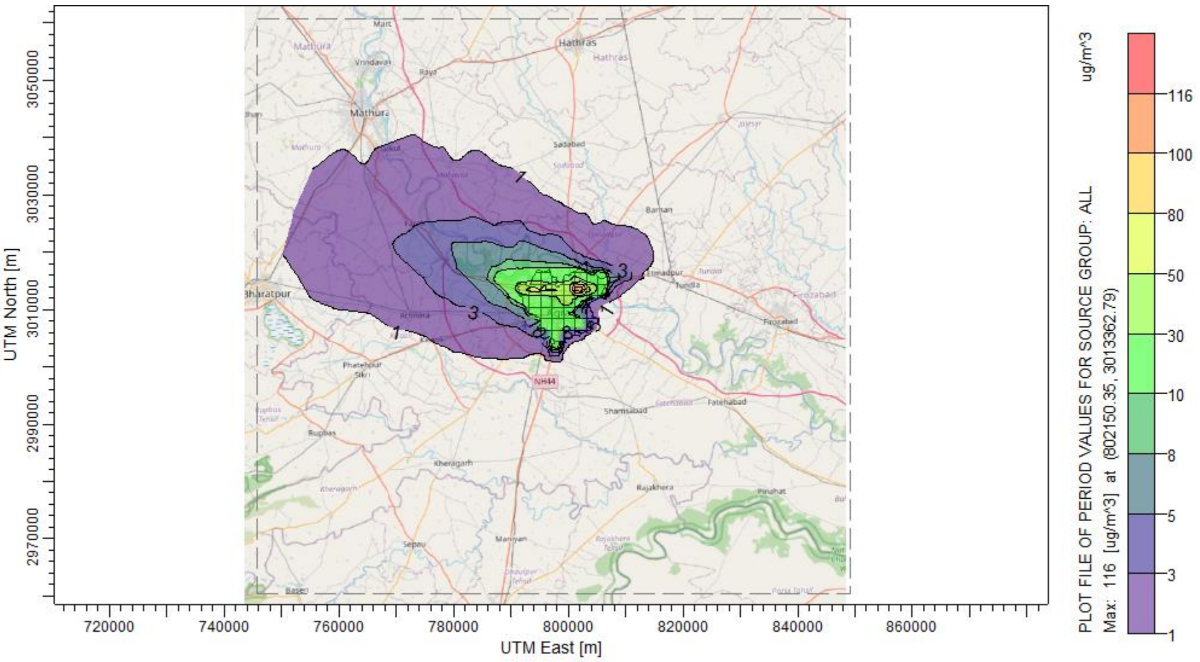


Figure 126: Contour Plot for Average Monthly $PM_{2.5}$ Concentration in the Agra Airshed (July)

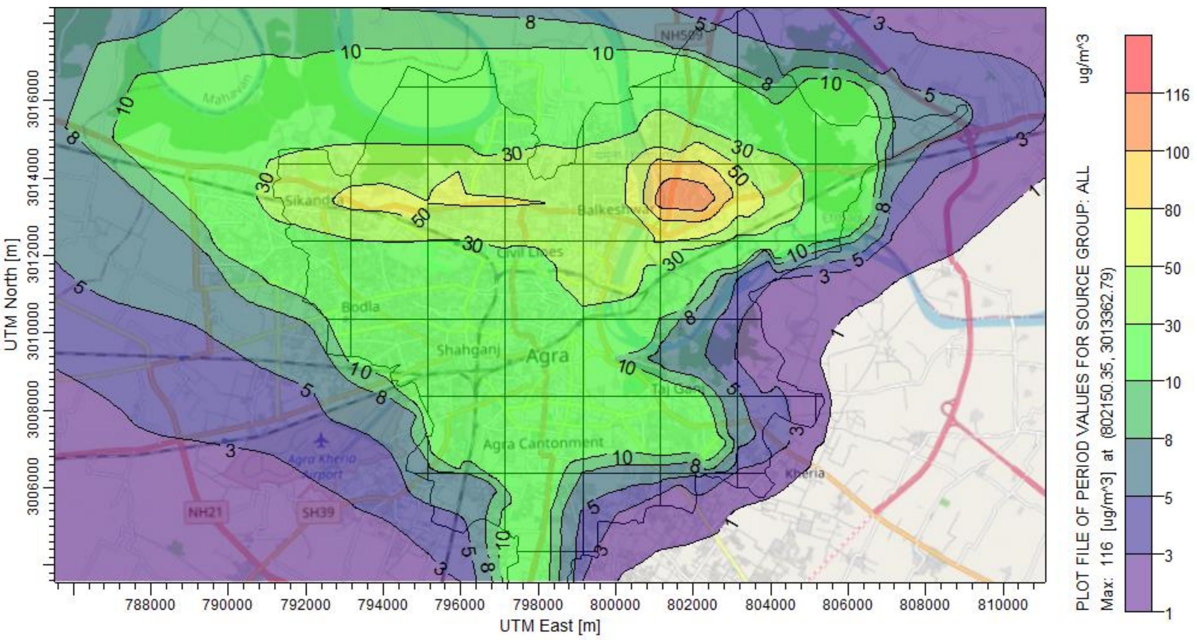


Figure 127: Contour Plot for Average Monthly $PM_{2.5}$ Concentration in the Agra City (July)

Table 43: Monthly Average $PM_{2.5}$ Concentration ($\mu g/m^3$) in the Agra City (July)

	Region 1	**Region 2**	**Region 3**	**Region 4**	**Region 5**
Construction	0.33	0.26	0.24	0.07	0.08
Domestic	1.56	1.54	0.44	0.99	0.36
Hotel	0.91	0.89	0.25	0.76	0.92
Industry	1.06	4.07	2.91	0.19	0.17
MSW	0.6	0.54	0.15	0.41	0.12
Road Dust	14.28	18.22	13.45	3.78	1.45
Vehicle	2.68	2.77	1.34	1.5	0.57
Others	0.05	0.04	0.01	0.02	0.02
All Sources	**21.58**	**28.42**	**18.82**	**7.79**	**3.72**

August

The highest 24-hour average $PM_{2.5}$ concentration in August was observed to be 253 $\mu g/m^3$. Road dust, vehicular, and industrial sources were the main contributors followed by MSW burning, hotels, and domestic sources. The constructions, hospital areas, DG sets, and open area sources contributed the

least. The plots for the highest 24-hour average $PM_{2.5}$ concentration for the Agra Airshed and the city region are given in Figure 128 and Figure 129, respectively.

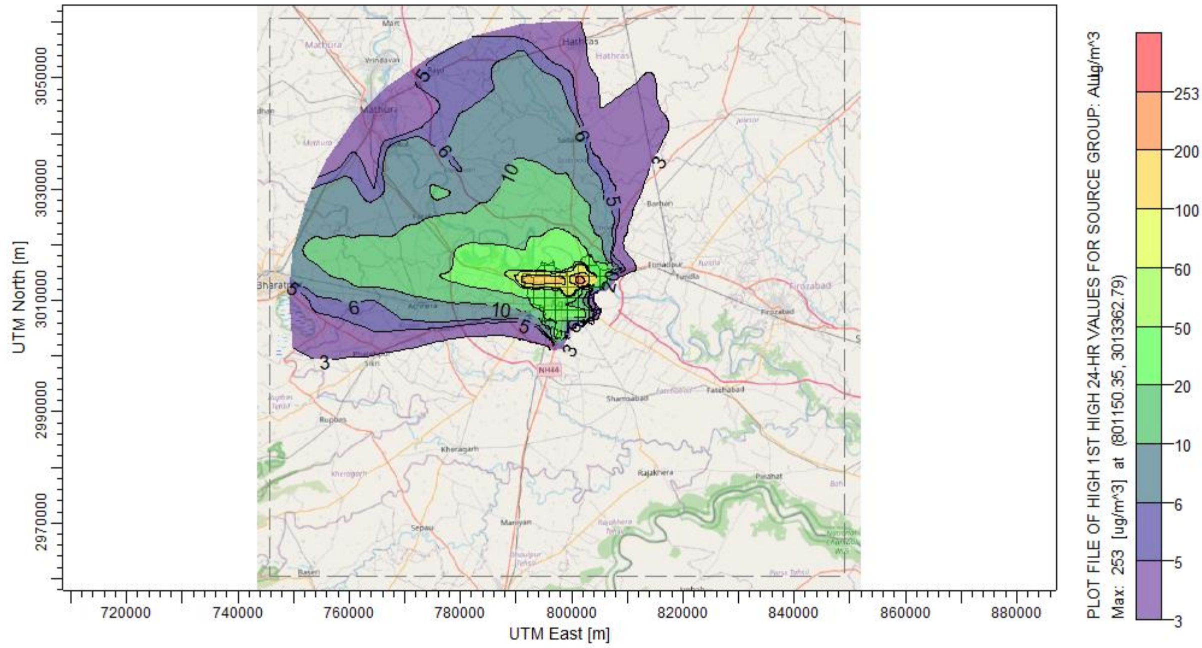


Figure 128: Contour Plot for highest 24-hour Average $PM_{2.5}$ Concentration in the Agra Airshed (August)

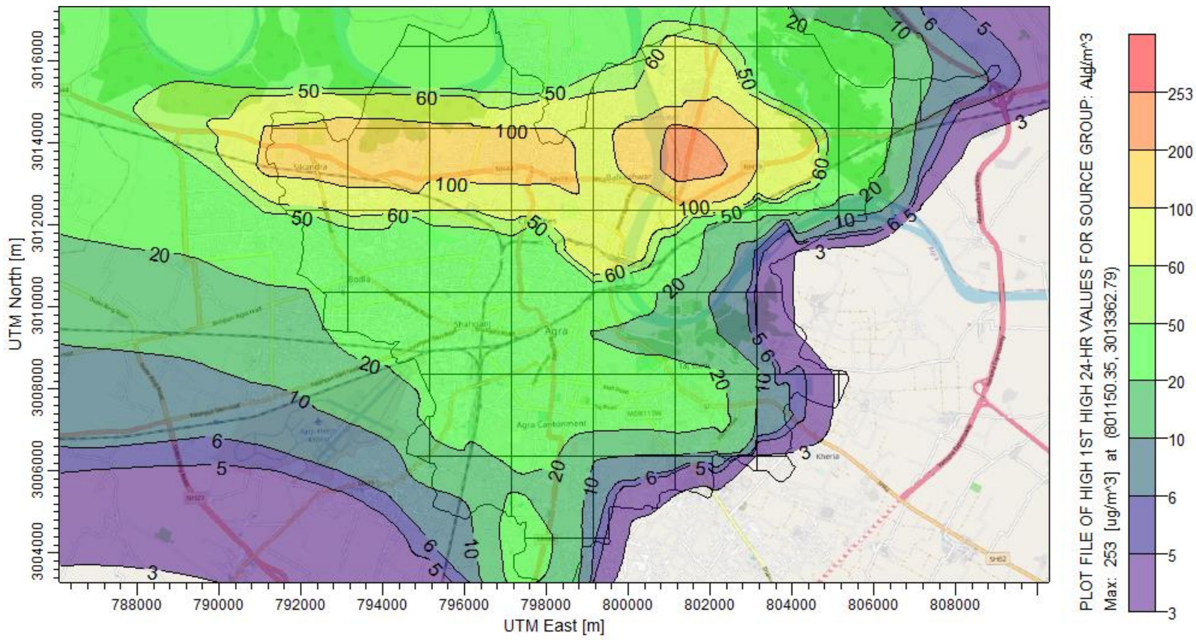


Figure 129: Contour Plot or Highest 24-hour Average $PM_{2.5}$ Concentration in the Agra City (August)

Table 44: Highest 24-hour Average $PM_{2.5}$ Concentration ($\mu g/m^3$) in the Agra City (August)

	Region 1	Region 2	Region 3	Region 4	Region 5
Construction	4.51	1.92	2.07	0.65	0.86
DG set	0.37	0.29	0.21	0.36	0.71
Domestic	7.11	6.85	3.18	7.07	3.04
Hospital	0.55	0.55	0.28	0.36	0.19
Hotel	6.39	6.39	4.4	7.41	14.39
Industry	9.14	43.84	43.84	2.49	3.42
MSW	3.71	2.51	1.12	3.84	0.94
Open Area	0.07	0.04	0.05	0.06	0.05
Road dust	99.27	185.9	185.9	24.22	24.22
Vehicle	14.51	16.51	16.51	7.77	5.87
All Sources	**130.85**	**252.56**	**252.56**	**36.8**	**36.8**

The highest monthly average $PM_{2.5}$ concentration in August was observed to be 100.5 $\mu g/m^3$. The contour plots for monthly average $PM_{2.5}$ concentration for the Agra Airshed and the city region are shown in Figure 130 and Figure 131, respectively. The highest 24-hour average $PM_{2.5}$ concentration and the monthly average $PM_{2.5}$ concentrations for different regions in the Agra City are given in Table 44 and Table 45, respectively.

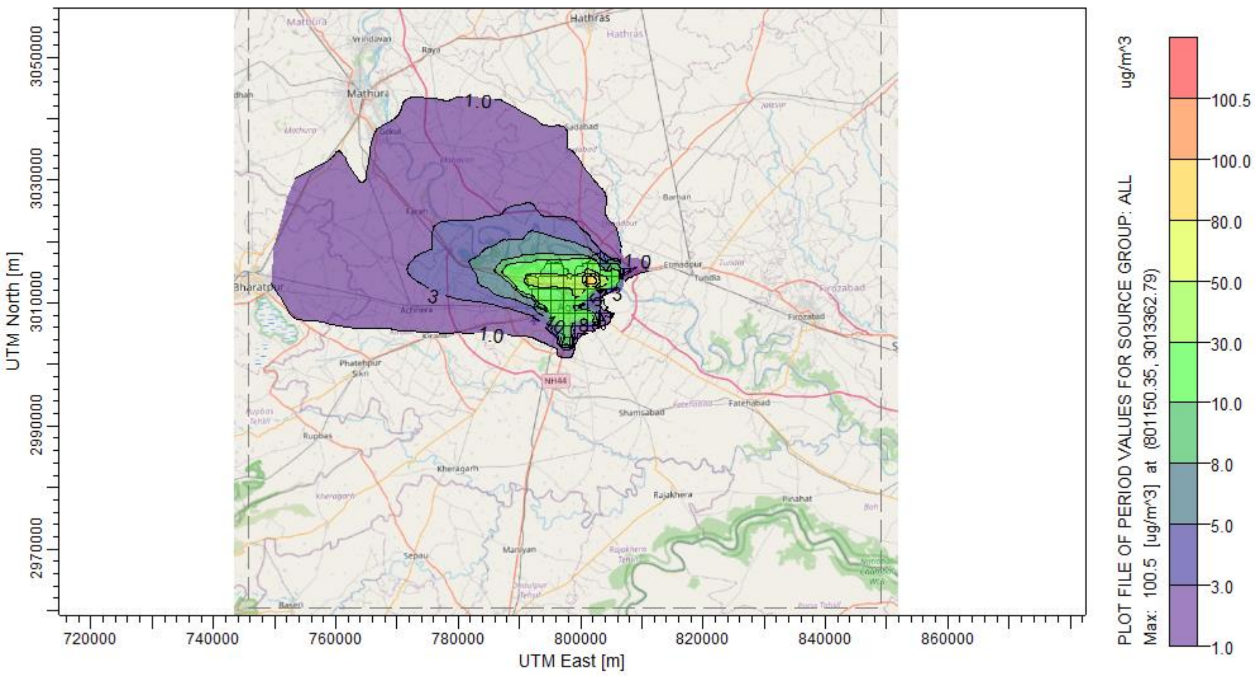


Figure 130: Contour Plot for Average Monthly $PM_{2.5}$ Concentration in the Agra Airshed (August)

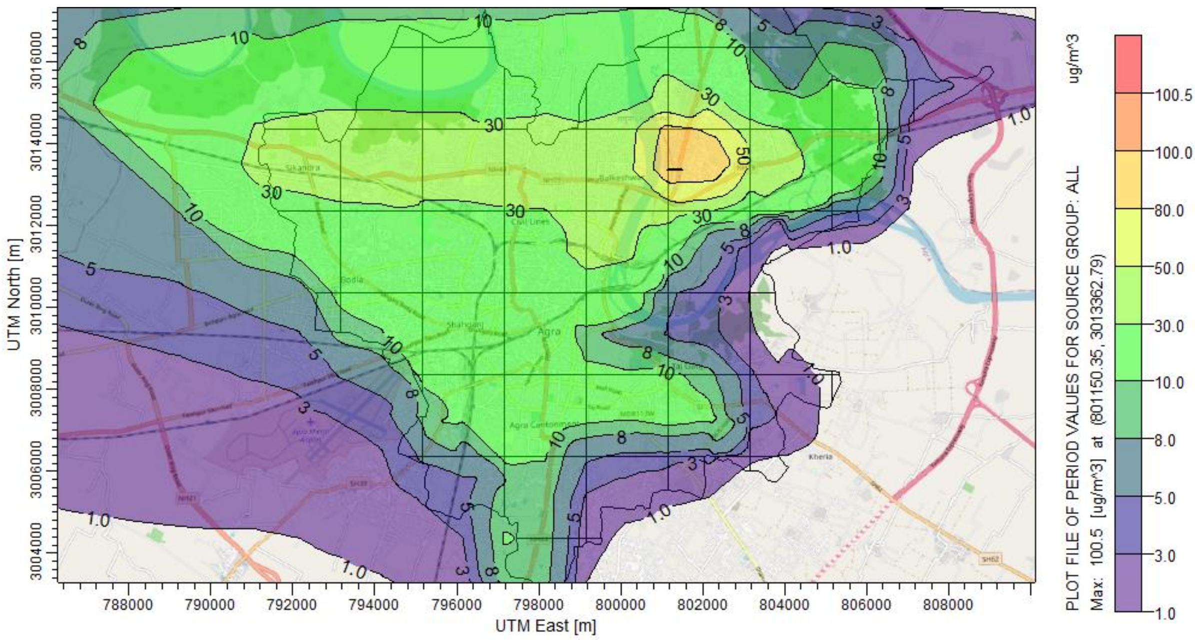


Figure 131: Contour Plot for Average Monthly $PM_{2.5}$ Concentration in the Agra City (August)

Table 45: Monthly Average $PM_{2.5}$ Concentration (µg/m^3) in the Agra City (August)

	Region 1	Region 2	Region 3	Region 4	Region 5
Construction	0.29	0.22	0.19	0.05	0.07
Domestic	1.44	1.32	0.28	0.82	0.25
Hotel	0.83	0.82	0.17	0.64	0.74
Industry	0.99	3.81	2.35	0.09	0.09
MSW	0.554	0.46	0.09	0.34	0.08
Road Dust	12.9	16.08	10.74	2.85	0.78
Vehicle	2.45	2.42	0.98	1.24	0.38
Others	0.04	0.04	0.01	0.02	0.01
All Sources	**19.59**	**25.23**	**14.83**	**6.09**	**2.43**

September

The highest 24-hour average $PM_{2.5}$ concentration in September was observed to be 336 µg/m^3. Road dust, vehicular, and industrial sources were the main contributors followed by MSW burning, hotels, and domestic sources. The constructions, hospital areas, DG sets, and open area sources contributed the least. The plots for the highest 24-hour average $PM_{2.5}$ concentration for the Agra Airshed and the city region are given in Figure 132 and Figure 133, respectively.

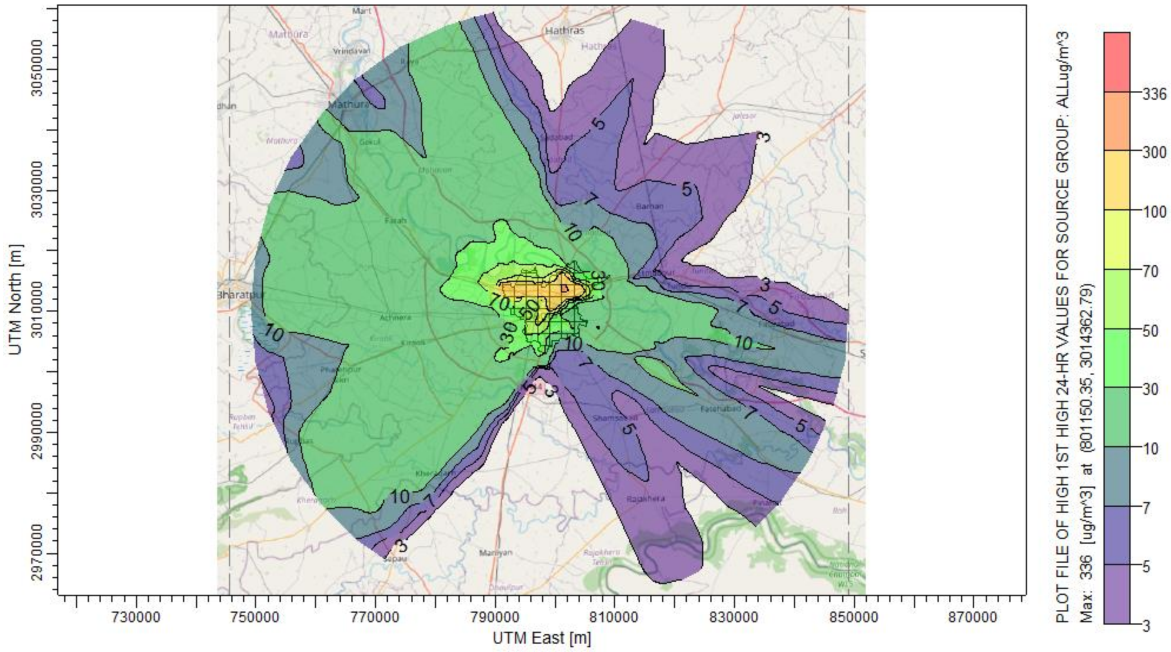


Figure 132: Contour Plot for Highest 24-hour Average $PM_{2.5}$ Concentration in the Agra Airshed (September)

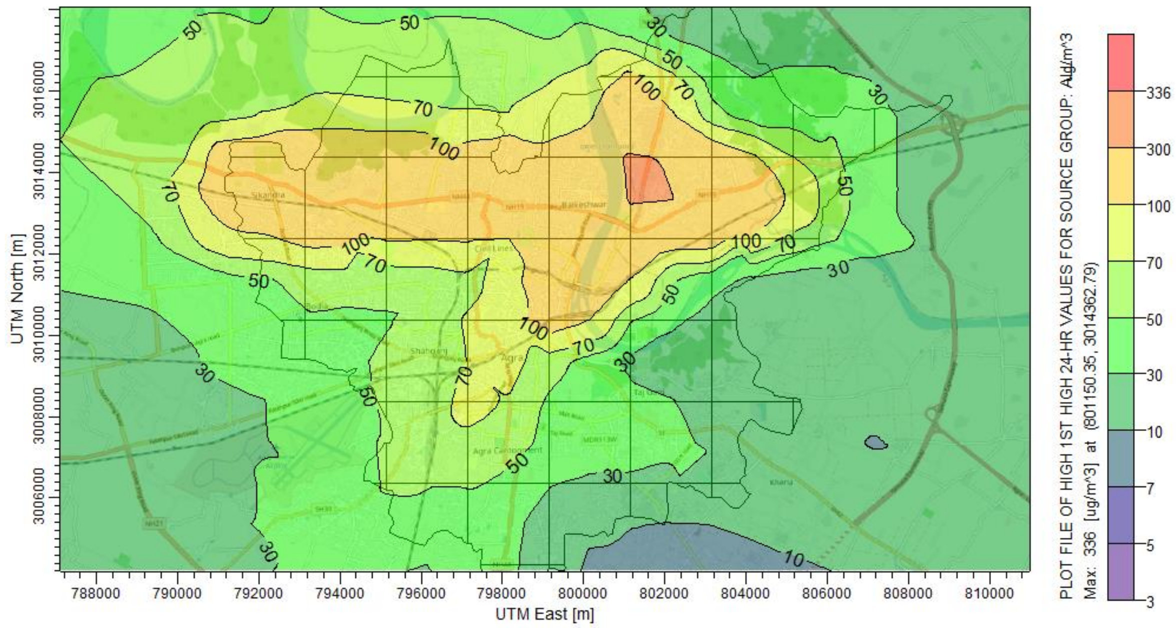


Figure 133: Contour Plot for highest 24-hour Average $PM_{2.5}$ Concentration in the Agra City (September)

Table 46: Highest 24-hour Average $PM_{2.5}$ Concentration ($\mu g/m^3$) in the Agra City (September)

	Region 1	Region 2	Region 3	Region 4	Region 5
Construction	5.82	2.59	2.66	1.5	1.05
DG set	0.49	0.45	0.32	0.43	0.89

Domestic	10.44	10.44	5.18	9.49	6.53
Hospital	0.74	0.74	0.43	0.53	0.25
Hotel	8.98	8.98	7.06	9.17	18.92
Industry	10.98	67.89	67.89	13.31	13.39
MSW	5.05	3.86	1.85	5.04	2.33
Open Area	0.09	0.05	0.07	0.08	0.07
Road dust	121.16	236.97	236.97	85.75	85.75
Vehicle	18.67	21.57	21.57	12.47	12.47
All Sources	**158.64**	**336.4**	**336.41**	**119.72**	**119.72**

The highest monthly average $PM_{2.5}$ concentration in September was observed to be 183 μg/m^3. The contour plots for monthly average $PM_{2.5}$ concentration for the Agra Airshed and the city region are shown in Figure 134 and Figure 135, respectively.

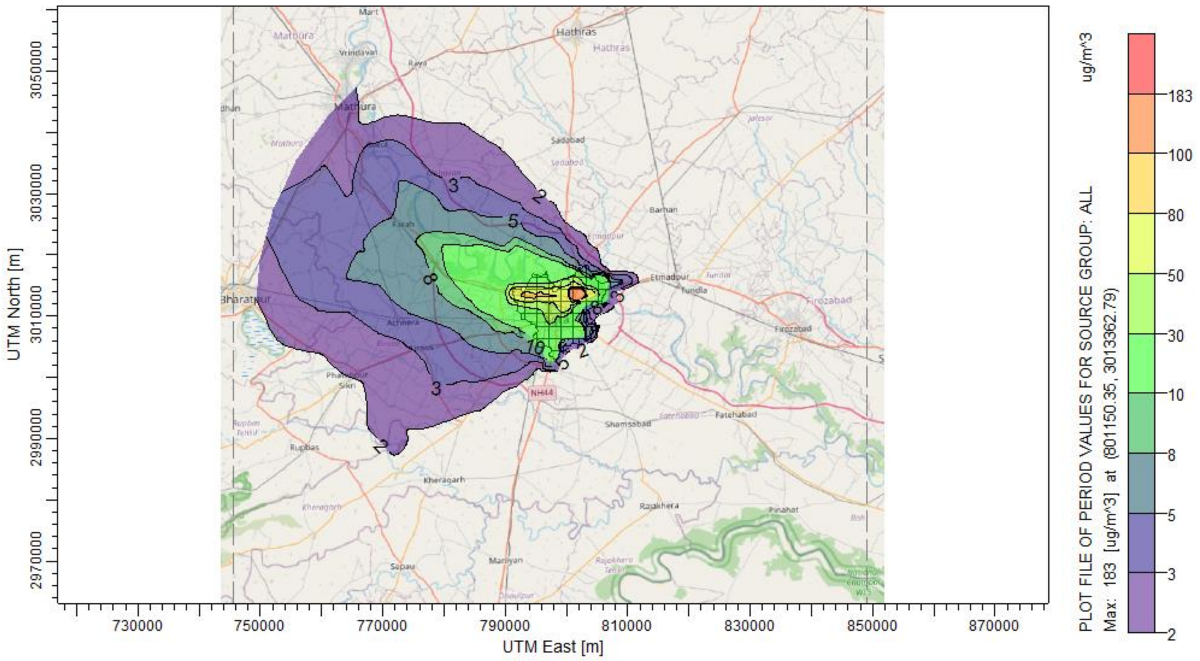


Figure 134: Contour Plot for Average Monthly $PM_{2.5}$ Concentration in the Agra Airshed (September)

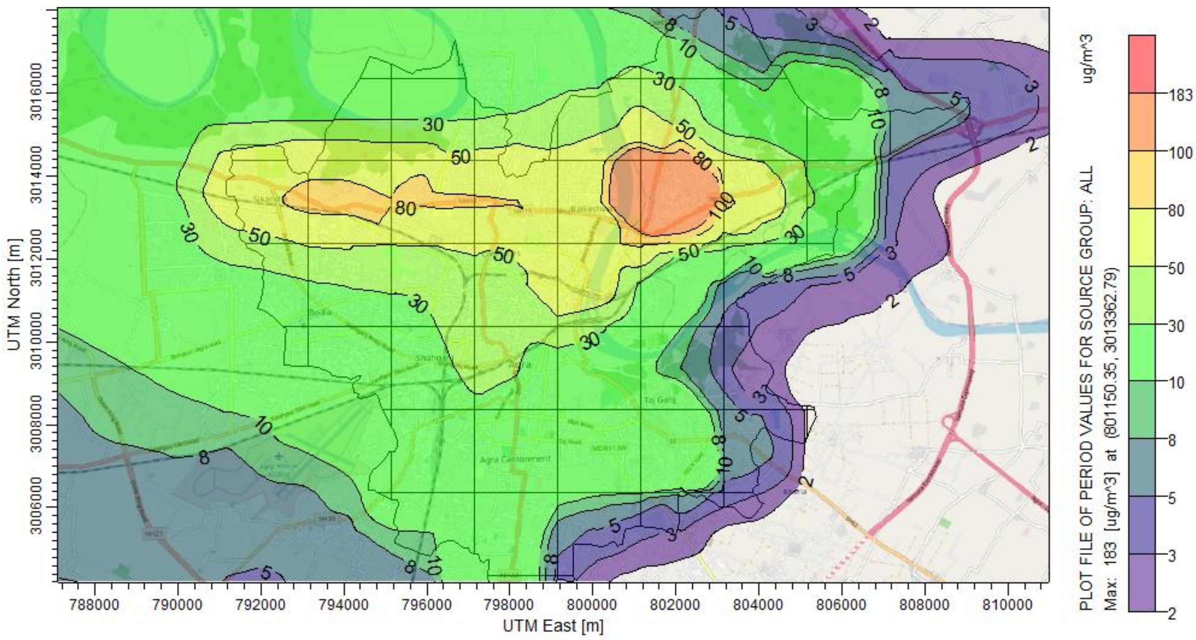


Figure 135: Contour Plot for Average Monthly $PM_{2.5}$ Concentration in the Agra City (September)

Table 47: Monthly Average $PM_{2.5}$ Concentration (µg/m^3) in the Agra City (September)

	Region 1	Region 2	Region 3	Region 4	Region 5
Construction	0.55	0.44	0.34	0.14	0.13
Domestic	2.62	2.31	0.52	1.72	0.55
Hotel	1.59	1.35	0.26	1.4	1.42
Industry	2.03	7.3	4.26	0.49	0.29
MSW	0.99	0.8	0.18	0.71	0.19
Road Dust	24.44	30.02	19.79	7.18	2.27
Vehicle	4.53	4.33	1.82	2.65	0.84
Others	0.08	0.06	0.02	0.04	0.03
All Sources	**37.02**	**46.75**	**27.23**	**14.42**	**5.77**

October

The highest 24-hour average $PM_{2.5}$ concentration in the month of October was observed to be 332 µg/m^3. Road dust, vehicular, and industrial sources were the main contributors followed by MSW burning, hotels, and domestic sources. The constructions, hospital areas, DG sets, and open area

sources contributed the least. The plots for the highest 24-hour average $PM_{2.5}$ concentration for the Agra Airshed and the city region are given in Figure 136 and
Figure 137, respectively.

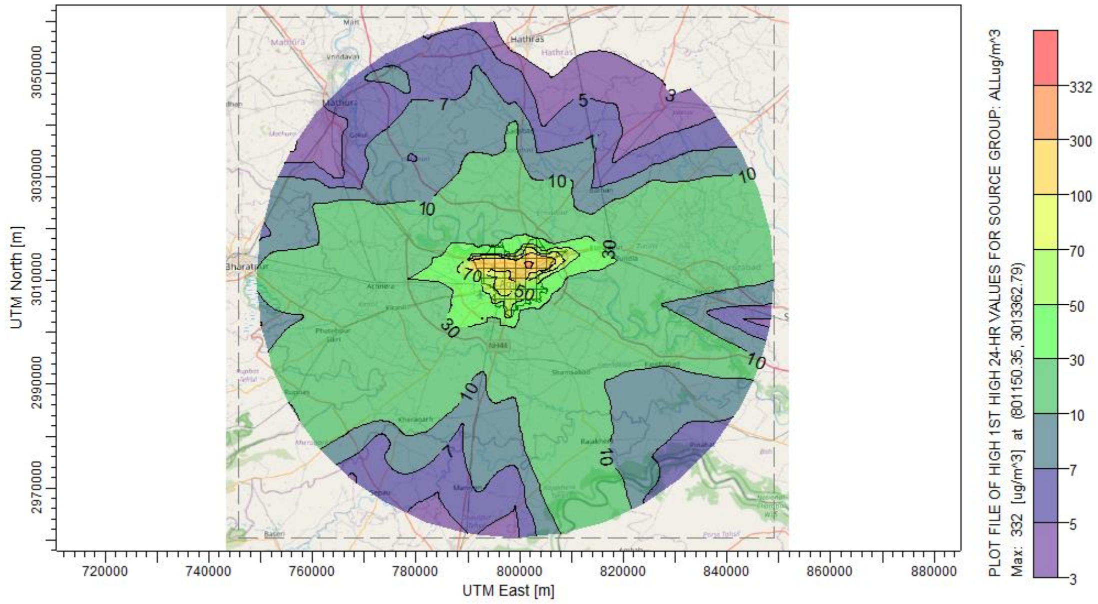


Figure 136: Contour Plot for Highest 24-hour Average $PM_{2.5}$ Concentration in the Agra Airshed (October)

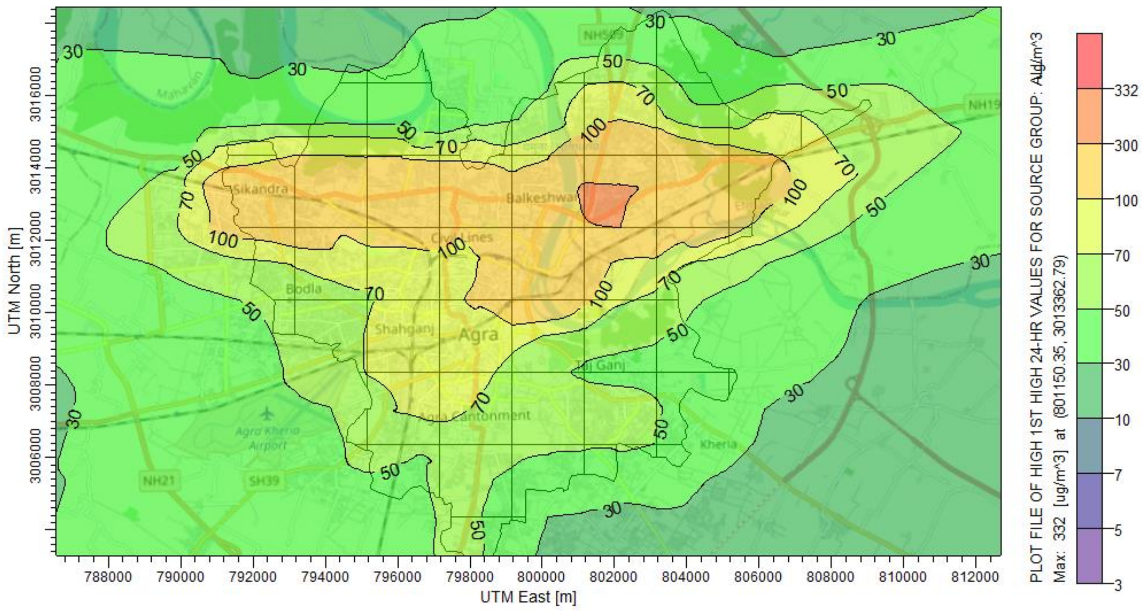


Figure 137: Contour Plot for Highest 24-hour Average $PM_{2.5}$ Concentration in the Agra City (October)

Table 48: Highest 24-hour Average $PM_{2.5}$ Concentration ($\mu g/m^3$) in the Agra City (October)

	Region 1	Region 2	Region 3	Region 4	Region 5
Construction	5.79	2.52	2.97	1.99	1.17
DG set	0.43	0.36	0.27	0.47	0.91

Domestic	10.77	10.77	6.61	10.77	8.42
Hospital	0.7	0.71	0.52	0.62	0.39
Hotel	6.92	6.91	5.09	10.22	18.98
Industry	11.36	60.89	60.9	15.89	21.13
MSW	4.33	3.96	2.39	5.47	3.19
Open Area	0.09	0.05	0.08	0.09	0.08
Road dust	129.22	240.89	240.89	111.03	111.04
Vehicle	18.05	21.79	22.13	16.13	16.14
All Sources	**167.38**	**332.35**	**332.35**	**155.1**	**155.1**

The highest monthly average $PM_{2.5}$ concentration in October was observed to be 213 µg/m^3. The contour plots for monthly average $PM_{2.5}$ concentration for the Agra Airshed and the city region are shown in Figure 138 and Figure 139, respectively. The highest 24-hour average $PM_{2.5}$ concentration and the monthly average $PM_{2.5}$ concentrations for different regions in the Agra City are given in Table 48 and Table 49, respectively.

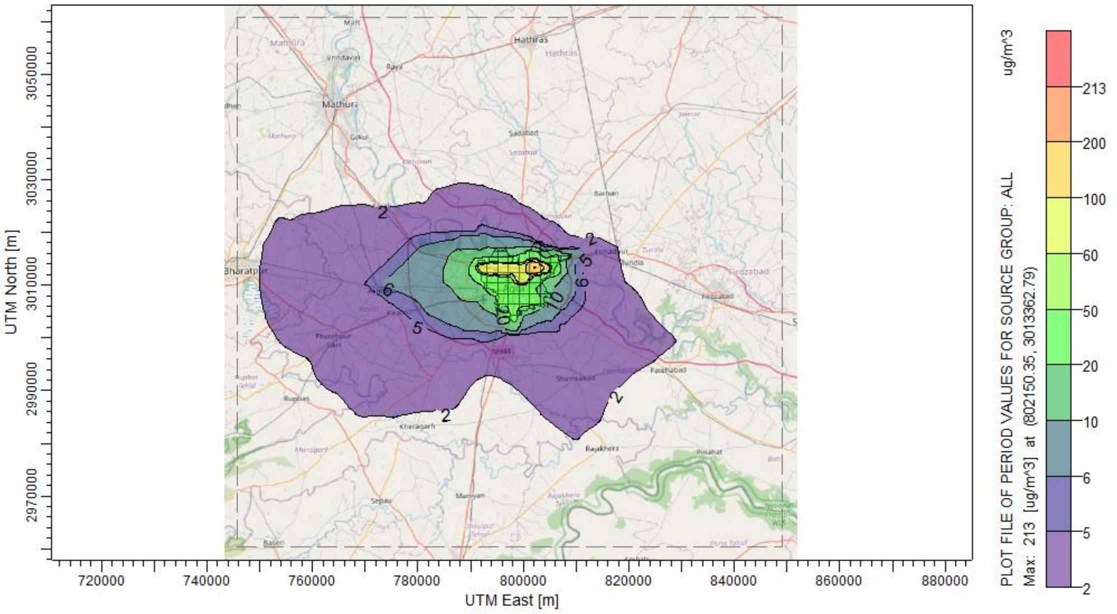


Figure 138: Contour Plot for Average Monthly $PM_{2.5}$ Concentration in the Agra Airshed (October)

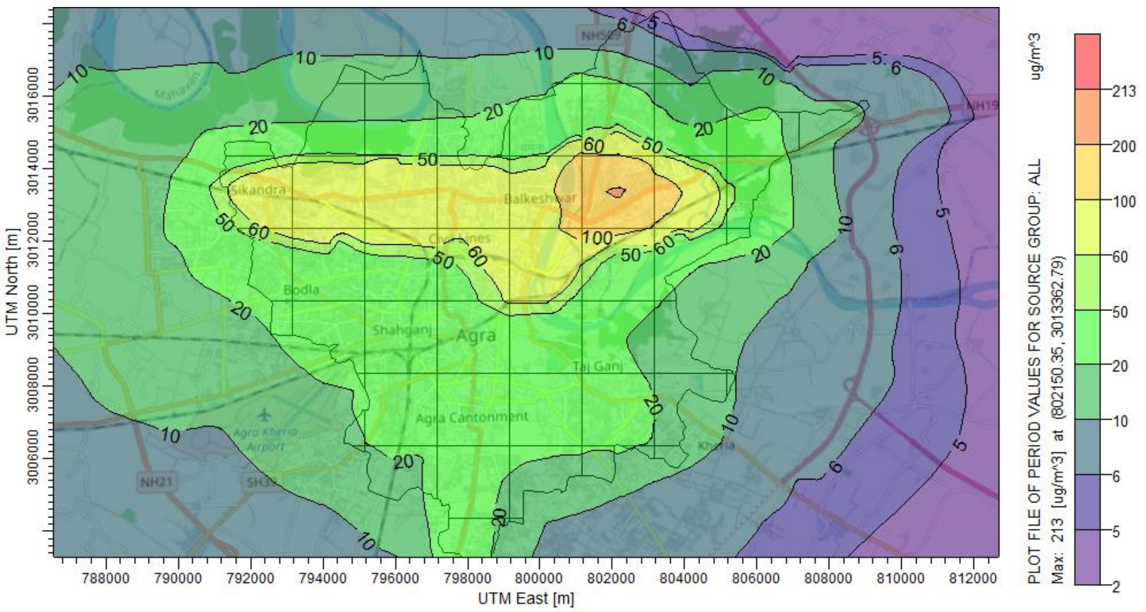


Figure 139: Contour Plot for Average Monthly $PM_{2.5}$ Concentration in the Agra City (October)

Table 49: Monthly Average $PM_{2.5}$ Concentration ($\mu g/m^3$) in the Agra City (October)

	Region 1	Region 2	Region 3	Region 4	Region 5
Construction	0.58	0.43	0.48	0.22	0.23
Domestic	2.32	2.68	0.91	2.37	1.21
Hotel	1.23	1.39	0.4	1.65	2.08
Industry	1.64	6.36	6.01	0.85	1.25
MSW	0.89	0.94	0.32	0.97	0.42
Road Dust	23.97	31.15	26.7	10.97	8.18
Vehicle	4.25	4.79	2.69	3.54	2.06
Others	0.07	0.07	0.03	0.05	0.04
All Sources	**35.11**	**47.96**	**37.6**	**20.75**	**15.6**

November

The highest 24-hour average $PM_{2.5}$ concentration in November was observed to be 370 $\mu g/m^3$. Road dust, vehicular, and industrial sources were the main contributors followed by MSW burning, hotels, and domestic sources. The constructions, hospital areas, DG sets, and open area sources contributed the least. Theplots for the highest 24-hour average $PM_{2.5}$ concentration for the Agra Airshed and the city region are given in

Figure 140 and Figure 141 respectively.

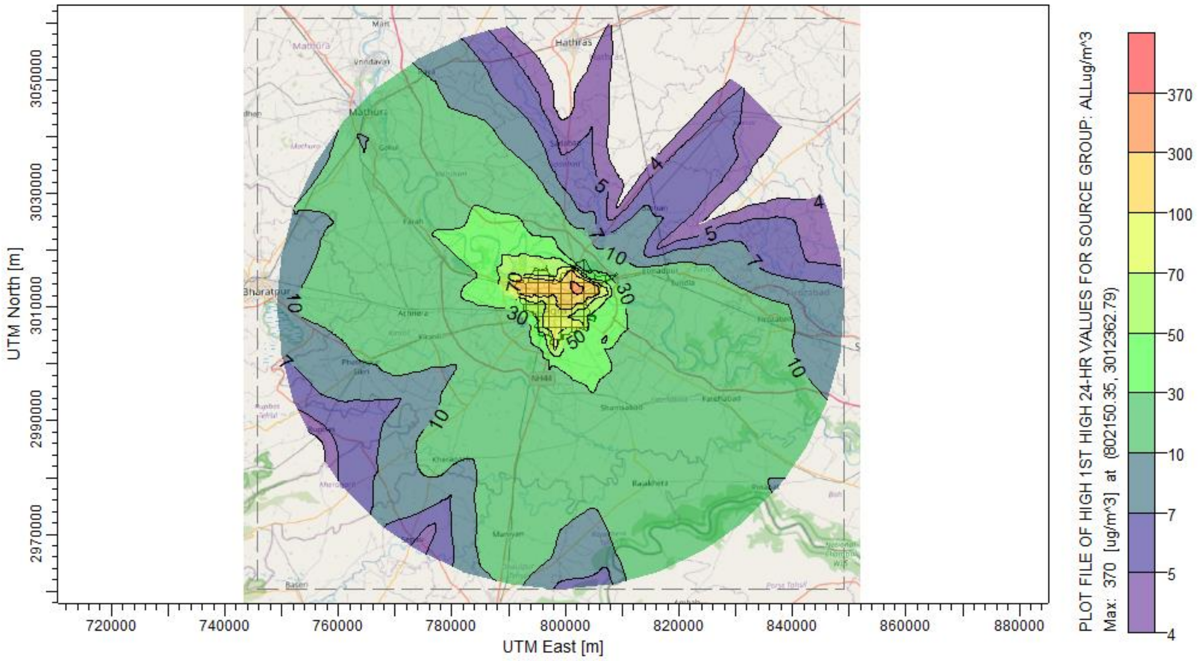


Figure 140: Contour Plot for Highest 24-hr Average $PM_{2.5}$ Concentration in the Agra Airshed (November)

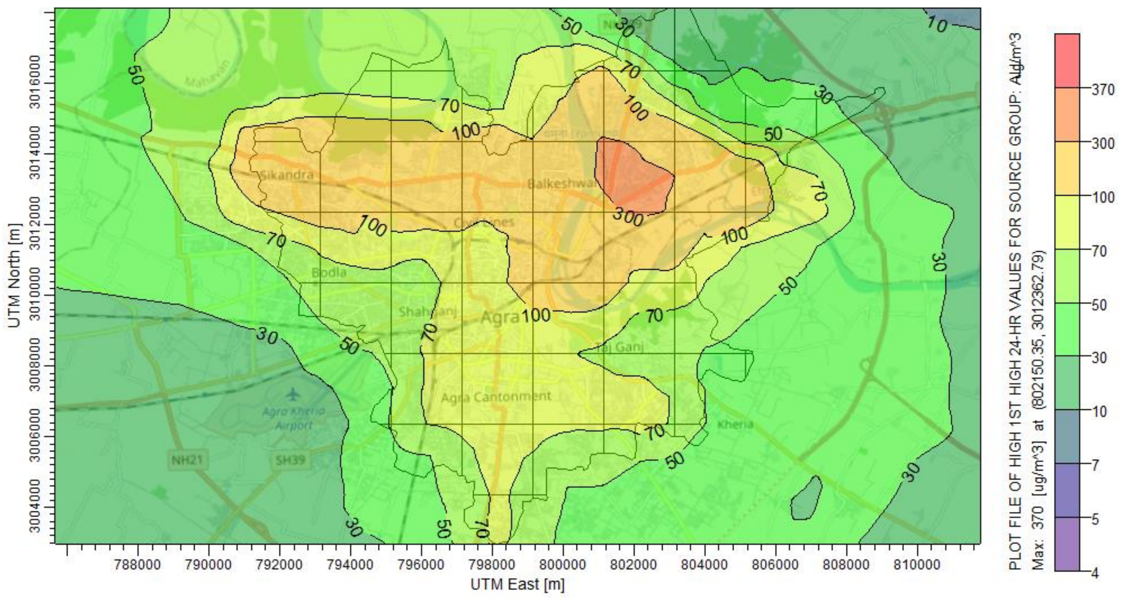


Figure 141: Contour Plot for Highest 24-hour Average $PM_{2.5}$ Concentration in the Agra City (November)

Table 50: Highest 24-hour Average $PM_{2.5}$ Concentration (µg/m^3) in the Agra City (November)

	Region 1	Region 2	Region 3	Region 4	Region 5
Construction	6.22	2.69	3.39	2.54	1.43
DG set	0.52	0.49	0.311	0.49	1.02
Domestic	12.04	12.04	6.68	12.04	9.41
Hospital	0.76	0.76	0.48	0.63	0.49
Hotel	9.69	9.67	7.07	10.4	21.43
Industry	11.27	72.08	72.08	10.82	26.91
MSW	5.05	4.31	2.32	5.86	3.52
Open Area	0.1	0.06	0.07	0.11	0.09
Road dust	124.64	247.81	265.51	89.79	124.67
Vehicle	19.07	23.18	24.29	16.01	17.69
All Sources	**164.25**	**354**	**370**	**134.92**	**169.17**

The highest monthly average $PM_{2.5}$ concentration in the month of November was observed to be 226 µg/m^3. The contour plots for monthly average $PM_{2.5}$ concentration for the Agra Airshed and the city region are shown in Figure 142 and Figure 143, respectively. The highest 24-hour average $PM_{2.5}$ concentration and the monthly average $PM_{2.5}$ concentrations for different regions in the Agra City are given in

Table 50 and Table 51, respectively.

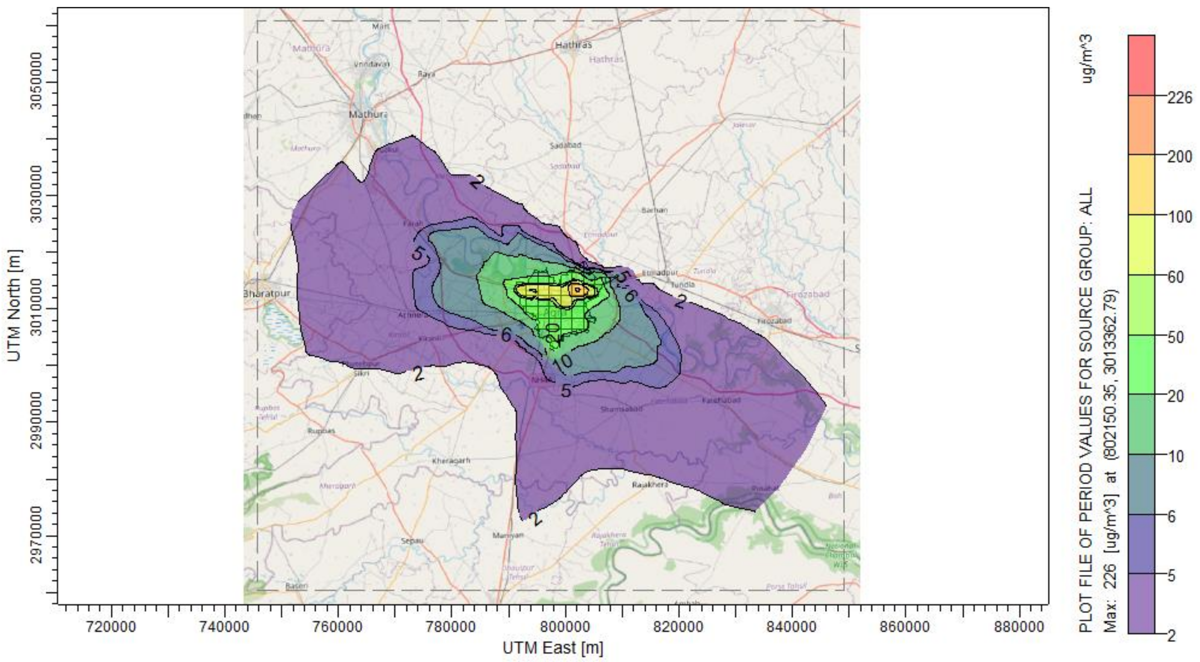


Figure 142: Contour Plot for Average Monthly $PM_{2.5}$ Concentration in the Agra Airshed (November)

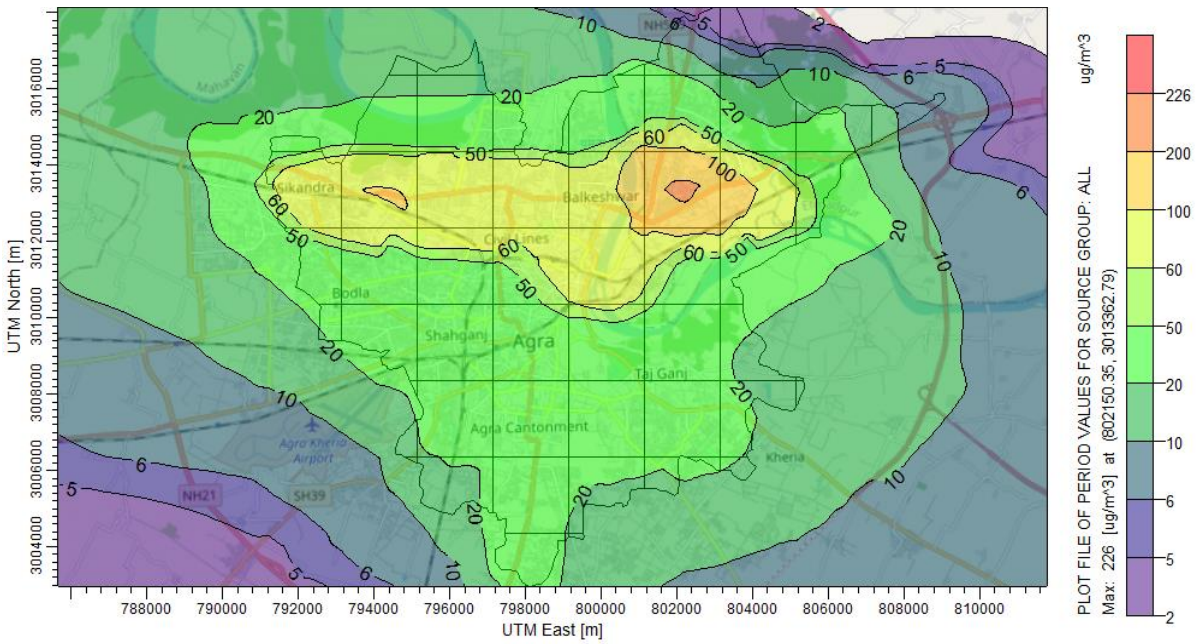


Figure 143: Contour Plot for Average Monthly $PM_{2.5}$ Concentration in the Agra City (November)

Table 51: Monthly Average $PM_{2.5}$ Concentration (µg/m^3) in the Agra City (November)

	Region 1	Region 2	Region 3	Region 4	Region 5
Construction	0.63	0.46	0.52	0.23	0.29

Domestic	2.57	2.84	0.93	2.49	1.53
Hotel	1.48	1.51	0.35	1.66	2.4
Industry	1.69	6.48	6.65	0.55	1.65
MSW	0.97	0.99	0.32	1.03	0.55
Road Dust	26.1	32.99	28.75	10.57	10.82
Vehicle	4.69	5.04	2.82	3.65	2.62
Others	0.08	0.08	0.03	0.06	0.06
All Sources	**38.4**	**50.53**	**40.43**	**20.34**	**20.03**

December

The highest 24-hour average $PM_{2.5}$ concentration in December was observed to be 437 µg/m^3. Road dust, vehicular, and industrial sources were the main contributors followed by MSW burning, hotels, and domestic sources. The constructions, hospital areas, DG sets, and open area sources contributed the least. The plots for the highest 24-hour average $PM_{2.5}$ concentration for the Agra Airshed and the city region are given in Figure 144 and Figure 145, respectively.

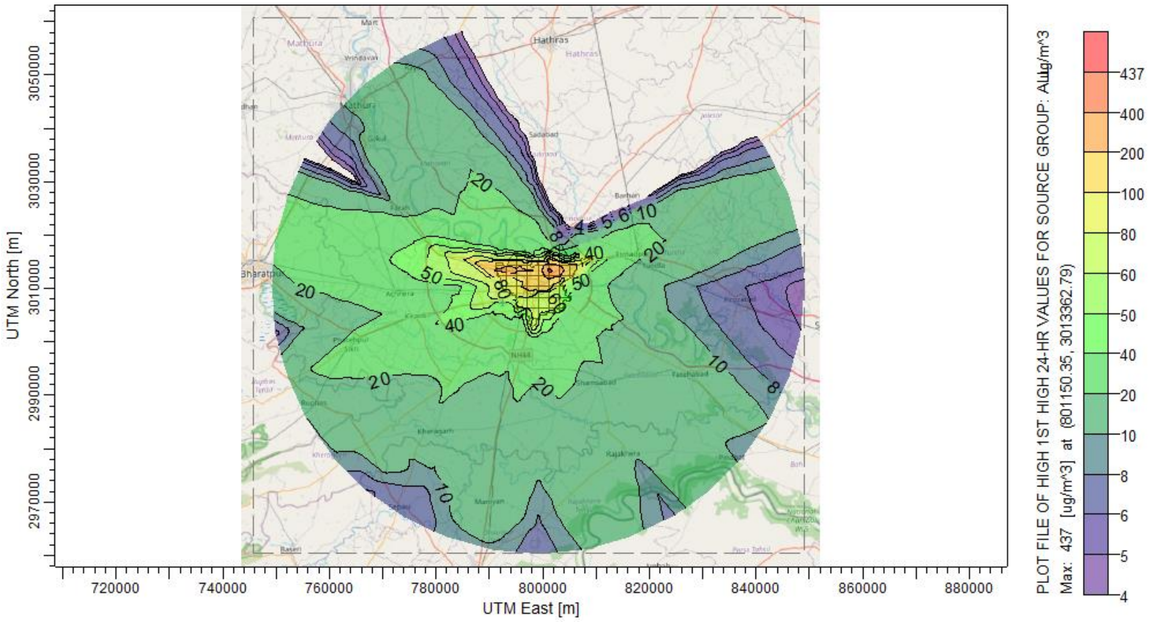


Figure 144: Contour Plot for Highest 24-hour Average $PM_{2.5}$ Concentration in the Agra Airshed (December)

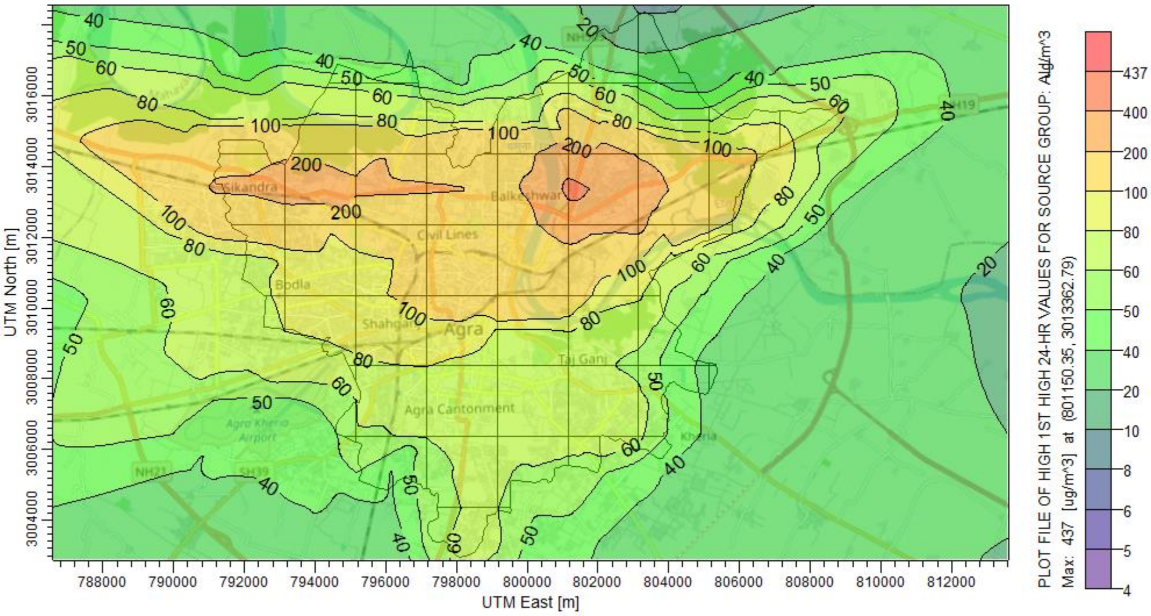


Figure 145: Contour Plot for Highest 24-hour Average $PM_{2.5}$ Concentration in the Agra City (December)

Table 52: Highest 24-hour Average $PM_{2.5}$ Concentration (µg/m^3) in the Agra City (December)

	Region 1	Region 2	Region 3	Region 4	Region 5
Construction	7.43	3.33	3.41	2.2	1.47
DG set	0.59	0.47	0.34	0.68	1.15
Domestic	12.04	10.82	7.32	12.04	9.33
Hospital	0.93	0.93	0.51	0.66	0.46
Hotel	9.4	9.4	4.98	14.03	23.95
Industry	19.12	78.91	78.91	16.92	25.34
MSW	6.05	4.02	2.68	6.68	3.51
Open Area	0.12	0.07	0.08	0.09	0.09
Road dust	186.17	319.38	319.37	117.04	117.04
Vehicle	25.49	27.96	27.96	15.92	15.93
All Sources	**241.43**	**436.79**	**436.79**	**157.91**	**157.91**

The highest monthly average $PM_{2.5}$ concentration in December was observed to be 222 µg/m^3. The contour plots for monthly average $PM_{2.5}$ concentration for the Agra Airshed and the city region are shown in Figure 146 and

Figure 147, respectively. The highest 24-hour average $PM_{2.5}$ concentration and the monthly average $PM_{2.5}$ concentrations for different regions in the Agra City are given in Table 52 and Table 53, respectively.

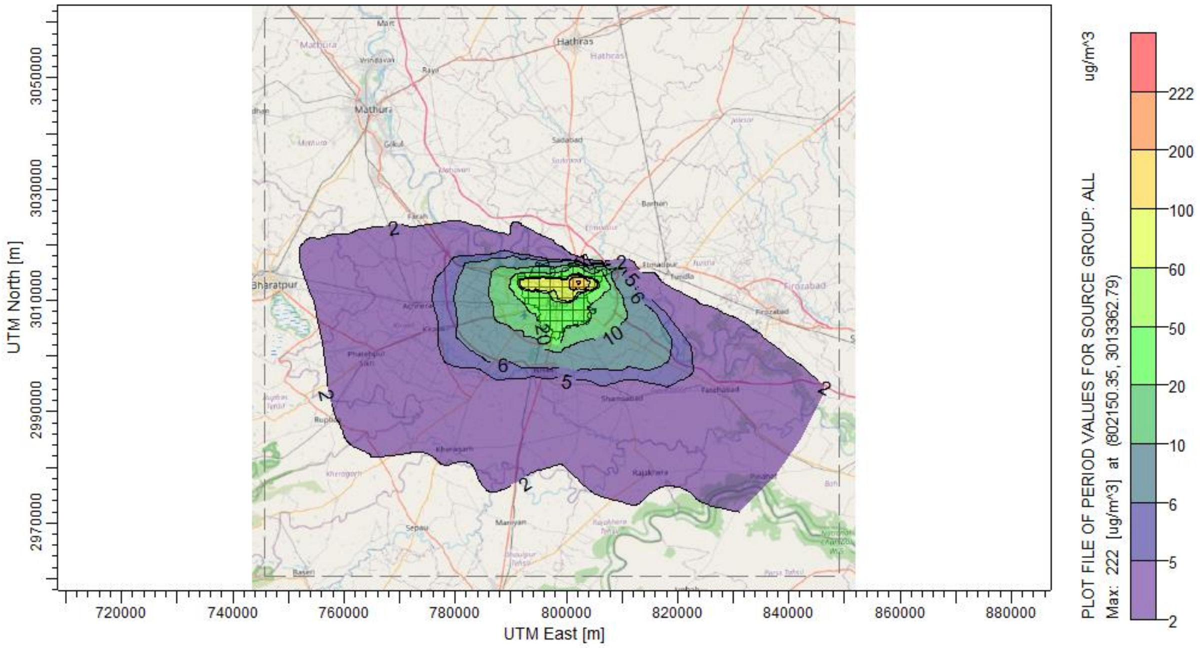


Figure 146: Contour Plot for Average Monthly $PM_{2.5}$ Concentration in the Agra Airshed (December)

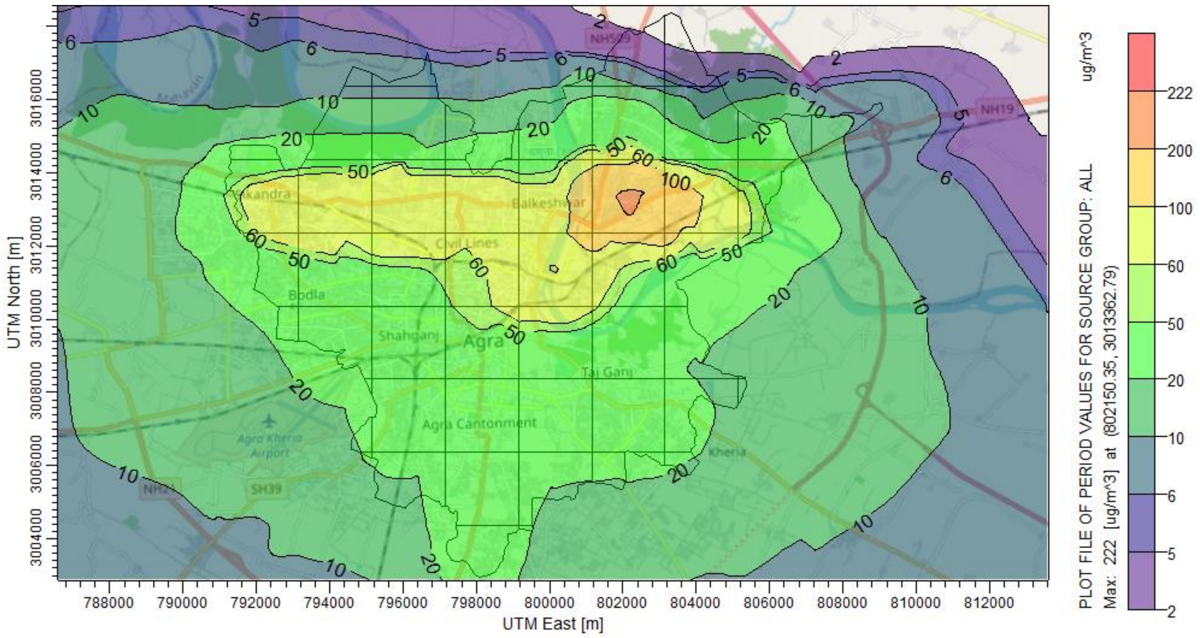


Figure 147: Contour Plot for Average Monthly $PM_{2.5}$ Concentration in the Agra City (December)

Table 53: Monthly Average $PM_{2.5}$ Concentration (μg/m^3) in the Agra City (December)

	Region 1	Region 2	Region 3	Region 4	Region 5
Construction	0.58	0.43	0.52	0.28	0.31

Domestic	2.09	2.64	0.96	2.72	1.66
Hotel	1.09	1.27	0.31	1.77	2.46
Industry	1.38	5.81	6.71	1.06	1.93
MSW	0.79	0.92	0.33	1.12	0.59
Road Dust	23.07	30.49	28.74	13.15	12.38
Vehicle	3.99	4.66	2.84	4.04	2.88
Others	0.07	0.07	0.03	0.07	0.06
All Sources	**33.23**	**46.41**	**40.49**	**24.34**	**22.41**

Summary

The top contributors of $PM_{2.5}$ were road dust (64%), industries (14%), MSW burning (5.9%), and vehicular emissions (6%) followed by hotels (5%), domestic sources (2.7%), constructions (1.4%), hospital areas (0.18%), DG sets (0.12%), and open areas sources (0.03%). The maximum of the highest 24-hr average $PM_{2.5}$ concentration was observed in December (437µg/m^3) and the minimum was observed in May (212µg/m^3). The maximum monthly average $PM_{2.5}$ concentration was observed in November (226 µg/m^3) and the minimum was observed in June (110 µg/m^3) (Figure 148). The highest annual average value was observed to be 167 µg/m^3.

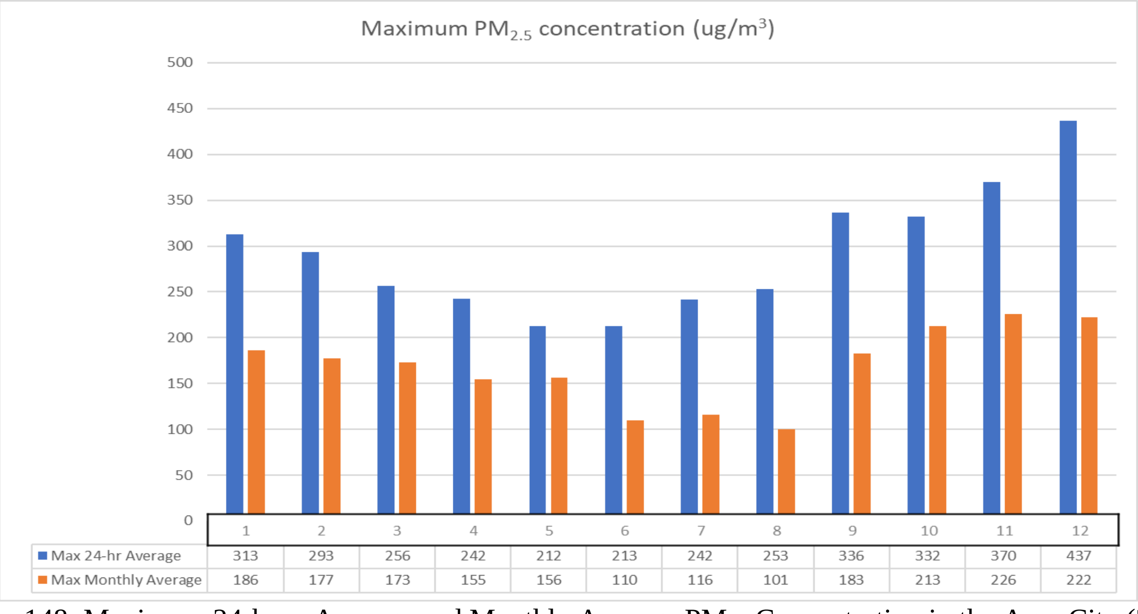


Figure 148: Maximum 24-hour Average and Monthly Average $PM_{2.5}$ Concentration in the Agra City (2018)

It was observed that the $PM_{2.5}$ concentration in the ambient air increases as the winter season approaches. During peak summer and monsoon seasons, the $PM_{2.5}$ concentration was minimum and increased steadily with the fall in temperature, which promoted stable atmospheric conditions and reduced dispersion of pollutants. From the annual average plot, the envelope of $PM_{2.5}$ concentration was seen to be elongated along the prevailing wind direction (N-E) (Figure 149). Within the Agra City, the standard annual average $PM_{2.5}$ concentration (40) is exceeded mostly in the area surrounding the National Highway 19 (NH-19) (Figure 150).

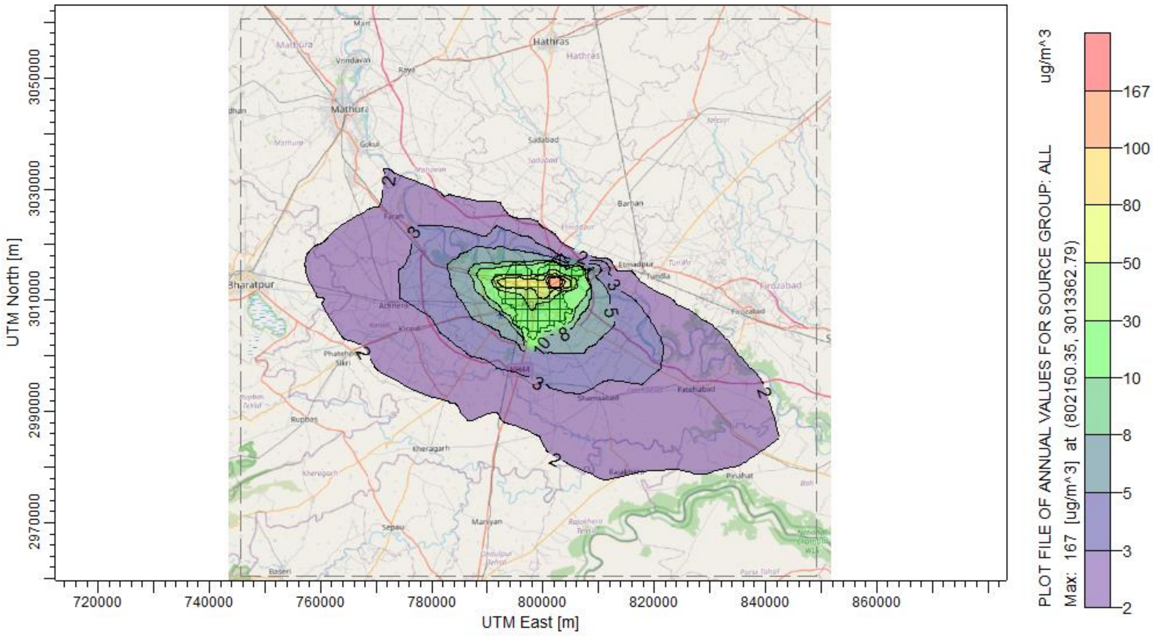


Figure 149: Contour Plot of Annual Average $PM_{2.5}$ Concentration in the Agra Airshed (2018)

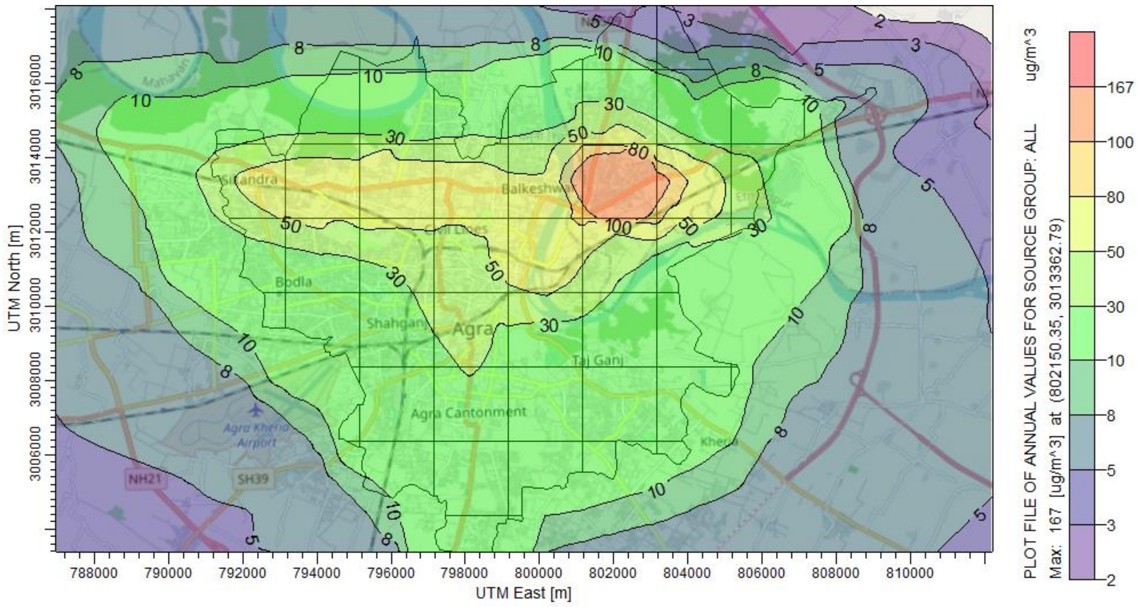


Figure 150: Contour Pplot of Annual Average $PM_{2.5}$ Concentration in the Agra City (2018)

4.8 Source-wise impact assessment in Agra Region (Package 6)

The highest 24-hour average, monthly average and annual average $PM_{2.5}$ concentration plots for various sources in the Agra City are given below (Figure 151 to Figure 180):

Construction and Demolition

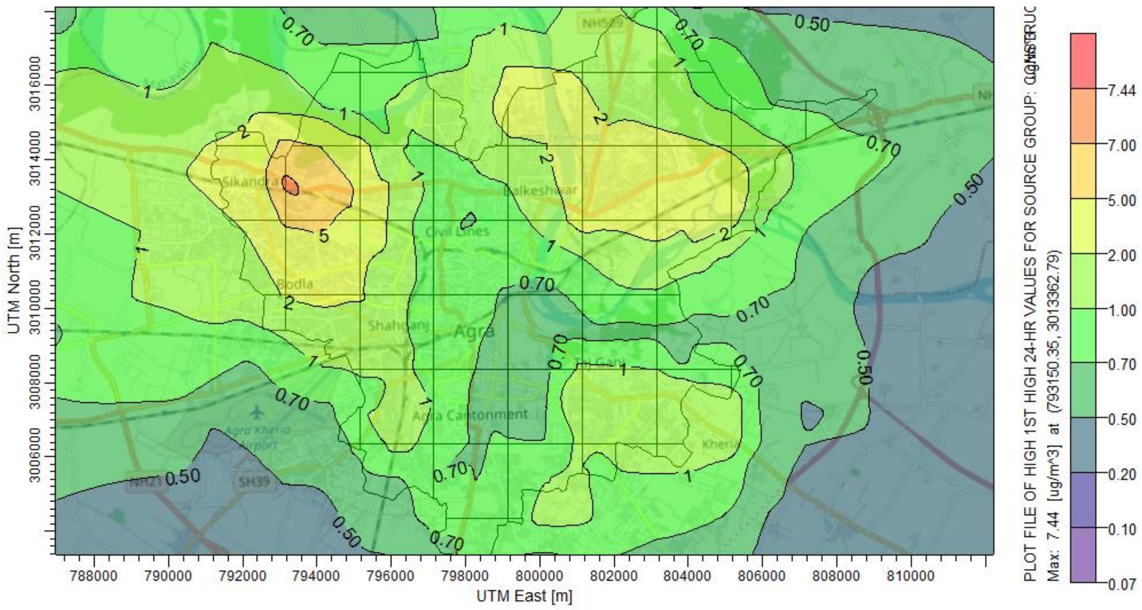


Figure 151: Contour Plot for Highest 24-hour Average $PM_{2.5}$ Concentration from Construction and Demolition in the Agra City

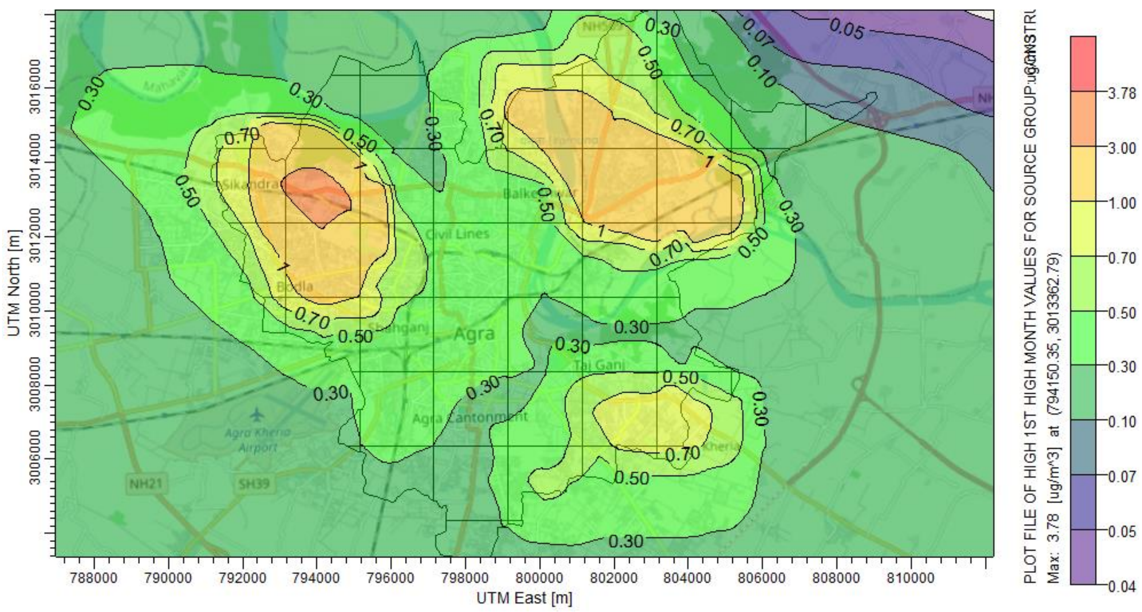


Figure 152: Contour Plot for Highest Monthly Average $PM_{2.5}$ Concentration from Construction and Demolition in the Agra City

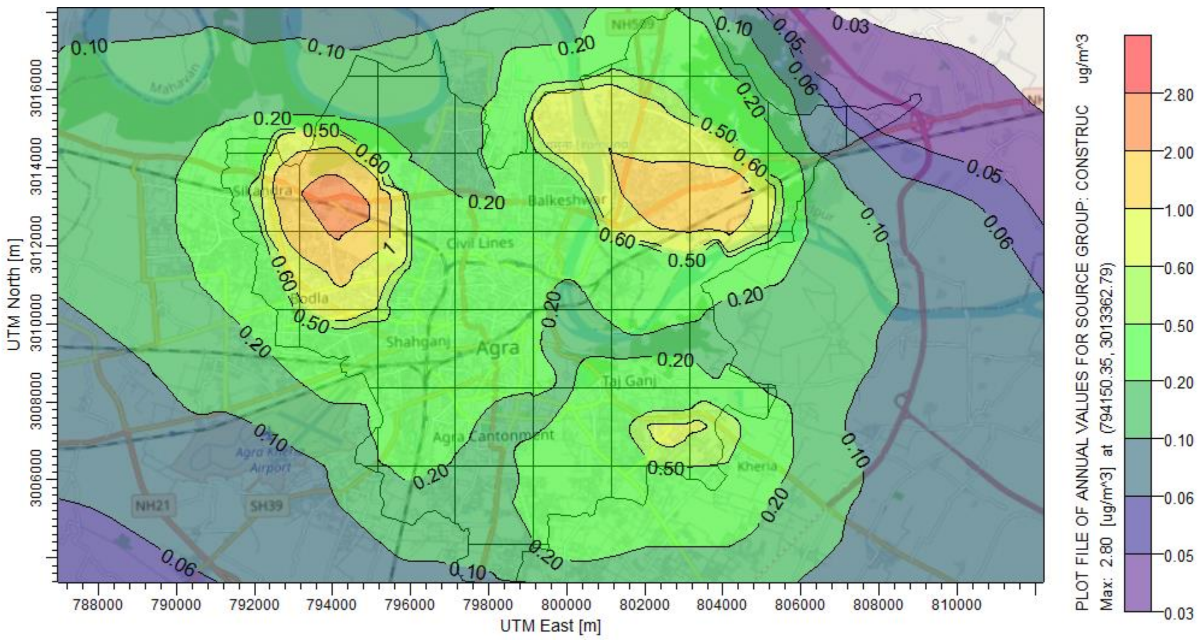


Figure 153: Contour Plot for Annual Average $PM_{2.5}$ Concentration from Construction and Demolition in the Agra City

Diesel Generator Sets (DG sets)

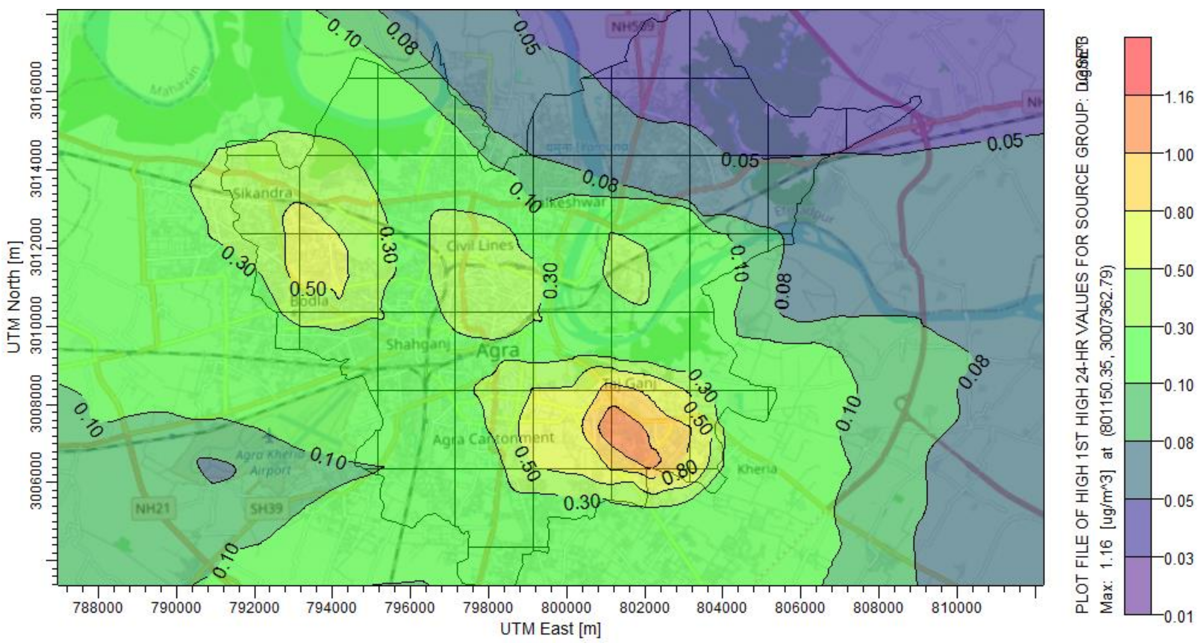


Figure 154: Contour Plot for Highest 24-hour Average $PM_{2.5}$ Concentration from DG Sets in the Agra City

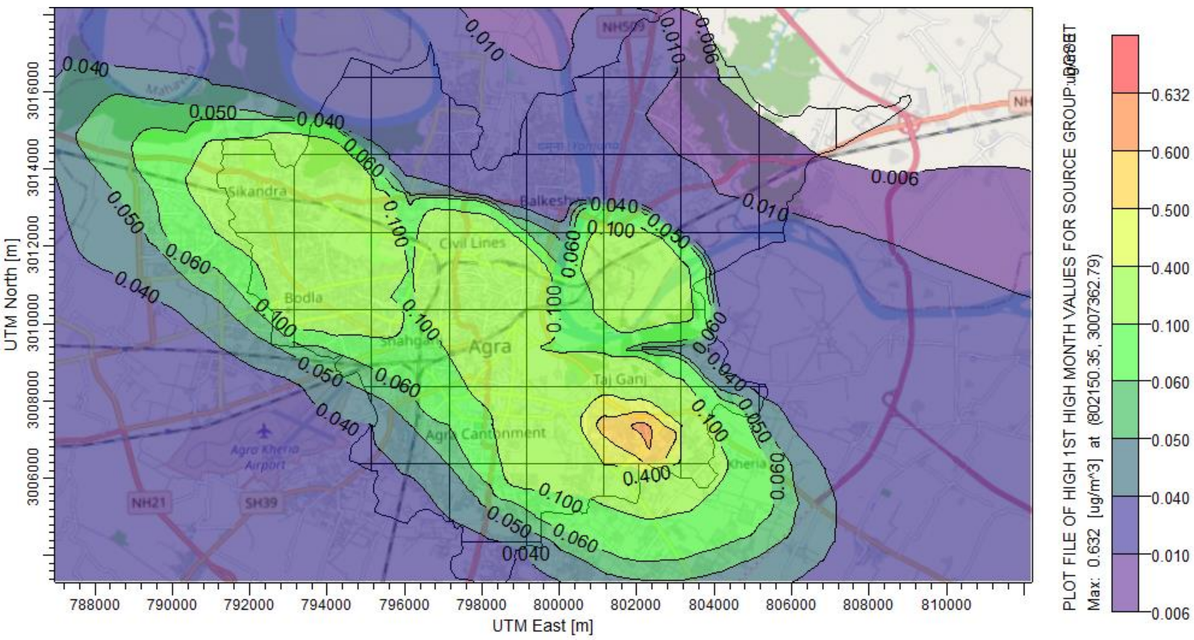


Figure 155: Contour Plot for Highest Monthly Average $PM_{2.5}$ Concentration from DG Sets in the Agra City

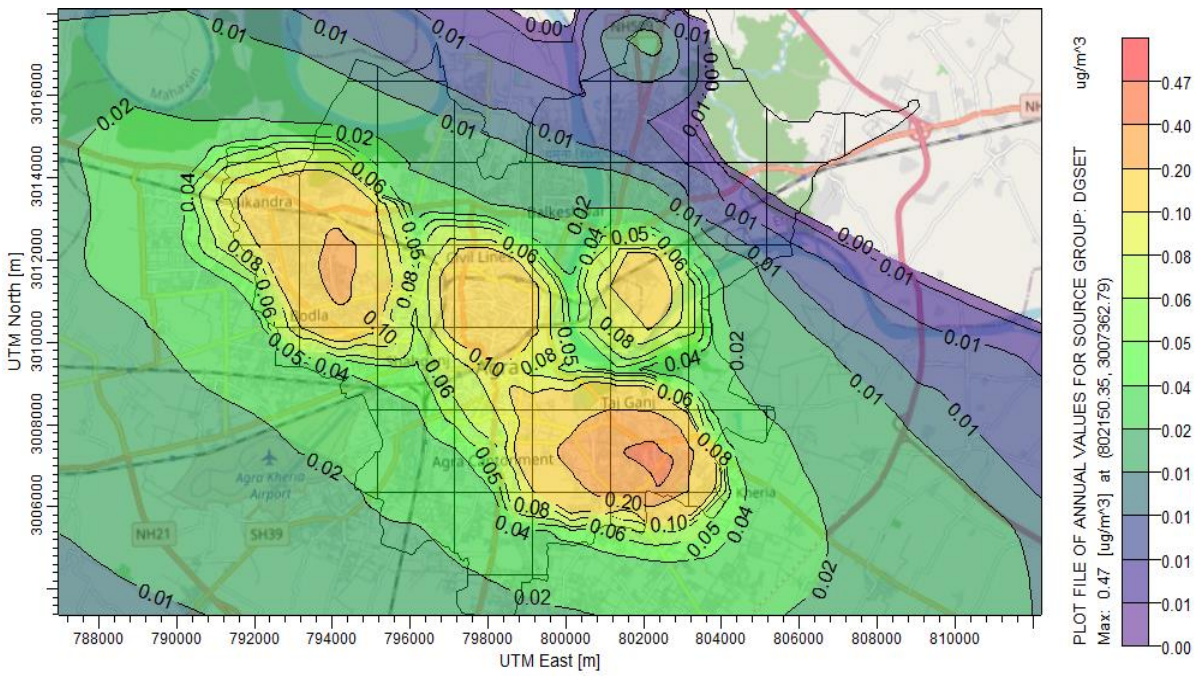


Figure 156: Contour Plot for Annual Average $PM_{2.5}$ Concentration from DG Sets in the Agra City

Domestic

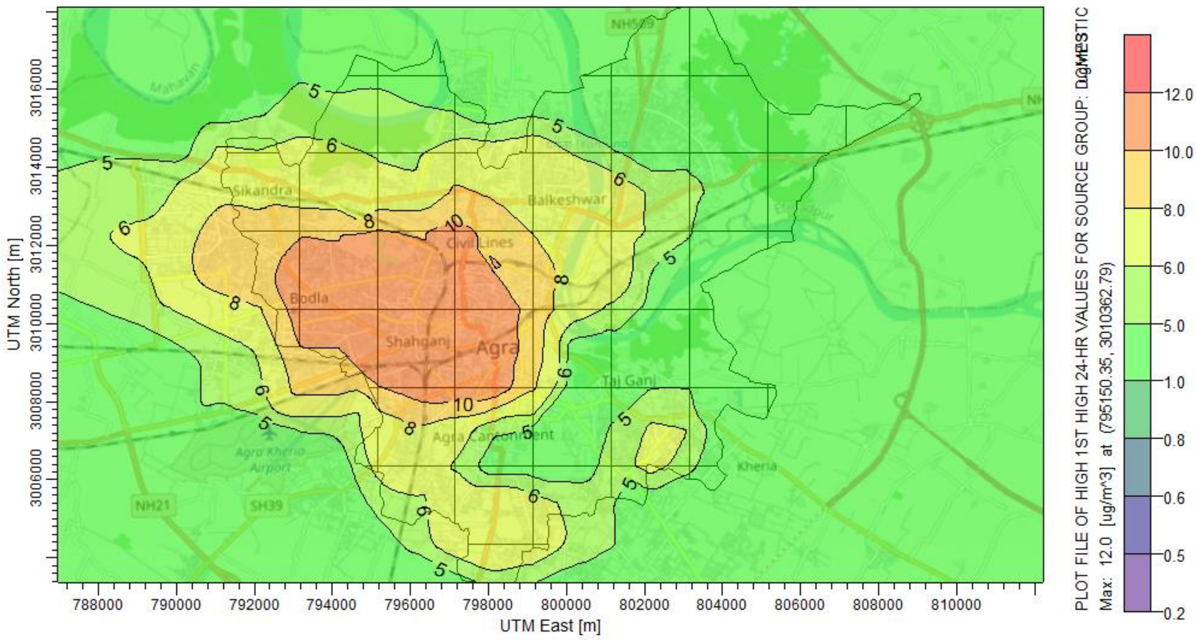


Figure 157: Contour Plot for Highest 24-hour Average $PM_{2.5}$ Concentration from Domestic Sources in the Agra City

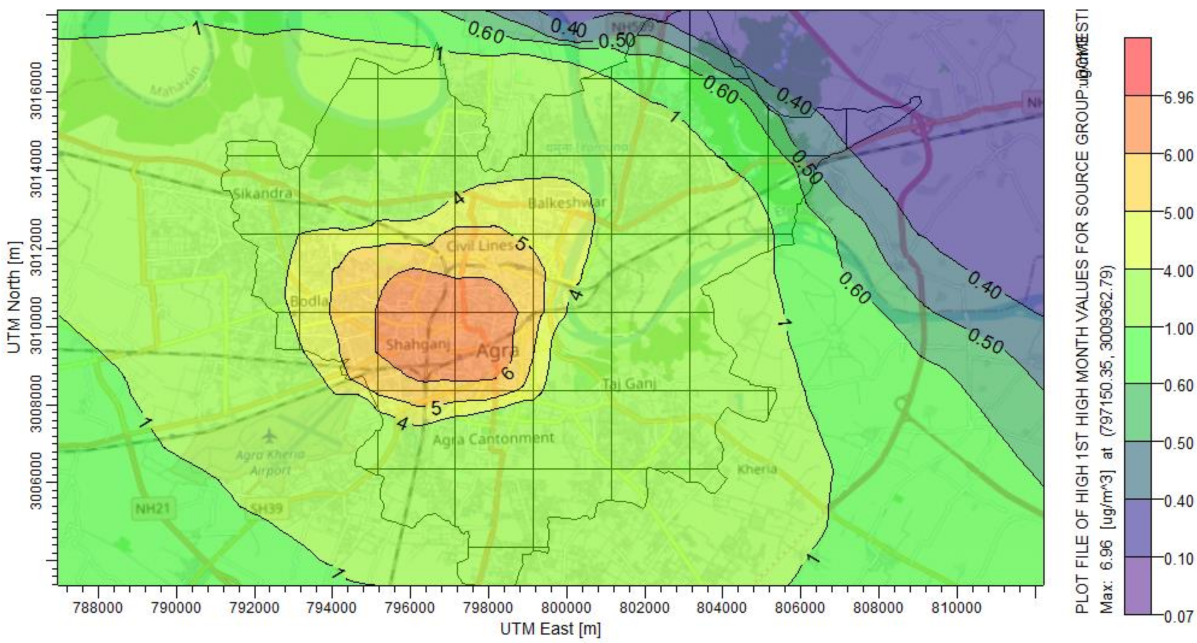


Figure 158: Contour Plot for Highest Monthly Average $PM_{2.5}$ Concentration from Domestic Sources in the Agra City

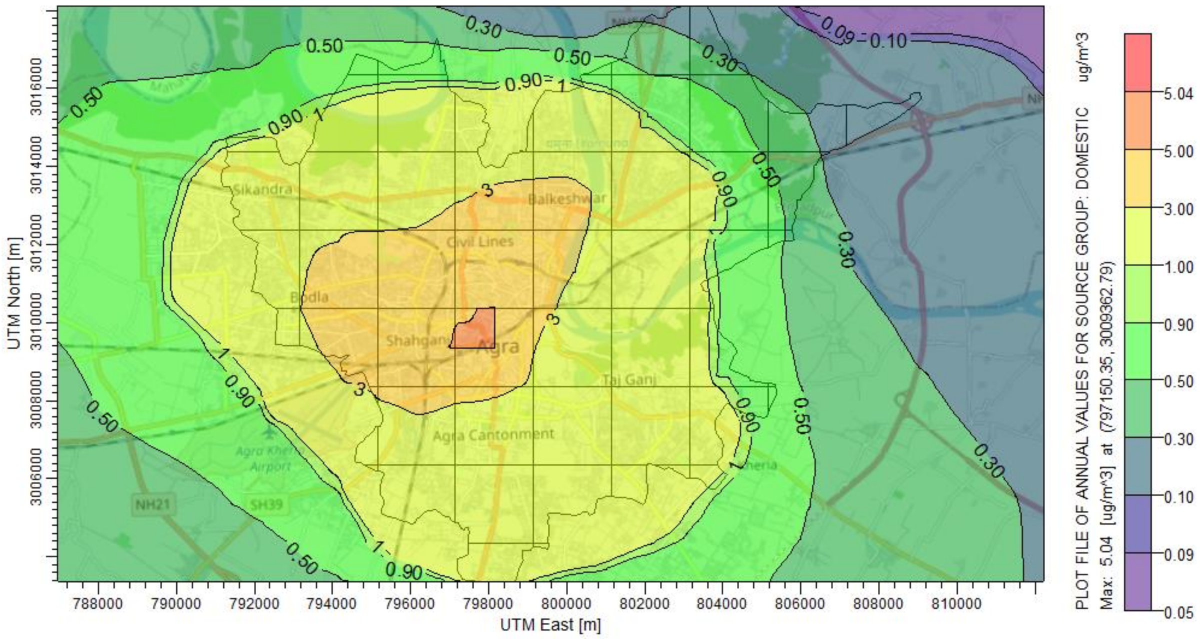


Figure 159: Contour Plot for Annual Average $PM_{2.5}$ Concentration from Domestic Sources in the Agra City

Hospital

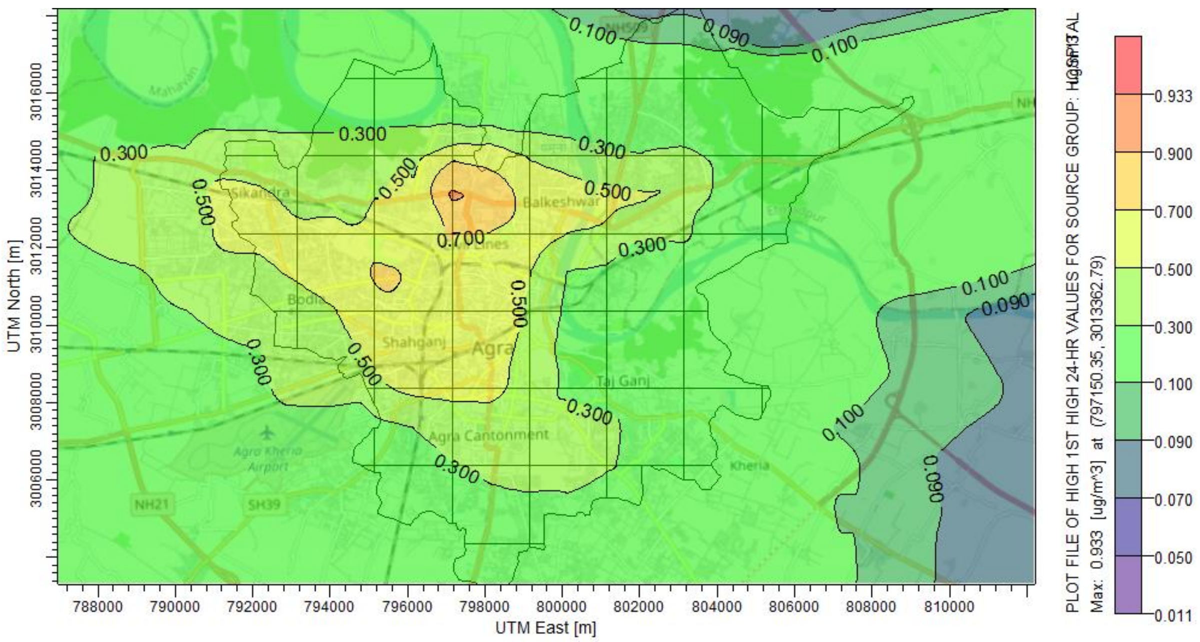


Figure 160: Contour Plot for Highest 24-hour Average $PM_{2.5}$ Concentration from Hospital Areas in the Agra City

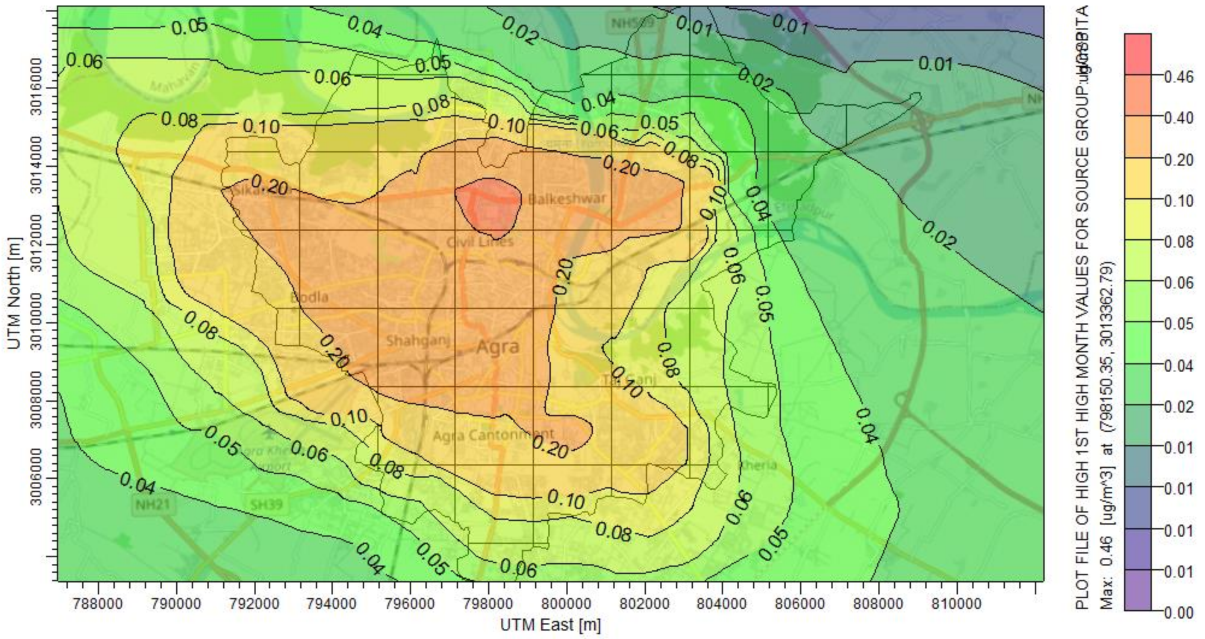


Figure 161: Contour Plot for Highest Monthly Average $PM_{2.5}$ Concentration from Hospital Areas in the Agra City

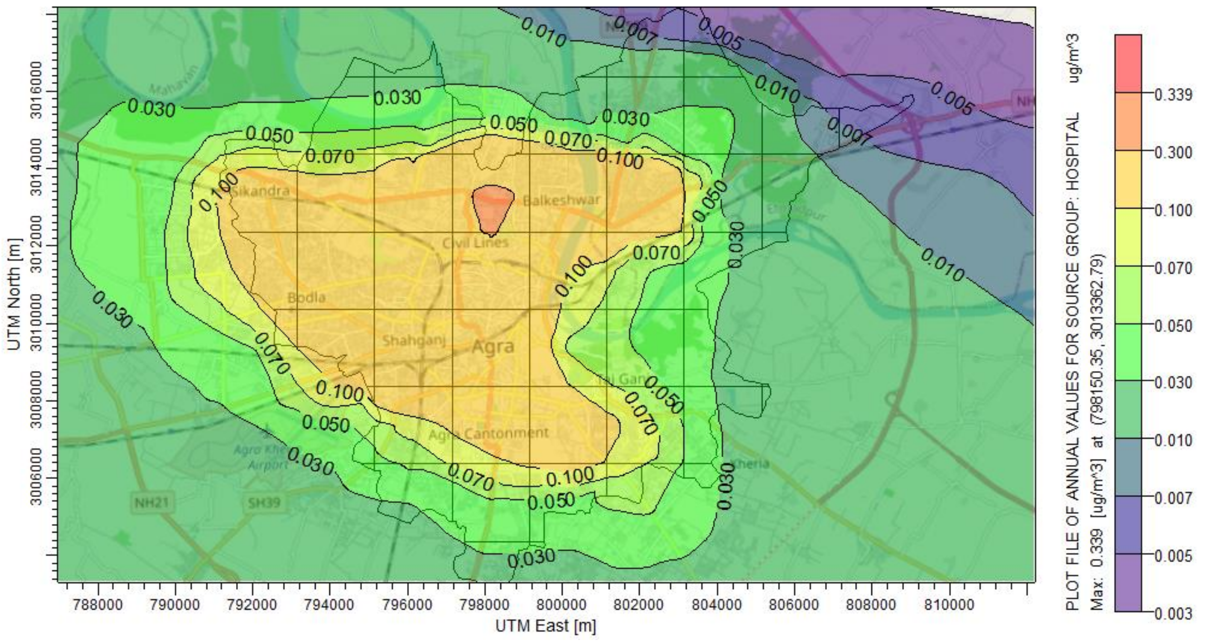


Figure 162: Contour Plot for Annual Average $PM_{2.5}$ Concentration from Hospital Areas in the Agra City

Hotels

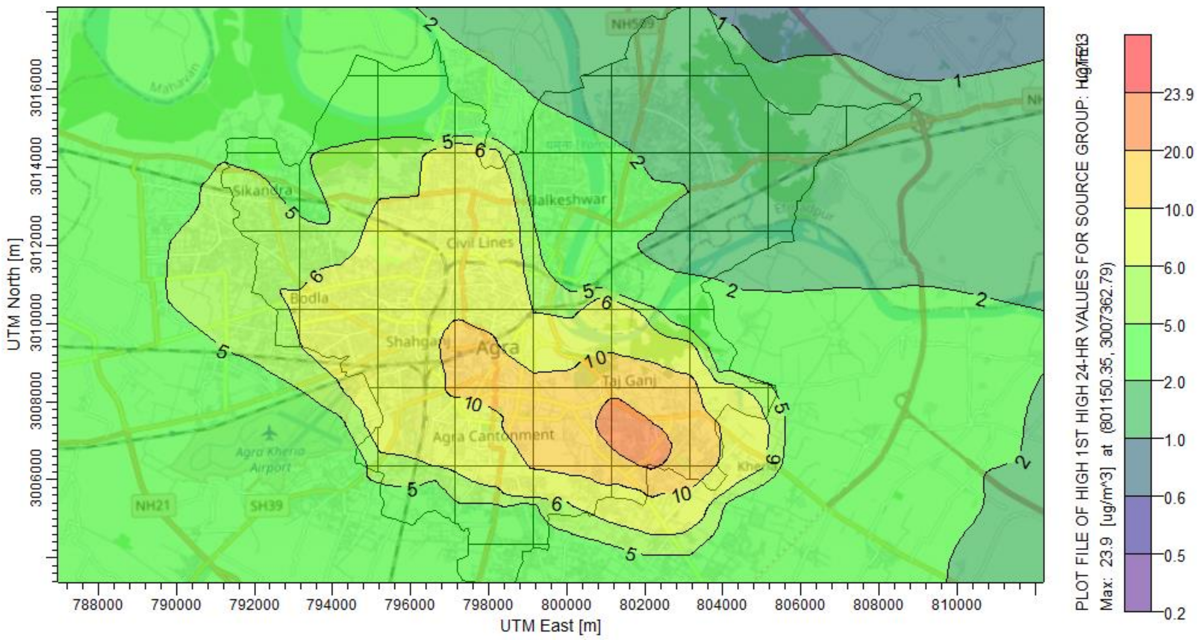


Figure 163: Contour Plot for Highest 24-hour Average $PM_{2.5}$ Concentration from Hotels in the Agra City

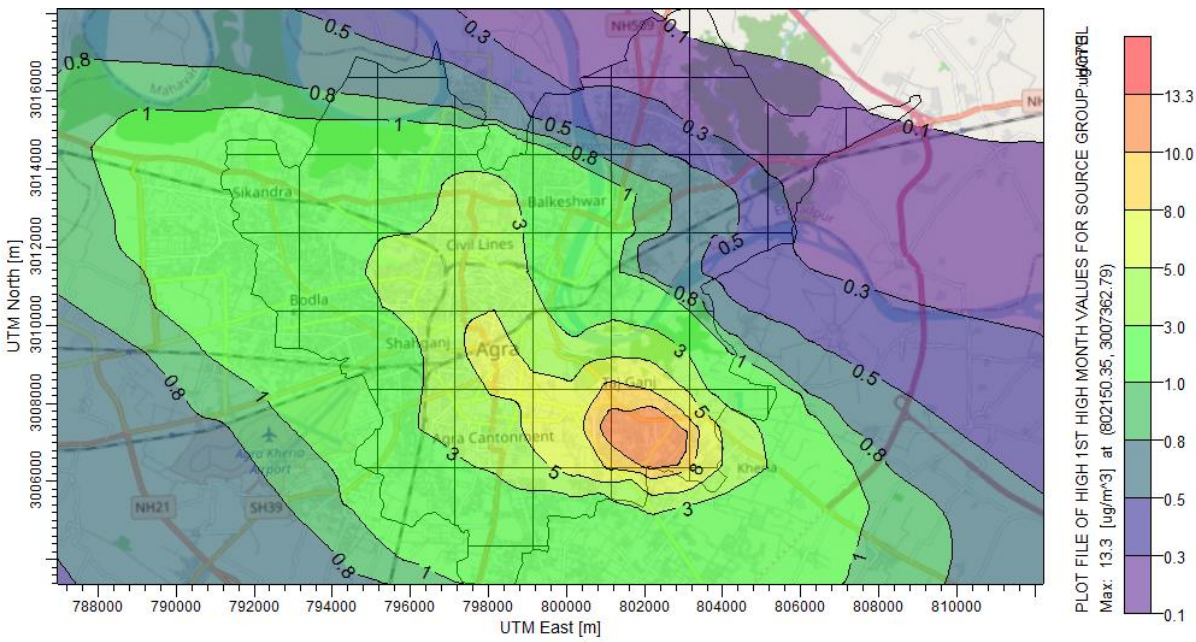


Figure 164: Contour Plot for Highest Monthly Average $PM_{2.5}$ Concentration from Hotels in the Agra City

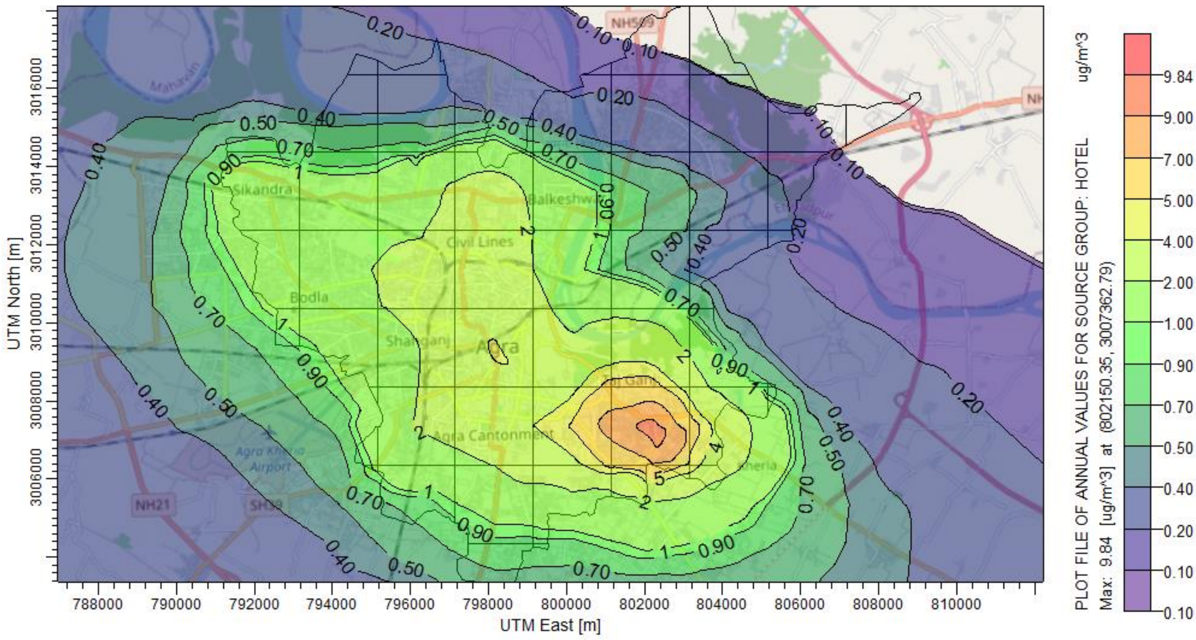


Figure 165: Contour Plot for Annual Average $PM_{2.5}$ Concentration from Hotels in the Agra City

Industry

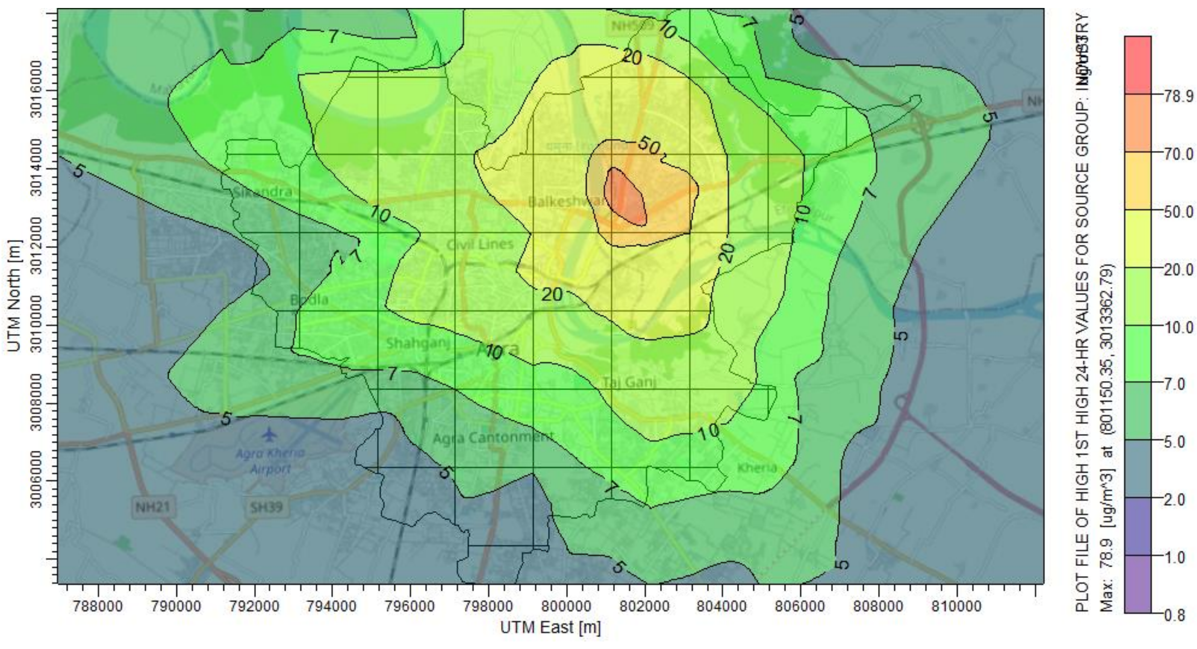


Figure 166: Contour Plot for Highest 24-hour Average $PM_{2.5}$ Concentration from Industries in the Agra City

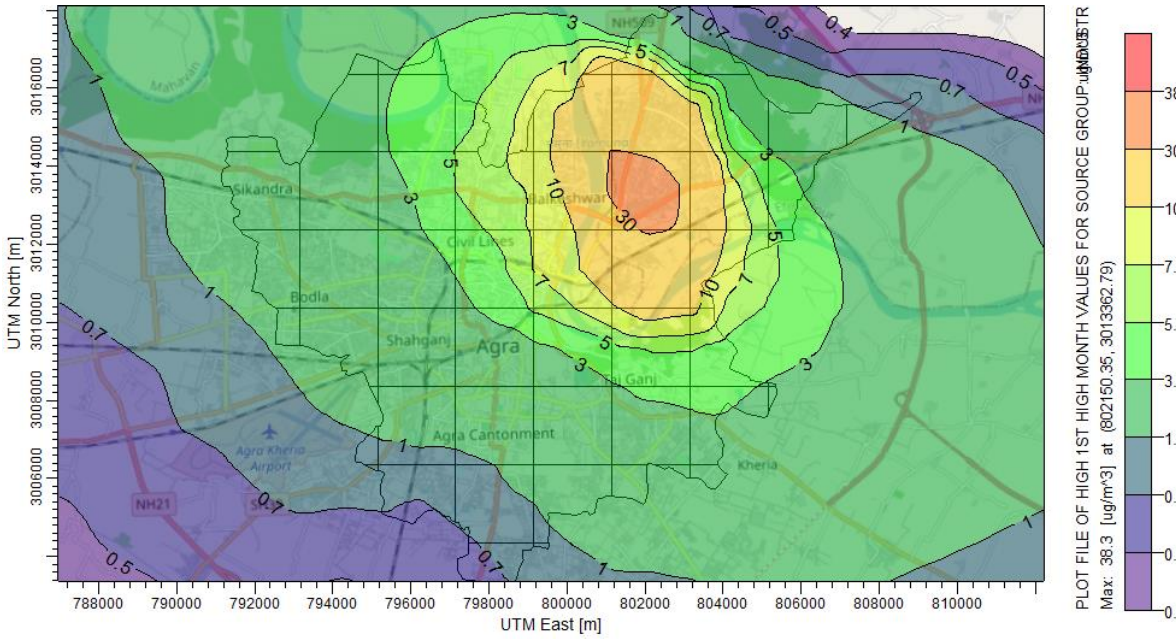


Figure 167: Contour Plot for Highest Monthly Average $PM_{2.5}$ Concentration from Industries in the Agra City

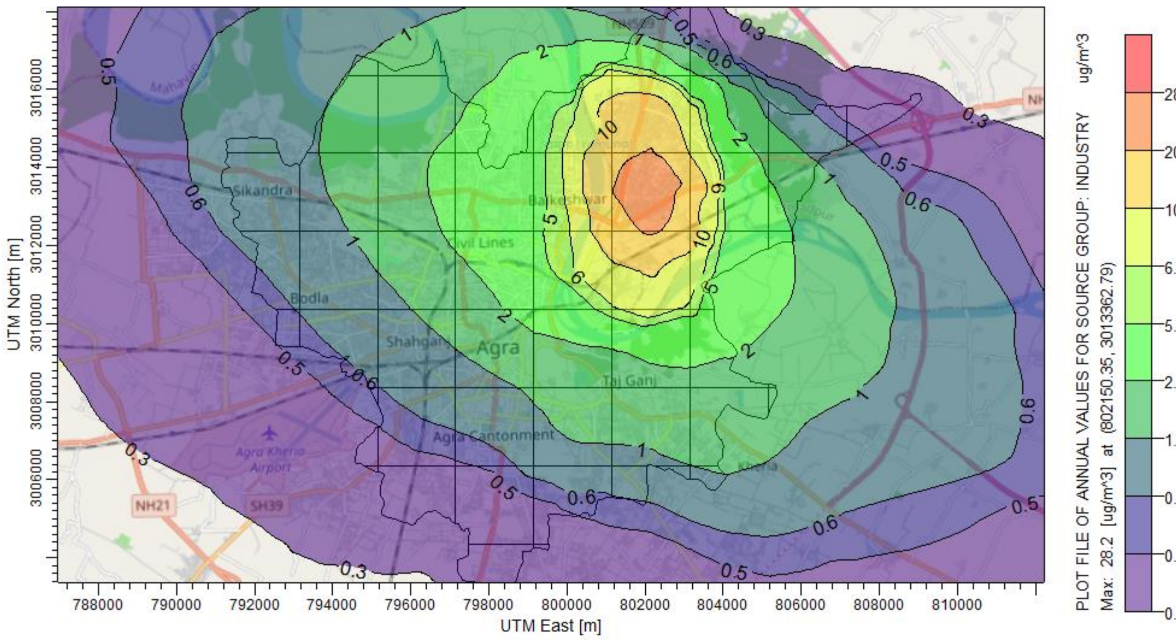


Figure 168: Contour Plot for Annual Average $PM_{2.5}$ Concentration from Industries in the Agra City

Municipal Solid Waste (MSW)

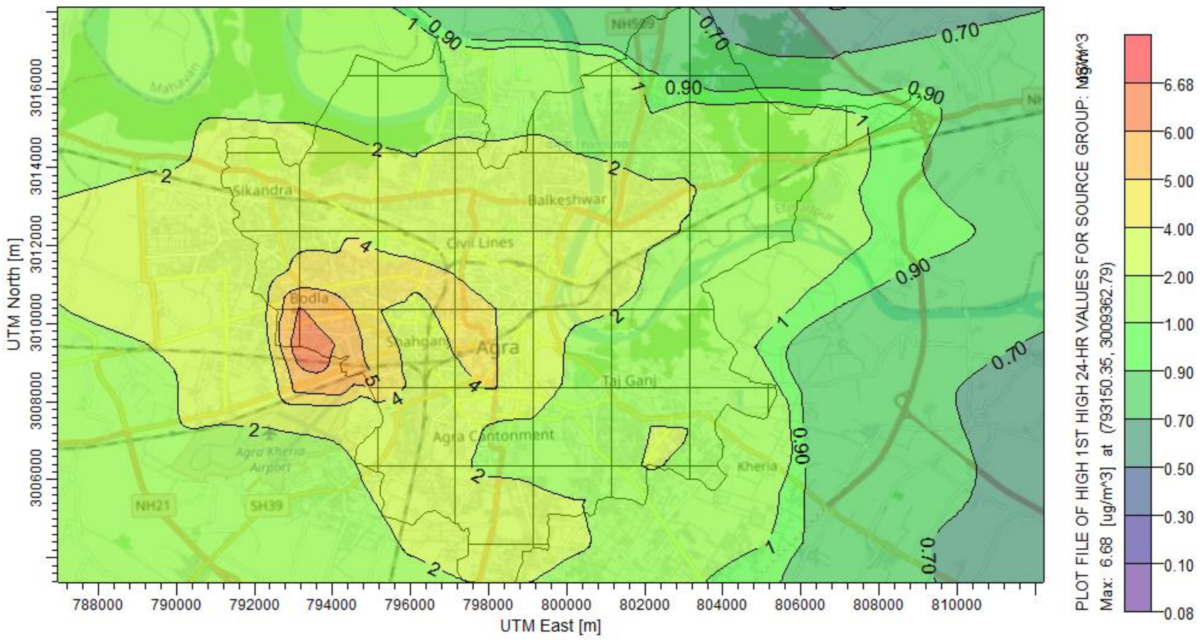


Figure 169: Contour Plot for Highest 24-hour Average $PM_{2.5}$ Concentration from MSW Burning in the Agra City

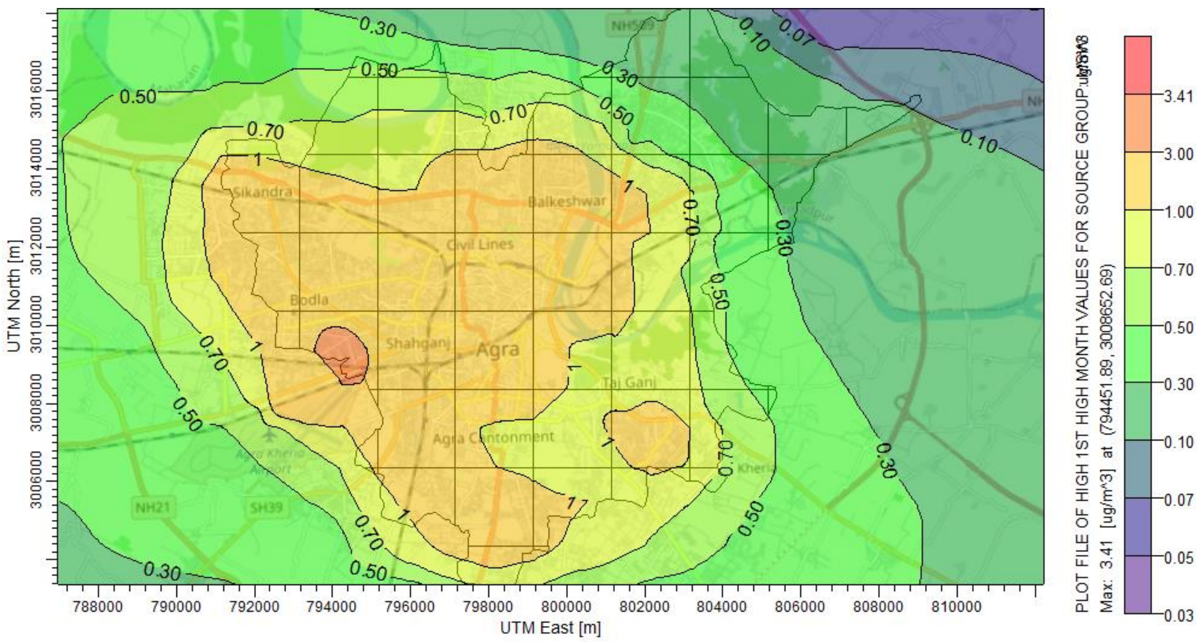


Figure 170: Contour Plot for Highest Monthly Average $PM_{2.5}$ Concentration from MSW Burning in the Agra City

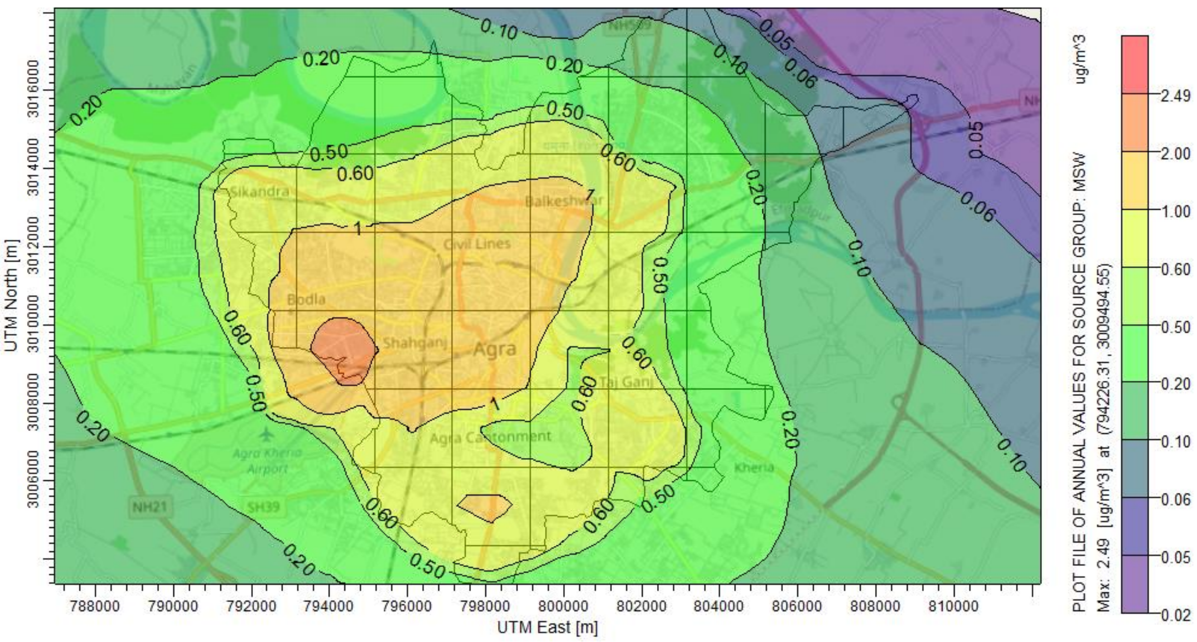


Figure 171: Contour Plot for Annual Aaverage $PM_{2.5}$ Concentration from MSW Burning in the Agra City

Open Area

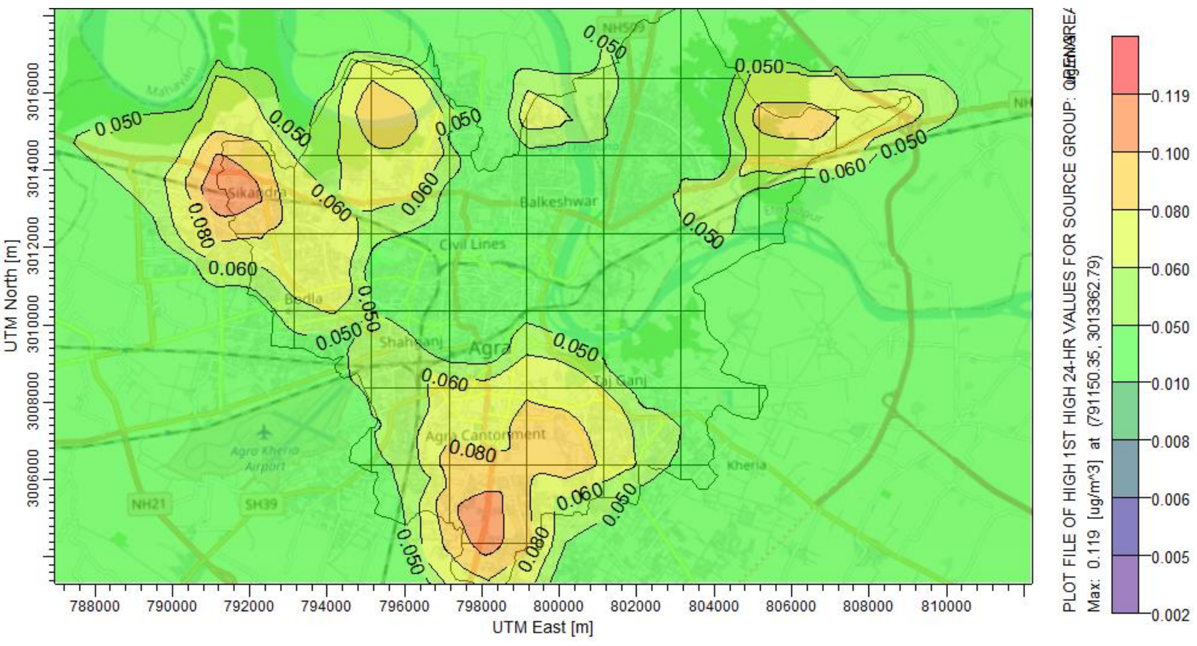


Figure 172: Contour Plot for Highest 24-hour Average $PM_{2.5}$ Concentration from Open Areas in the Agra City

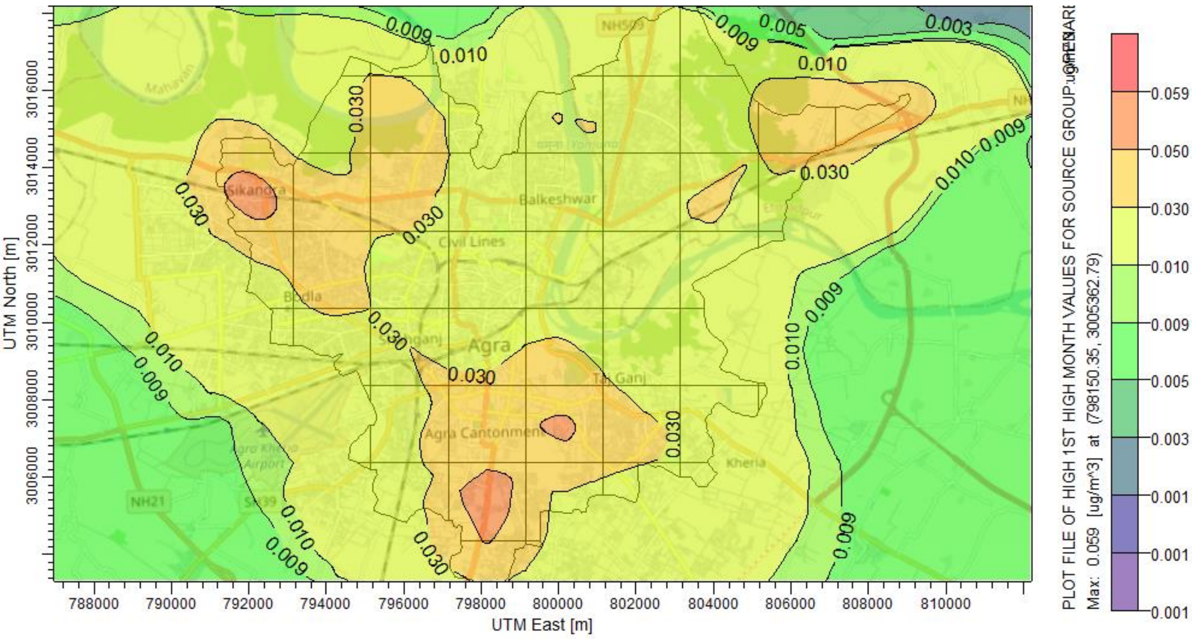


Figure 173: Contour Plot for Highest Monthly Average $PM_{2.5}$ Concentration from Open Areas in the Agra City

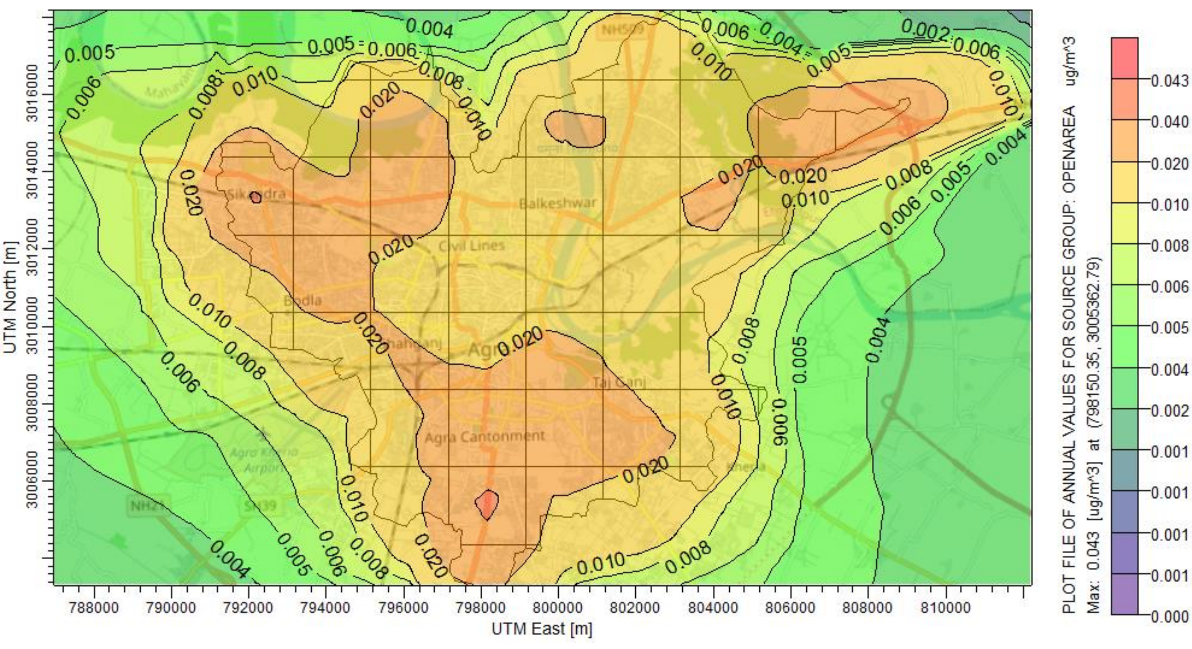


Figure 174: Contour Plot for Annual Average $PM_{2.5}$ Concentration from Open Areas in the Agra City

Road Dust

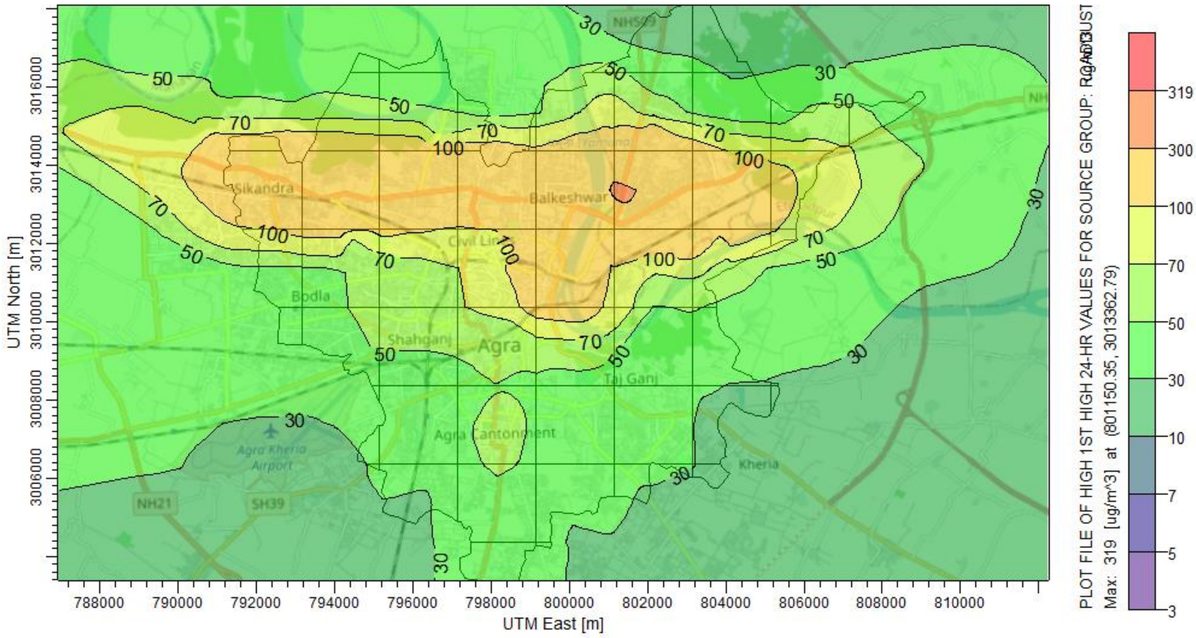


Figure 175: Contour Plot for Highest 24-hour Average $PM_{2.5}$ Concentration from Road Dust in the Agra City

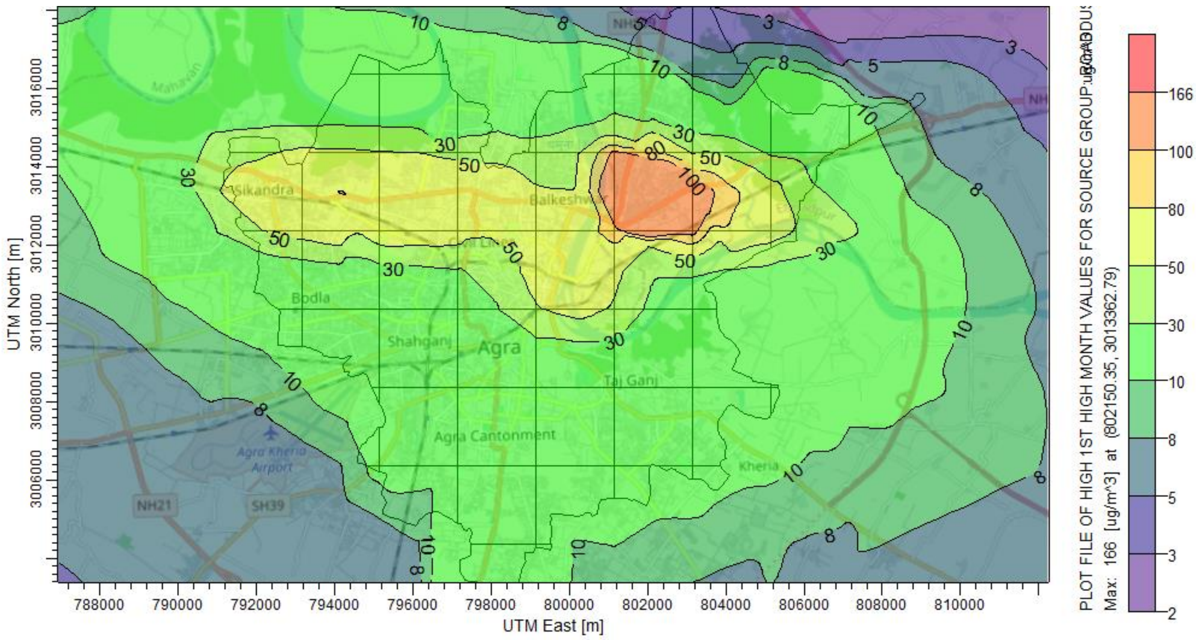


Figure 176: Contour Plot for Highest Monthly Average $PM_{2.5}$ Concentration from Road Dust in the Agra City

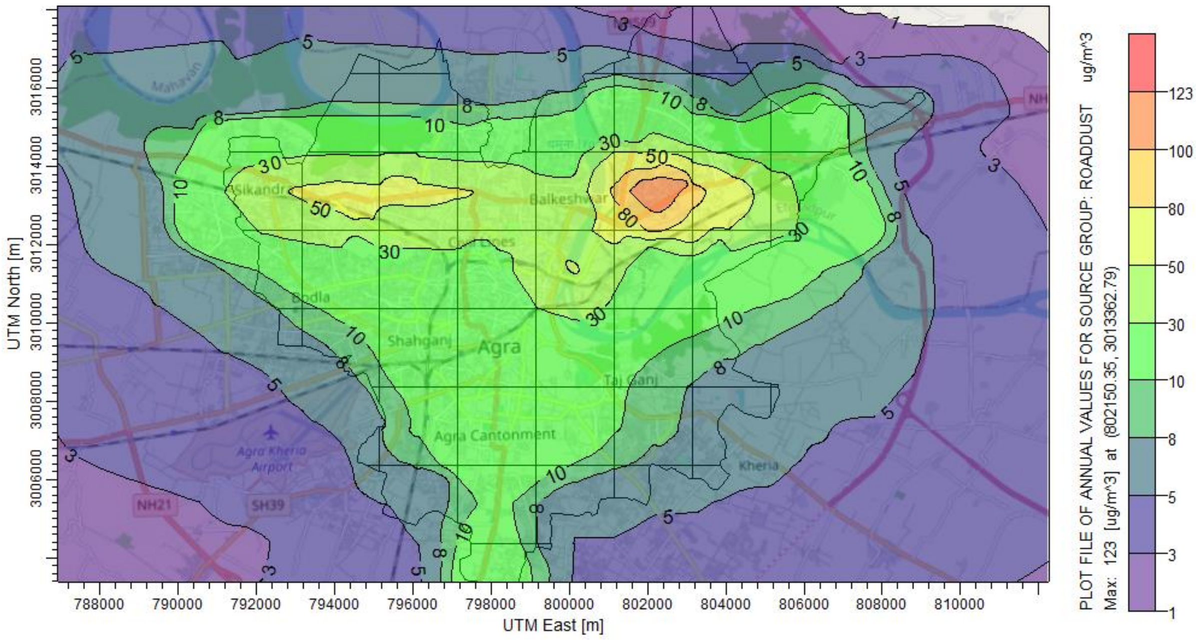


Figure 177: Contour Plot for Annual Average $PM_{2.5}$ Concentration from Road Dust in the Agra City

Vehicles

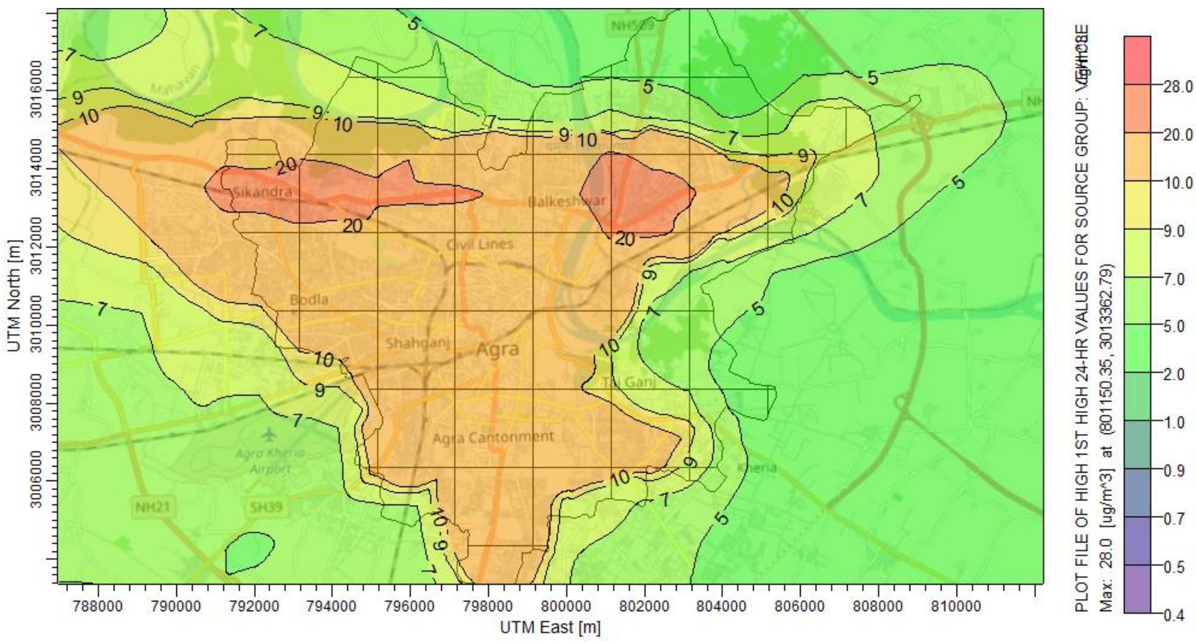


Figure 178: Contour Plot for Highest 24-hour Average $PM_{2.5}$ Concentration from Vehicles in the Agra City

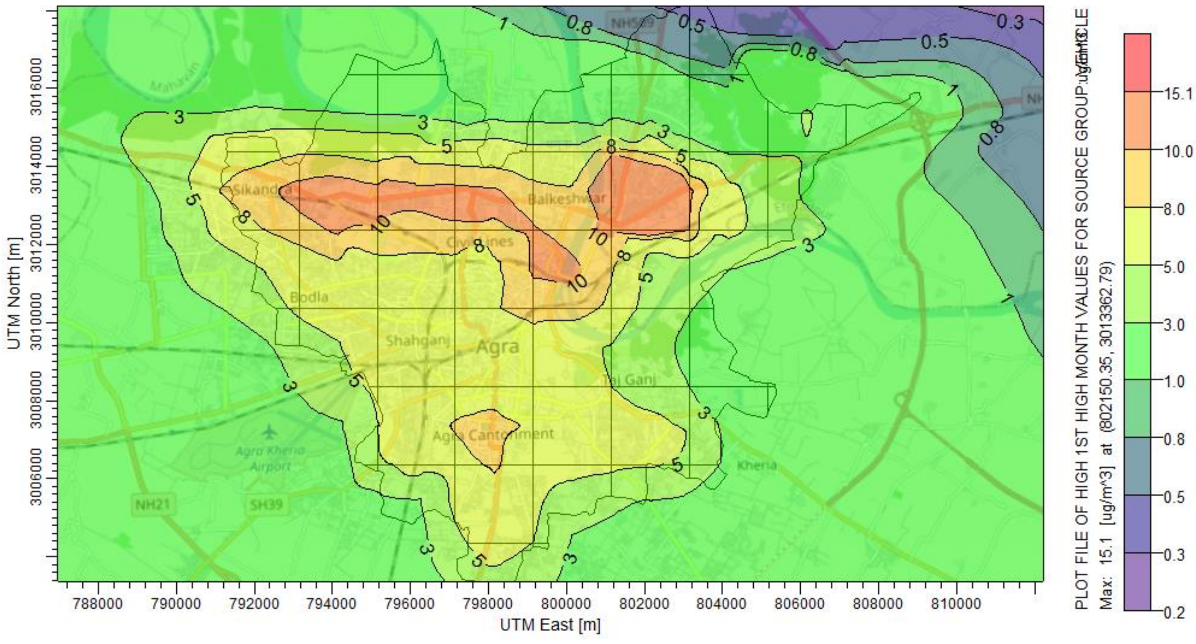


Figure 179: Contour Plot for Highest Monthly Average $PM_{2.5}$ Concentration from Vehicles in the Agra City

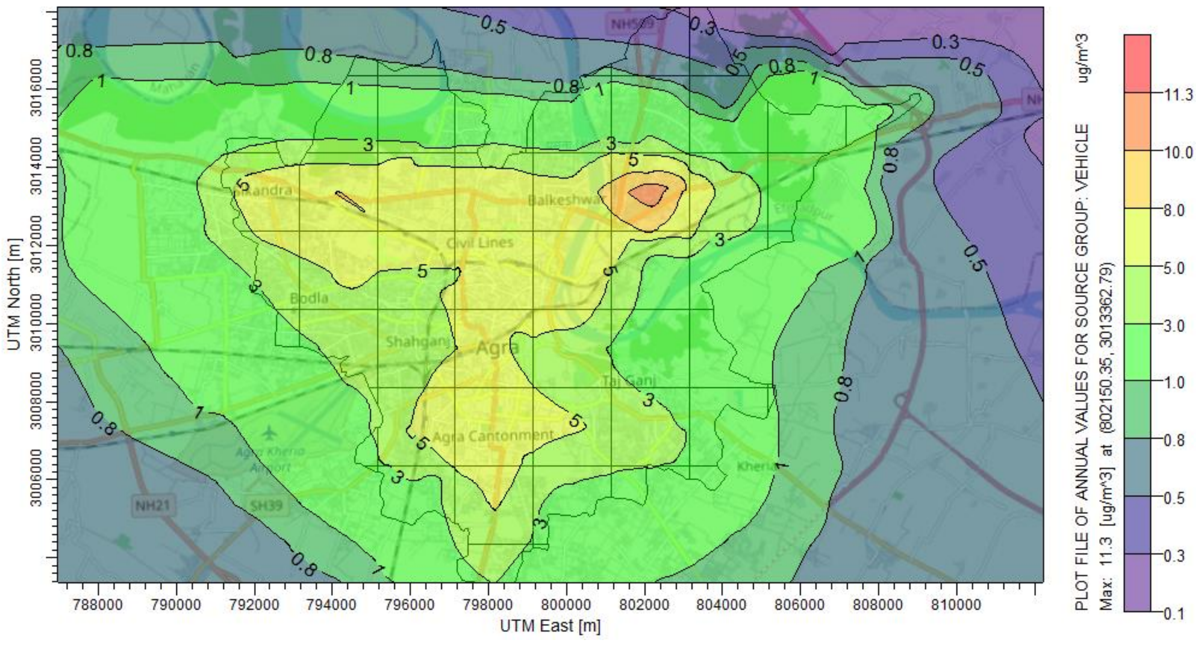


Figure 180: Contour Plot for Annual Average $PM_{2.5}$ Concentration from Vehicles in the Agra City

The combined impact of all the sources

The highest 24-hour average, monthly average, and annual average $PM_{2.5}$ concentration plots for all sources in the Agra City are given in Figure 181, Figure 182 and Figure 183, respectively. The highest values of $PM_{2.5}$ concentration were obtained from road dust, industrial, and vehicular sources. DG sets, hospital areas, and open area sources contributed the least to the $PM_{2.5}$ concentration in the Agra City (Table 54).

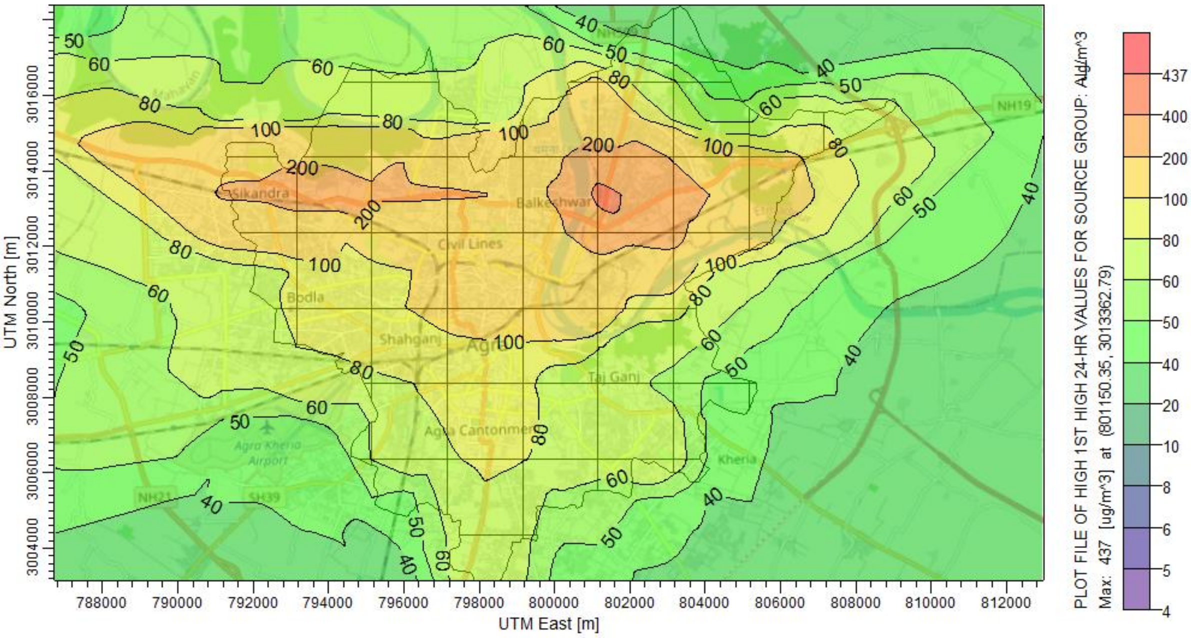


Figure 181: Contour Plot for Highest 24-hour Average $PM_{2.5}$ Concentration in the Agra City (All Sources)

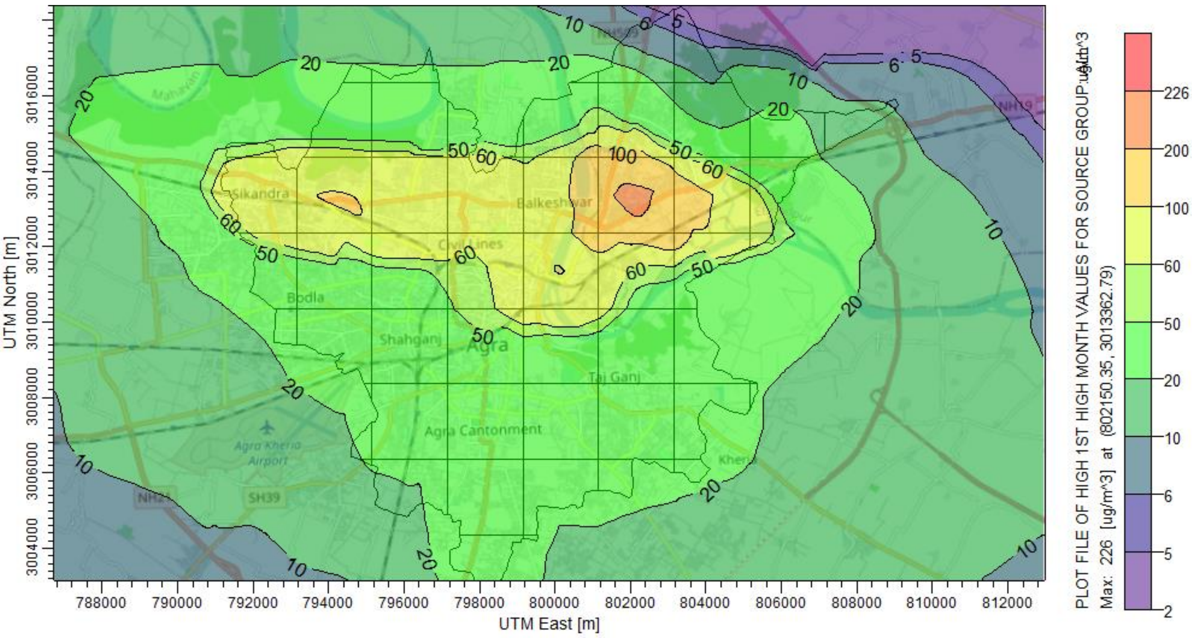


Figure 182: Contour Plot for Highest Monthly Aaverage $PM_{2.5}$ Concentration in the Agra City (All Sources)

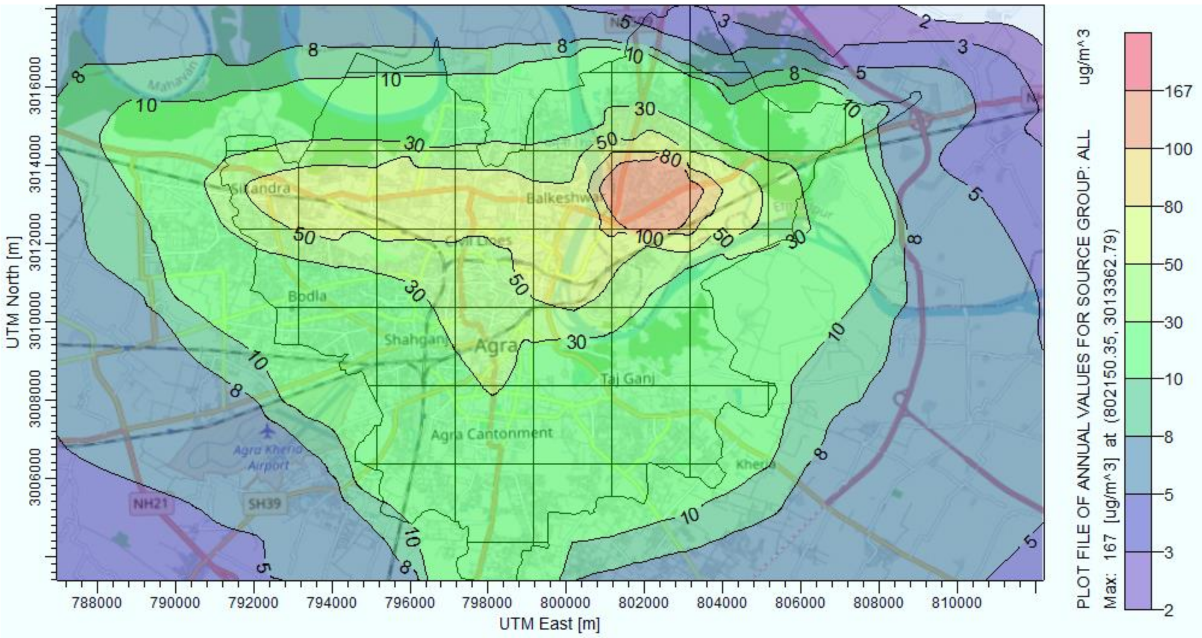


Figure 183: Contour Plot for Annual Average $PM_{2.5}$ Concentration from All Sources in the Agra City

Table 54: Maximum $PM_{2.5}$ Concentration ($\mu g/m^3$) Averaged over different time periods for All Sources

	Max. 24-hr Average	Max. Monthly Average	Max Annual Average
Construction	7.4	3.8	2.8
DG set	1.2	0.6	0.5
Domestic	12.0	7.0	5.0
Hospital	0.9	0.5	0.3
Hotel	23.9	13.3	9.8
Industry	78.9	38.3	28.2
MSW	6.7	3.4	2.5
Open Area	0.1	0.1	0.0
Road dust	319.0	166.0	123.0
Vehicle	28.0	15.1	11.3
All Sources	**437**	**226**	**167**

4.9 Influx of $PM_{2.5}$ into the Agra City from Airshed (Only Industrial Sources)

All the industrial sources were considered to quantify the influx of $PM_{2.5}$ in the Agra City from the airshed. WRF-Chem was run to get the results in the form of contour plots for six months (three months each in the summer and winter seasons).

4.9.1 Summers (March, April, and May 2018)

The mean monthly $PM_{2.5}$ concentration plots from various industrial sources in the airshed for summer season are given in Figure 184 and Figure 185. The mean monthly $PM_{2.5}$ concentration in the Agra City was 3.5 µg/m^3, 2.5 µg/m^3, and 3 µg/m^3 in March, April, and May 2018, respectively.

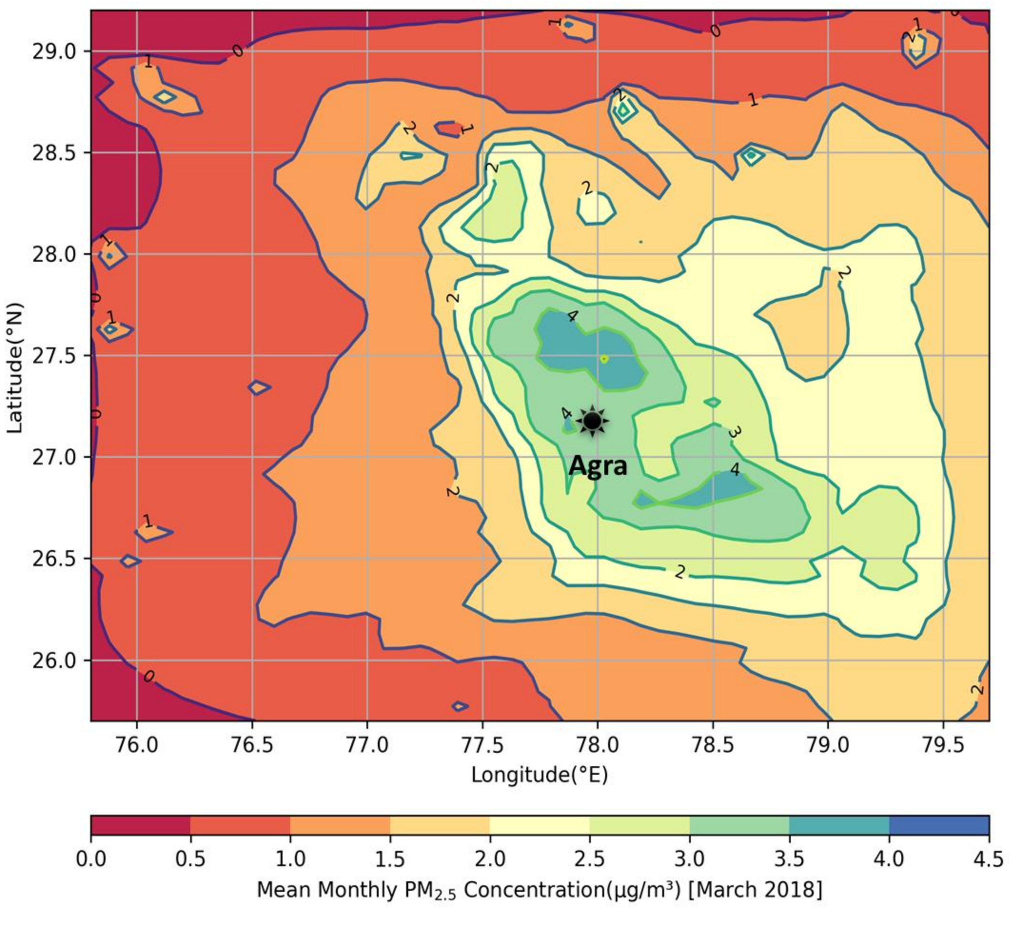


Figure 184: Mean Monthly $PM_{2.5}$ Concentration (ug/m^3) (March 2018)

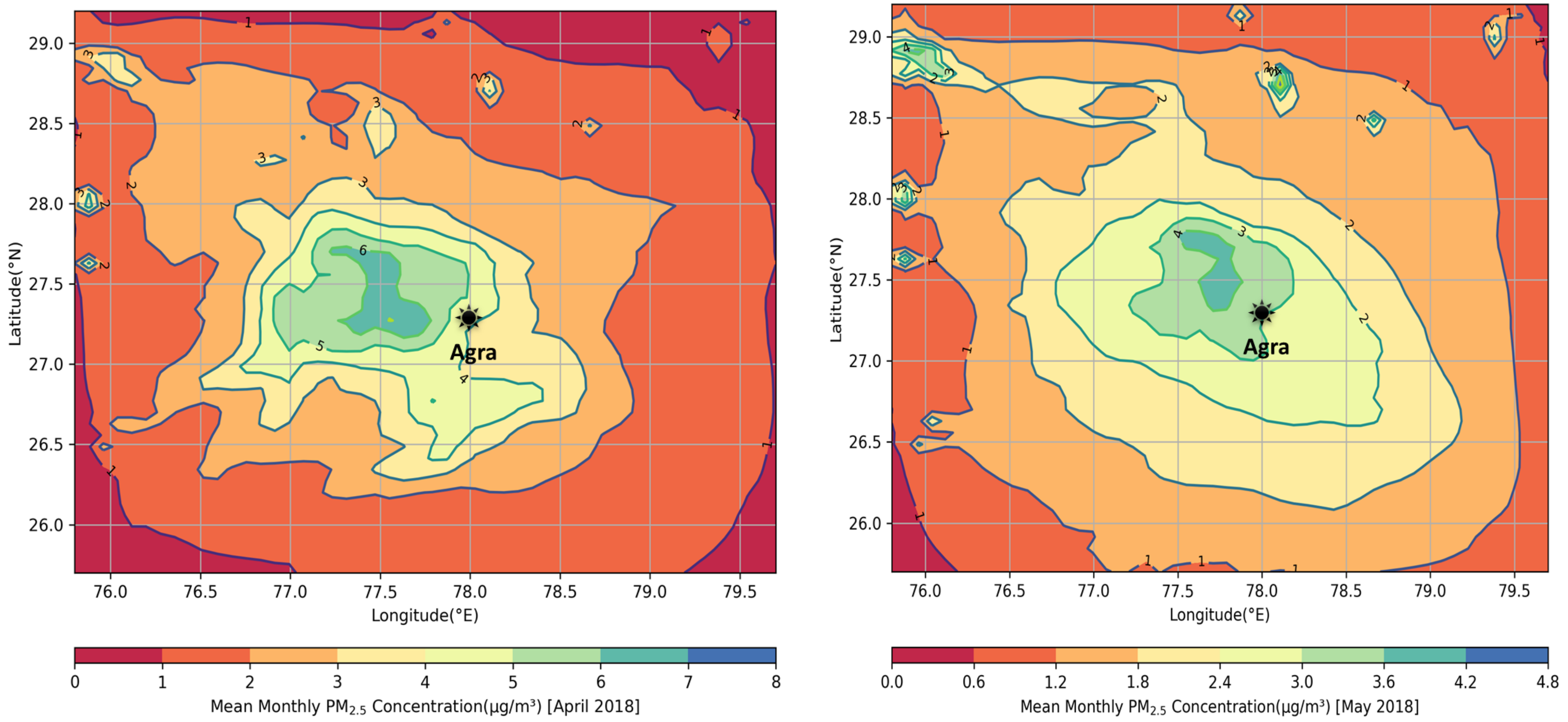


Figure 185: Mean Monthly $PM_{2.5}$ Concentration (ug/m^3) (April and May 2018)

4.9.2 Winters (October, November, and December 2018)

The mean monthly $PM_{2.5}$ concentration plots from various industrial sources in the airshed for the winter season are given in Figure 186 and Figure 187. The mean monthly $PM_{2.5}$ concentration in the Agra City was 3.2 µg/m^3, 4 µg/m^3, and 3.6 µg/m^3 in October, November, and December 2018, respectively.

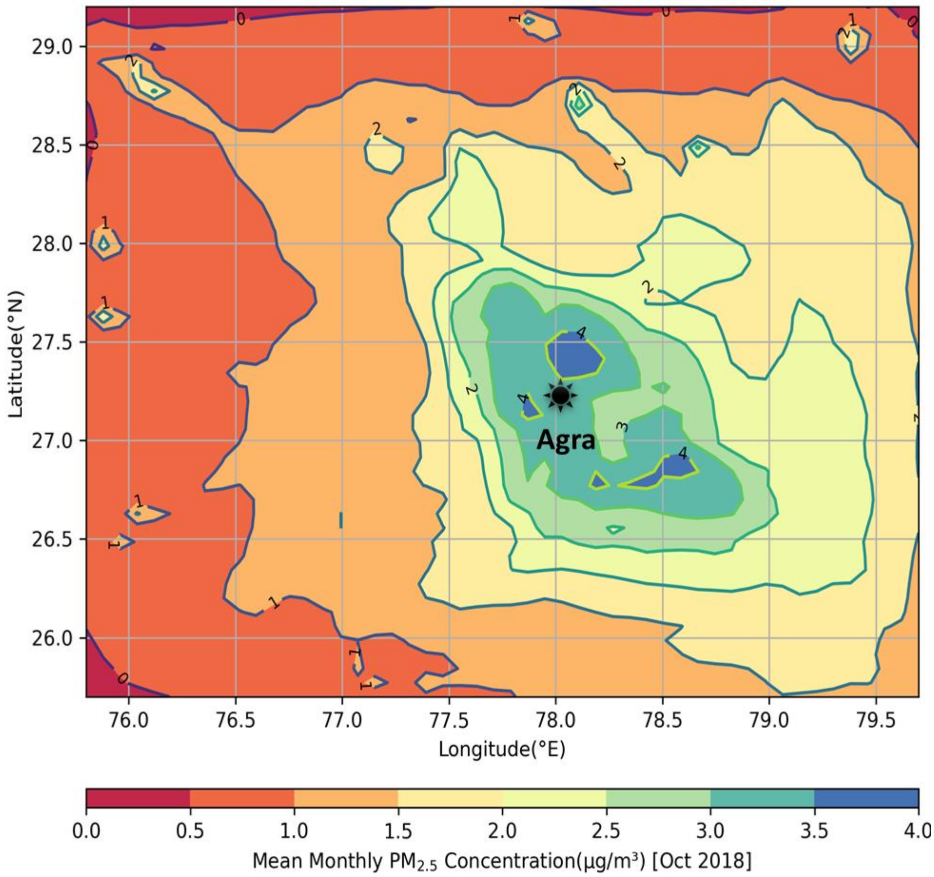


Figure 186: Mean Monthly $PM_{2.5}$ Concentration (ug/m^3) (October 2018)

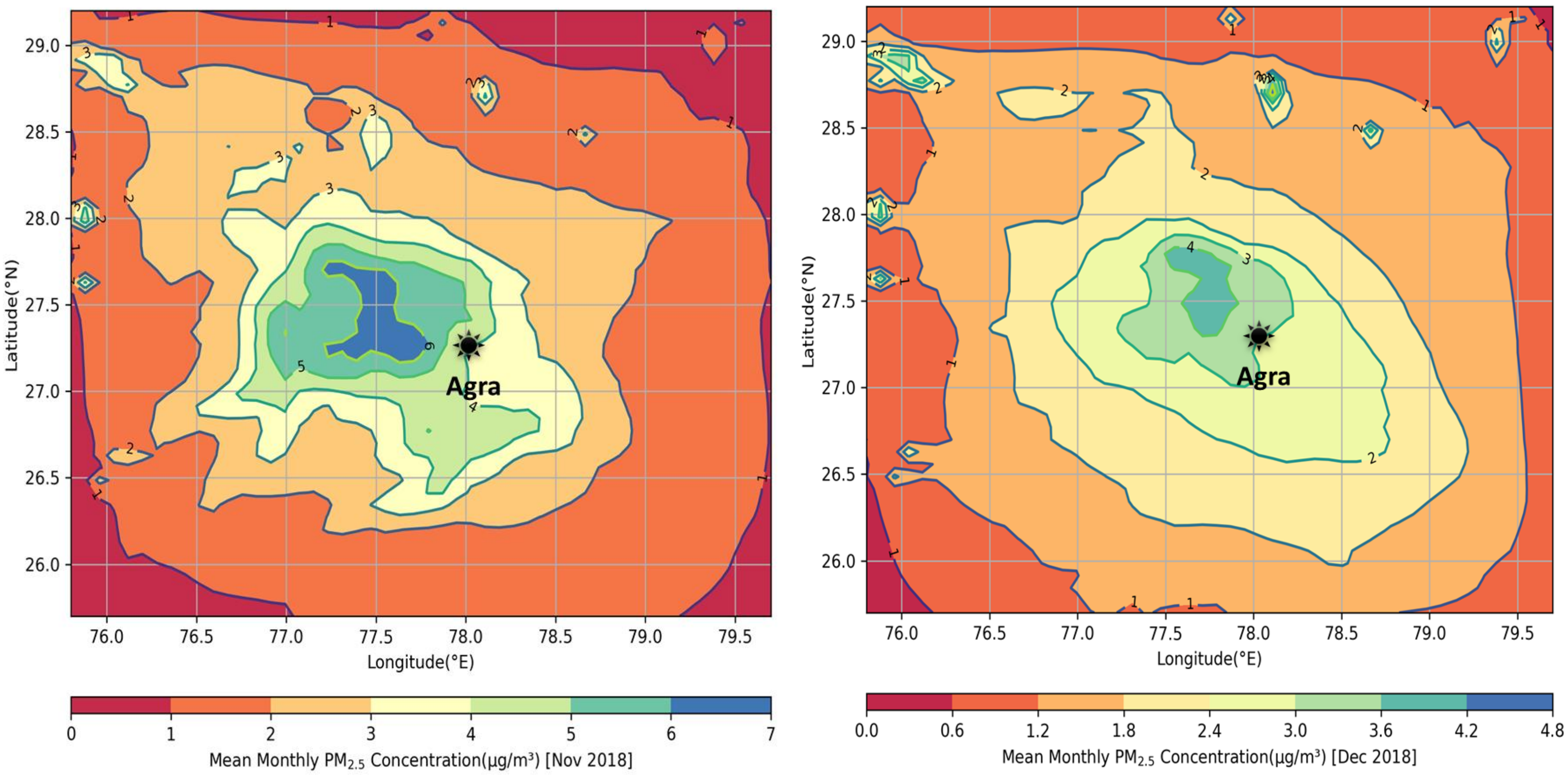
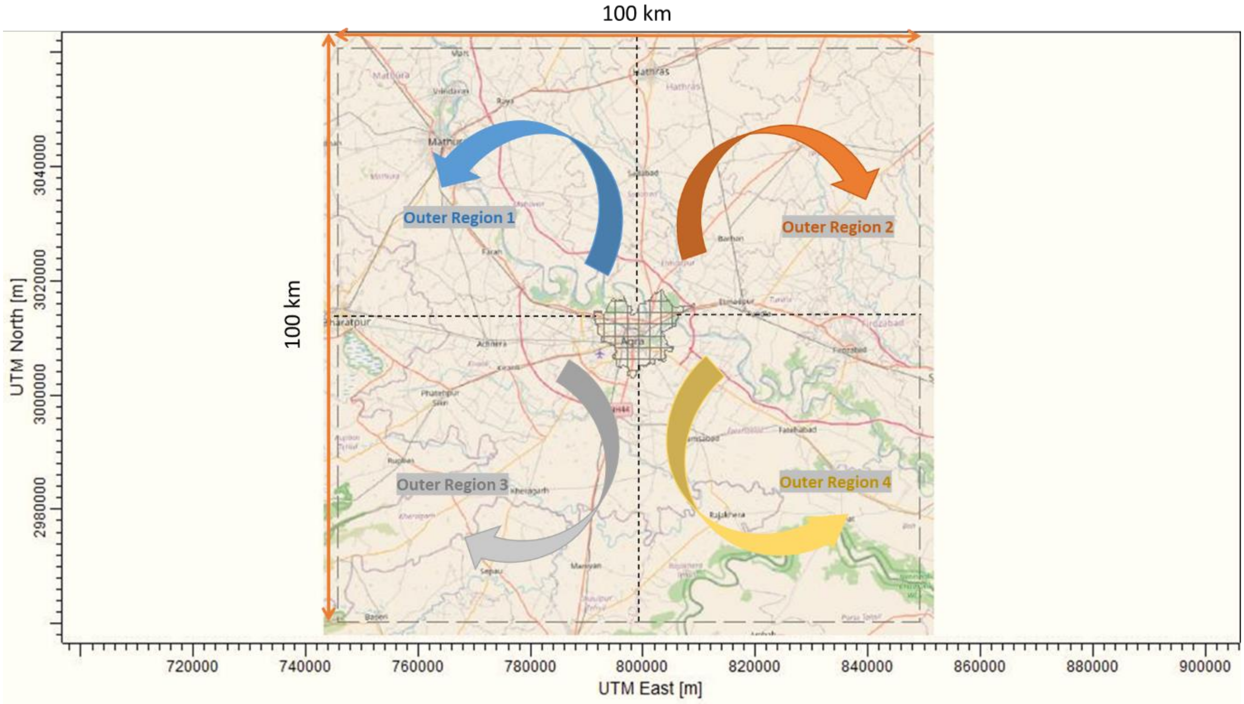


Figure 187: Mean Monthly $PM_{2.5}$ Concentration (ug/m^3) (November and December 2018)

4.10 Efflux of $PM_{2.5}$ from Agra

(Package 7: Reverse modeling to be carried to assess the impact of emission from the Agra City to the surrounding areas)

The sources of $PM_{2.5}$ within the city boundary were also contributing to the $PM_{2.5}$ concentration in the surrounding regions. This contribution was plotted in terms of the highest 24-hr average concentration of $PM_{2.5}$ in all the 12 months. It was observed that outer region 1 and outer region 2 were the most impacted ones among all other regions. Also, it is worth noting that the maximum efflux was from October to February in almost all the regions (Figure 189).



<u>Figure 188: Efflux of $PM_{2.5}$ from the Agra City to the Airshed</u>

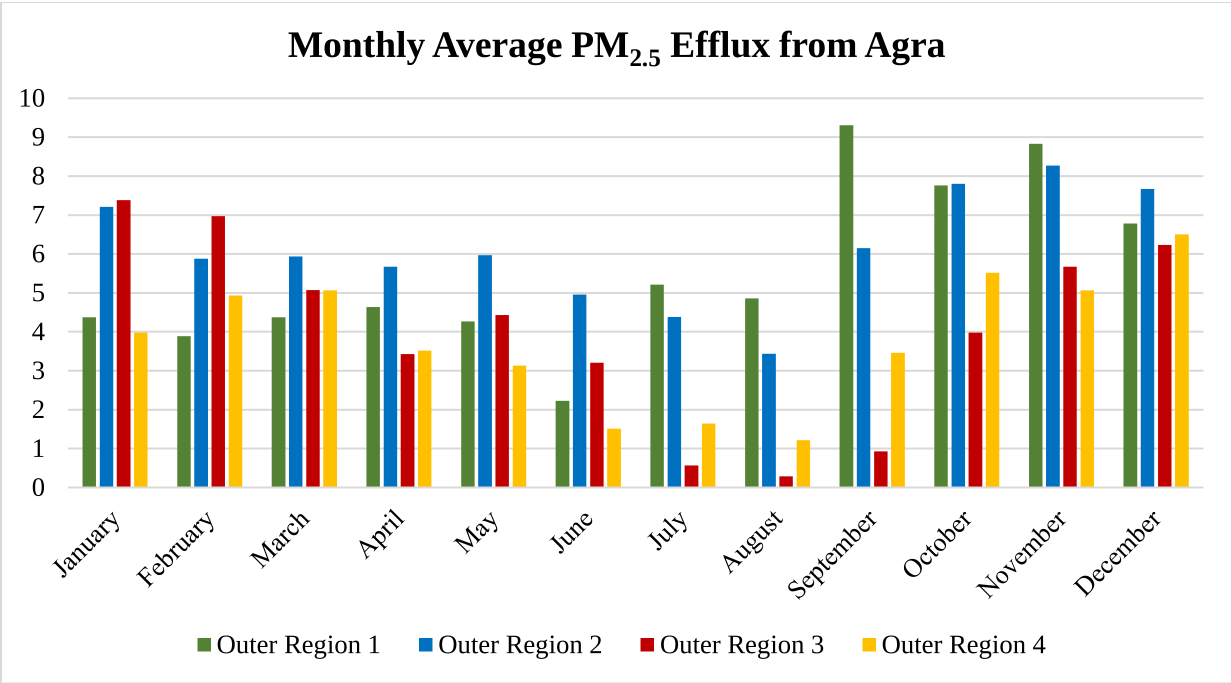
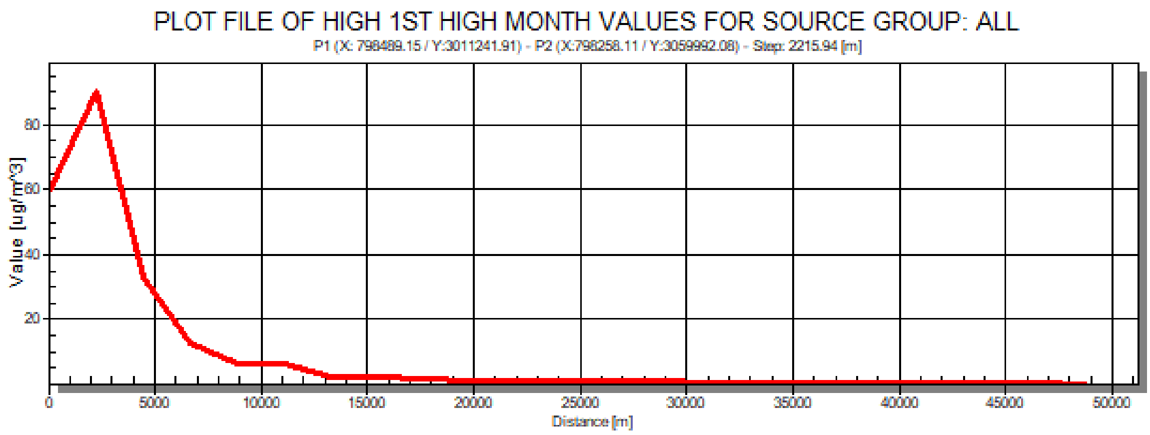


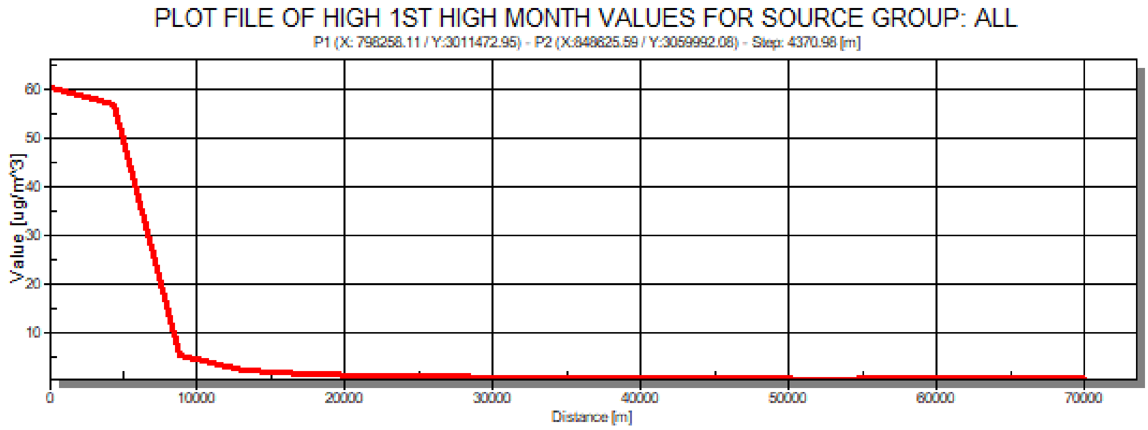
Figure 189: Monthly Average $PM_{2.5}$ Efflux from Agra

The following plots show the variation of average monthly $PM_{2.5}$ concentration along 8 directions upto 50 km from the Agra City. The monthly average $PM_{2.5}$ concentration generally reaches a level of 5 - 9µg/m^3 after a distance of around 15 km from the city. After about 30-40 km, the contribution of the Agra City becomes negligible (i.e. < 2 µg/m^3).

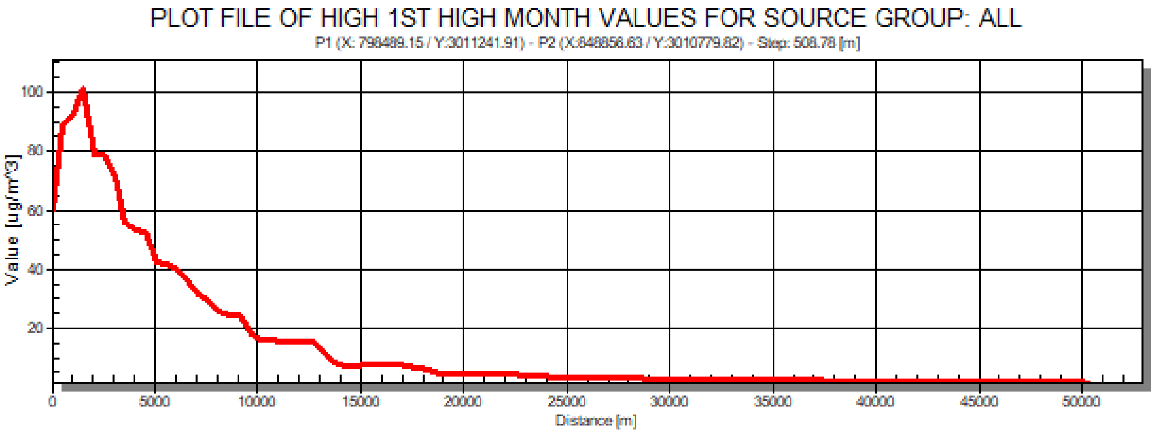
1) North Direction



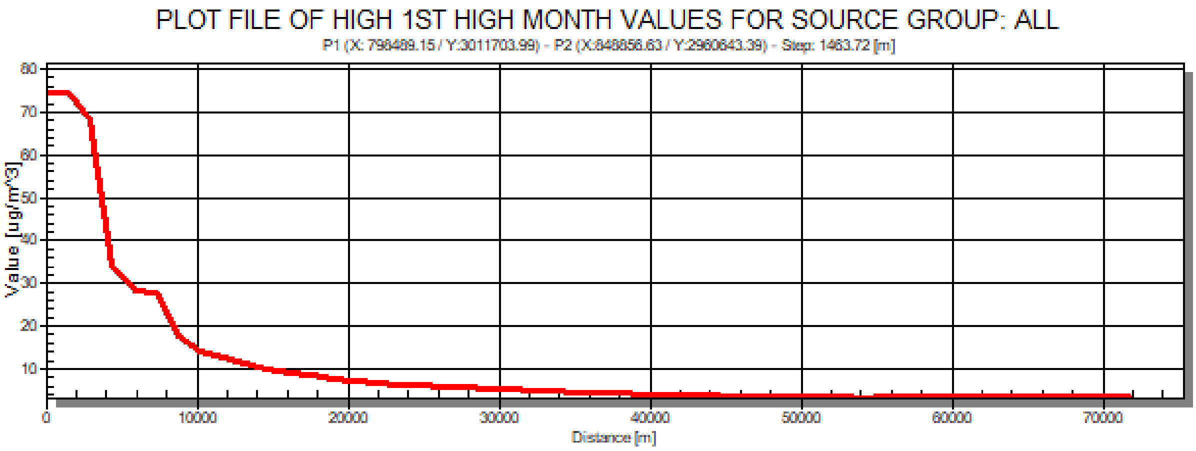
2) North-East Direction



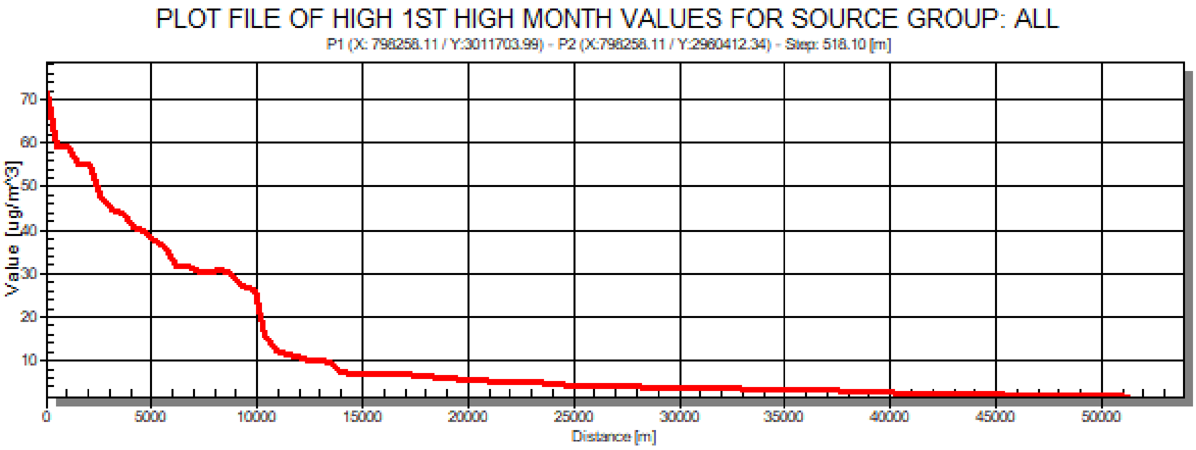
3) East Direction



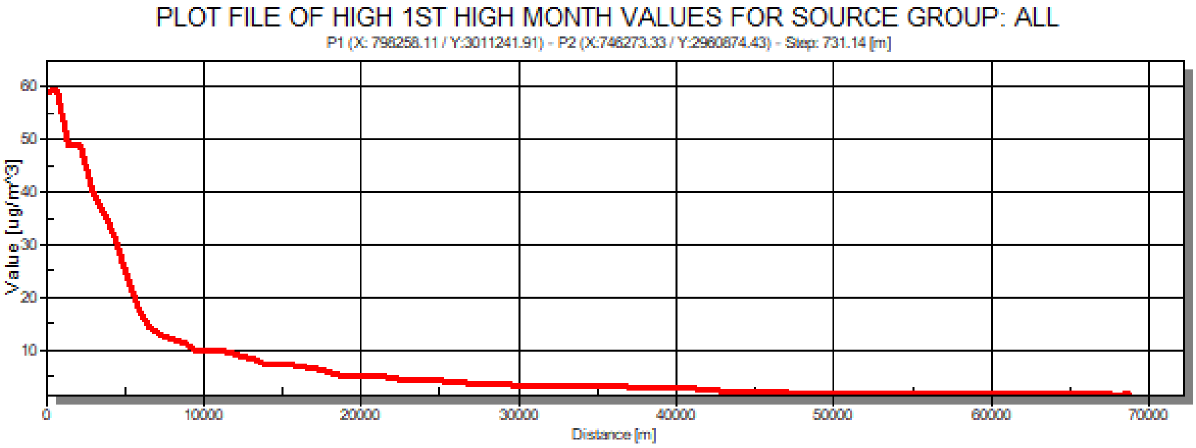
4) South-East Direction



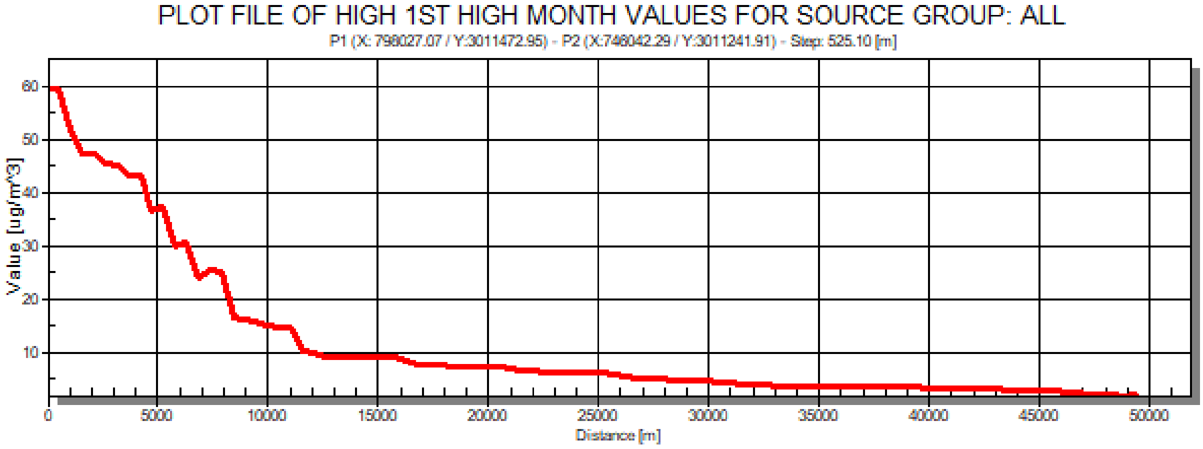
5) <u>South Direction</u>



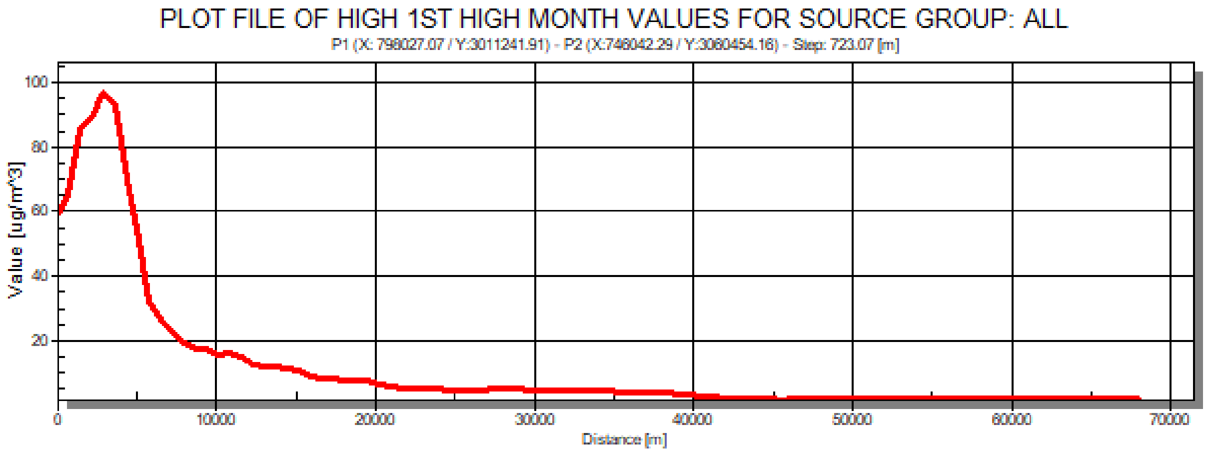
6) <u>South-West Direction</u>



7) <u>West Direction</u>



8) North-West Direction



4.11 Intercomparison of modelling results

(Package 8: Inter-compare the modeling results of this study with the results of other groups for the same domain)

A modelling study was done by UEinfo (urbanemissions.info) in 2015 under the Air Pollution Knowledge Assessment (APnA) City Program. They customized the SIM-air family of tools to fit the base information collated from the CPCB, State Pollution Control Board, Census Bureau, National Sample Survey Office, Ministry of Road Transport and Highways, an annual survey of industries, Central Electrical Authority, Ministry of Heavy Industries, Municipal Waste Management, Geographical Information Systems, Meteorological Department, and publications from academic and non-governmental institutions.

They calculated the ambient $PM_{2.5}$ concentrations and the source contributions, using gridded emissions inventory, 3D meteorological data (from WRF), and the CAMx regional chemical transport model. The model simulated concentrations at 0.01° grid resolution and sector contributions, which included contributions from primary emissions, secondary sources via chemical reactions, and long-range transport via boundary conditions.

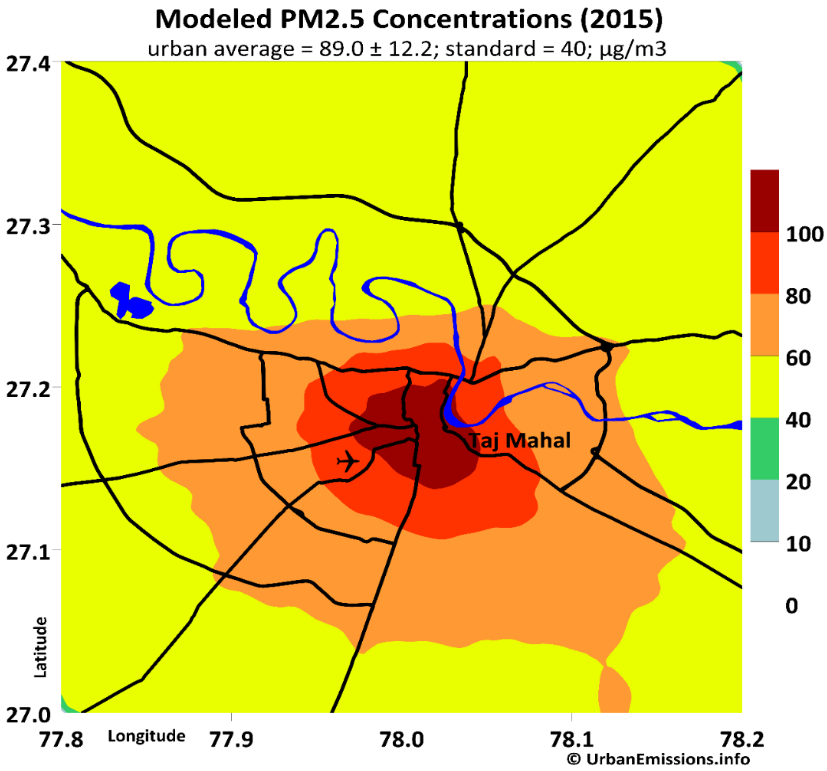


Figure 190: Contour Plot of the Annual Average of $PM_{2.5}$ Concentrations for the Agra Region (2015)

It is important to note that the peak annual concentration from the model used in this study is in the range of 100 – 167 µg/m^3 (Figure 191). The study by UEinfo (urbanemissions.info) shows peak annual concentration is in the range of 100-120 µg/m^3 (Figure 190). The two models are reasonably close in predicting peak annual concentration. The identified hotspots from both models are also nearly in the same area.

As far comparison with other independent dispersion modelling is concerned, no other dispersion modelling studies have been published for Agra.

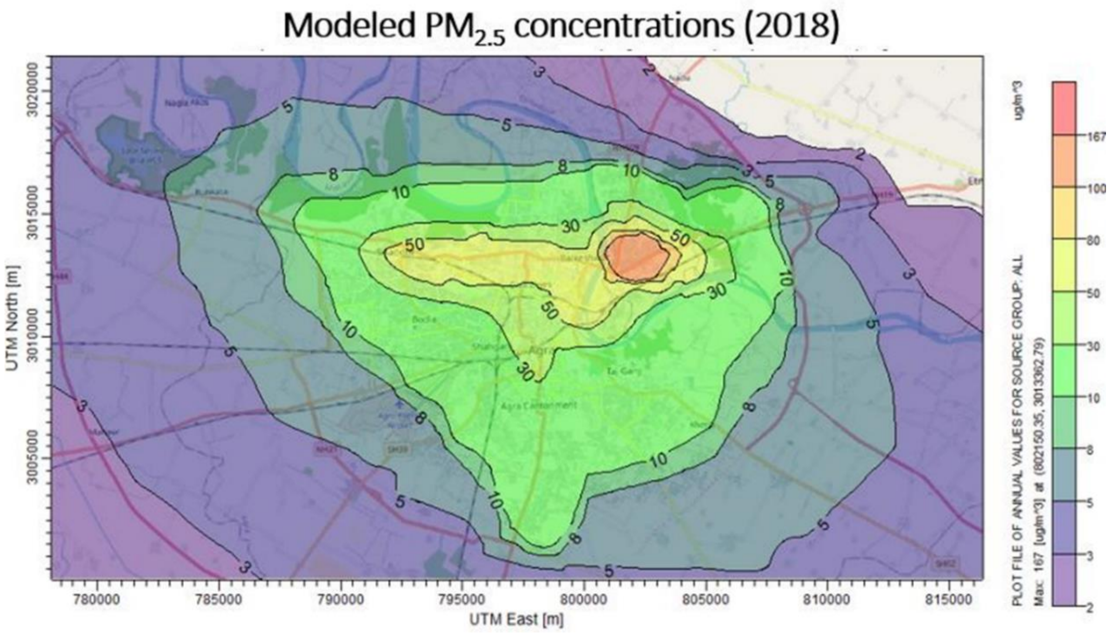


Figure 191: Contour Plot of Annual Average $PM_{2.5}$ Concentration for the Agra Region (2018)

4.12 Scenario Analysis

(Package 9: Develop and demonstrate sector-wise (including industry) policy control measures (two-three scenarios) on air quality improvements)

The study has taken into account three scenarios to assess the improvement in the air quality of the Agra City. Maximum 24-hour average $PM_{2.5}$ concentration is the parameter considered to analyse different scenarios. Road dust, vehicular, and industrial sources have been focused upon as they are the major contributors to $PM_{2.5}$ concentration within the city. The three scenarios are presented below.

Scenario: Baseline Scenario

Table 55 represents the current status of modelled air quality (maximum $PM_{2.5}$ concentration) in different regions of Agra when no intervention has been taken.

Table 55: Highest 24-hour Average $PM_{2.5}$ Concentration (µg/m^3) in Different Regions

Maximum	Region 1	Region 2	Region 3	Region 4	Region 5
January	135	261	313	134	154
February	116	231	293	118	137
March	112	206	256	100	110
April	110	197	242	79	79
May	93	186	212	74	87

June	79	155	213	73	78
July	110	242	242	63	70
August	131	253	253	37	37
September	159	336	336	120	120
October	167	332	332	155	155
November	164	354	370	135	169
December	241	437	437	158	158

Scenario 1. 30% Reduction in Road Dust, Vehicular, and Industrial Sources Emissions

Table 56 represents the status of air quality (maximum $PM_{2.5}$ concentration) in different regions of Agra when the emissions from road dust, vehicles, and industrial sources are reduced by 30%.

Table 56: Highest 24-hour Average $PM_{2.5}$ Concentration (µg/m3) in Different Regions (Scenario 1)

	Region 1	Region 2	Region 3	Region 4	Region 5
January	101	196	235	100	115
February	87	173	220	88	103
March	84	155	192	75	83
April	82	148	182	59	59
May	69	140	159	55	65
June	59	117	160	55	59
July	82	182	181	47	53
August	98	189	189	28	28
September	119	252	252	90	90
October	126	249	249	116	116
November	123	266	278	101	127
December	181	328	328	118	118

Scenario 2. 50% Reduction in Road Dust, Vehicular, and Industrial Sources Emissions

Table 57 represents the status of air quality (maximum $PM_{2.5}$ concentration) in different regions of Agra when the emissions from road dust, vehicles, and industrial sources are reduced by 50%.

Table 57: Highest 24-hour Average $PM_{2.5}$ Concentration (μg/m³) in Different Regions under Scenario 2

	Region 1	Region 2	Region 3	Region 4	Region 5
January	88	170	203	87	100
February	75	150	190	77	89
March	73	134	166	65	72
April	72	128	157	51	51
May	60	121	138	48	57
June	51	101	138	47	51
July	72	157	157	41	46
August	85	164	164	24	24
September	103	218	218	78	78
October	109	216	216	101	101
November	107	230	241	88	110
December	157	284	284	103	103

The overall improvement in air quality for $PM_{2.5}$ under the two scenarios will be close to 25% in Scenario 1 and 45% in Scenario 2 in the peak 24- hourly concentration (Figure 192). Since maximum contribution is from road dust, the maximum advantage will be by improving road conditions. Sweeping, road washing, and paved shoulders will be effective ways to control the road dust emissions.

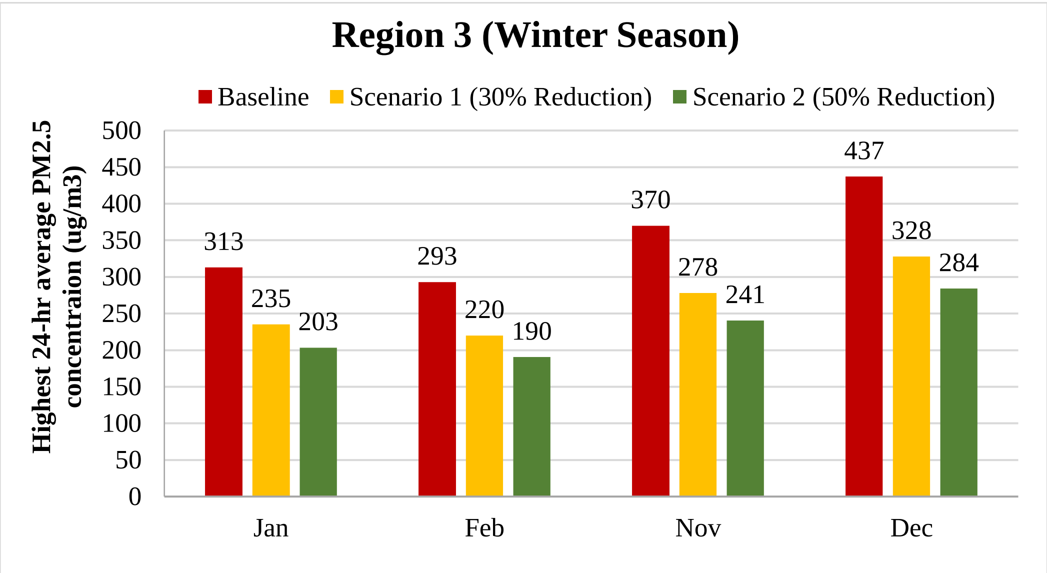


Figure 192: Air Quality Improvement in Scenarios 1 and 2 in Peak 24-hour Average PM2.5 Levels

4.13. Summary of the Air Quality Modelling and interpretations

The major findings from the air quality modelling studies are summarized below:

The WRF model for meteorology parameters was validated against the measured data from Agra continuous air quality monitoring station. The model performed satisfactorily (a statistically significant coefficient of correlation) for predicting wind speeds in the months of February, March, April, June, and September. In general, the wind speeds were overestimated by a factor of 1.2. Furthermore, the time-series plot of observed hourly ambient temperature values with modelled values showed a good agreement for all the months of 2018. It was concluded that the WRF model provided realistic meteorology and the WRF outputs were used in air quality modelling.

The $PM_{2.5}$ modelled and observed levels over one year showed a good linear association, R^2 = 0.414 (for over 350 data points). However, the noteworthy point is that the model under-predicts the concentration by a factor of more than 2.0. The probable reasons for underestimation by the model are (i) over prediction of wind speed by the WRF model, (ii) inventory may be incomplete and some source may be missing, and (iii) there is a substantial contribution of sources present outside the Agra City. Since the linear association in the model-computed and observed levels is very good, the model could be used for decision-making and useful insights.

The deficit in the model and measured (referred to as unidentified) $PM_{2.5}$ levels were highest during the January-February and November-December months. Also, it is worth noting that there was a sudden spike in these unidentified concentrations of $PM_{2.5}$ during the first week of November. This episodic spike in the unidentified $PM_{2.5}$ concentrations with an average value was 119 ug/m^3 in the city which can be attributed to the influx from the surrounding regions outside the city.

For a better insight, Agra city was divided into five regions (Figure 93). Regions 2 (north) and 3 (north-east) showed the highest $PM_{2.5}$ levels. The regions are densely populated and region 2 also has a major industrial area. The highest 24-hour average $PM_{2.5}$ concentrations were computed for all 12 months of the year 2018. It was observed that region 3 had the 24-hour peak $PM_{2.5}$ concentration at 298 ± 62 µg/m^3 followed by region 2 with 175 ± 63 µg/m^3, and region 1 with 140 ± 44 µg/m^3. Region 5 (south-east) had the least 24-hour average $PM_{2.5}$ at 76

± 24 µg/m^3. The highest 24-hour average $PM_{2.5}$ concentrations were observed during the winter (November to February) while the lowest during the summer (May to July).

The highest contributing source was road dust in all the regions followed by vehicular sources in regions 1, 4 and 5. Industrial sources were the second-highest contributors in regions 2 and 3. Domestic sources were the third-highest contributors in region 1 and 4, where the residential population is concentrated, and industry in region 5 (Table 29).

Overall city level contributors to $PM_{2.5}$ were road dust (64%), vehicles (13%), industry (9%), domestic (7%), and hotels (3%).

From the annual average plots, there is an envelope of $PM_{2.5}$ concentration which gets elongated along the prevailing wind direction (N-E) within the Agra City. The annual standard for $PM_{2.5}$ concentration (40µg/m^3) is exceeded in the area surrounding the National Highway 19 (NH-19).

The efflux of $PM_{2.5}$ emission from the Agra City was examined in 8 directions up to 50 km from the centre of the city. The monthly average $PM_{2.5}$ concentration generally reached a level of 5 - 9 µg/m^3 at a distance of around 15 km from the city. After about 30-40 km, the contribution of Agra city became negligible (i.e. < 2 µg/m^3).

The maximum annual concentration from the model used in the study was in the range of 100 – 167 µg/m^3 (Figure 191). The study by UEinfo (Urbanemissions.info) showed the maximum annual concentration in the range of 100-120 µg/m^3 (Figure 190). The two models were reasonably close in predicting peak annual concentration. The identified hotspots from both the models were also nearly in the same area (i.e. on NH-19).

5 Action Plan and Control Strategies

5.1 Controlling of Sources within the City

Hotels/Restaurants

There are approximately 1300 big hotels/restaurants (with a sitting capacity of more than 10 persons) in the city of Agra, which use LPG and small amounts of coal/charcoal (mostly in tandoors). The PM emission in the form of fly ash contributes to air pollution. It is proposed that all restaurants with a sitting capacity of more than 10 persons should not use coal in any form and shift fully to electric or gas-based appliances including tandoors. It is also seen that the ash/residue from the tandoor and other activities are indiscriminately disposed on the roadside. The ash or any dust should be locally collected and disposed of centrally.

Municipal Solid Waste (MSW) Burning

Any form of garbage burning should be strictly prohibited and its compliance needs to be monitored everyday. It will require development of infrastructure (including access to remote and congested areas) for effective collection of MSW and disposal at a scientific landfill site.

The Agra Municipal Corporation should prioritize the MSW collection mechanism starting systematically in each ward. Special attention is required for fruits, vegetable markets, commercial areas, and high-rise residential buildings, where MSW burning is common (Trans Yamuna Mandi and Sikandra Mandi).

A mechanism should be developed to carry out a mass balance of MSW generation and disposal on a daily and monthly basis. Any type of garbage burning should be stopped and ensured by the Municipal Corporation. Slum and low-income group areas should be focused (Ghatiya Azam Khan, Bijlighar, Belanganj, Jeoni Mandi, Chippi Tola, Sadar Bhatti, Naiki Mandi, Jagdishpura, Bhim Nagar and Bhogipura). Collection and disposal of the MSW should be improved primarily in the regions 1 and 4. Also, landfills and waste to energy plants can be established for efficient handling of MSW.

Desilting and cleaning of municipal drains should be undertaken on a regular interval, as the interaction of silt with biological activities can cause emission of air pollutants like H_2S, NH_3, VOCs, etc. Burning of waste in industrial areas has also been observed (Foundry Nagar, Nunhai, Sikandra Industrial Area and Transport Nagar). Hazardous waste is being dumped on the roads (oil, grease, and paint). Several residents in the locality of the Sikandra Industrial Area have reported instances of leather burning which must be stopped immediately under the supervision of UPPCB. It is recommended that there should be a separate industrial non-hazardous dump site for industrial waste, and they should not be allowed to dispose of the waste on roads or in front of the industry.

There is also a strong need to sensitize people and media through workshops and literature distribution to prevent waste burning and its unauthorized disposal; this activity may be undertaken by Agra Municipal Corporation, UPPCB, and NGOs.

Construction and Demolition

The construction and demolition (C&D) emission can be classified as temporary or short-term. In the industrial area, these activities are frequent. This source is one of the significant ground-level emission sources. Construction activities in Sectors 5, 7, and 8 of Awas Vikas Colony and the budding residential townships along the Fatehabad Road till Yamuna Expressway are contributing to dust load in the area.

Every C&D activity should fully comply with C&D Waste Management Rules, 2016. If required, a C&D waste recycling facility must be created, which is a common practice in large cities. The control measures for emission may include:

- Wet suppression
- Wind speed reduction (for large construction site)
- Waste should be properly disposed of. It should not be kept lying near the roads as it may contribute to road dust emission.
- Proper handling and storage of raw material: cover the storage and provide the windbreakers.
- Vehicle cleaning and specific fixed wheel washing on leaving the site and damping down of haul routes
- The actual construction area should be covered with a fine screen.
- No storage (no matter how small) of construction material near roadside (up to 10 m from the edge of the road) should be allowed

The above control measures should be coordinated and supervised under the Agra Development Authority, Uttar Pradesh Housing Board, Agra Municipal Corporation, Urban Development Department, PWD and UPPCB.

Domestic Sector

Although in Agra, 85% of the households use LPG for cooking, the remaining 15% use wood, crop residue, cow dung, kerosene, and coal for cooking (Census, 2011). The LPG should be made available to the remaining 15% of households to make the city 100% LPG-fuelled. The Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian Oil, HP, etc.) may formulate a time-bound plan for every household.

Soil and Road Dust

It has been observed that the soil and road dust emission and its contribution to ambient air concentration is consistent and it is one of the largest sources of PM_{10} and $PM_{2.5}$ emissions. The silt load on roads varies from 7.4 to 55.1 g/m^2. The industrial area, where heavy vehicle movement is seen, also has high road dust emission. It is suggested that high traffic density roads should be properly maintained, paved carpet, and shrubs should be planted on road dividers and the unpaved area near the roadside. Overall city level contributors to $PM_{2.5}$ were road dust (64%), vehicles (13%), industry (9%), domestic (7%), and hotels (3%).

From the annual average plots, there is an envelop of $PM_{2.5}$ concentration which gets elongated along the prevailing wind direction (N-E) within the Agra City. The annual standard for $PM_{2.5}$ concentration (40µg/m^3) is exceeded in the area surrounding the National Highway 19 (NH-19).

The following control measures are evaluated and suggested to reduce the dust emissions on major roads:

1. Convert unpaved roads to paved roads. PWD (Public Works Department) and the city administration should act immediately to reduce the pollution load from road dust.
2. Municipal Council should carry out vacuum-assisted sweeping. The efficiency of vacuum-assisted sweeping is taken as 90% (Amato et al., 2010). If the sweeping is done twice a month, the road dust emission will be reduced by 42% (FHWA and efficiency of different vacuum sweeping machines).

3. If the silt load is greater than 3 gm/m^2, the vacuum-assisted sweeping should be carried out.
4. It is more important that the condition of the roads is maintained properly, and shoulder paved by interlocking concrete or similar types of blocks.
5. The truck carrying construction material, or any airborne material should be covered.
6. Vacuum sweeping of major roads should be carried out at least four times a month. Additionally carpeting of shoulders and maintenance of roads, dividers, and kerbs should be carried out at regular intervals.
7. Mechanical sweeping with water wash can also opted for.Small shrubs, perennial forages or grass covers should be planted on the medians wherever possible.

Vehicles

The vehicle emission contribution to air quality is second important source after road dust. There is a relatively large contribution of diesel vehicles (trucks, buses, LCVs, cars, etc.) to PM_{10}, $PM_{2.5}$ CO, $SO_{2,}$ and NOx. Out of about 3.5 tons/d emissions of PM_{10} and $PM_{2.5}$ from vehicles, over 80% is from diesel vehicles, especially from trucks and buses. Therefore, control measures have to focus on advanced technological interventions for diesel vehicles or change in fuel to CNG especially for local transportation, buses, and LCVs. A coordinated effort should be made by the Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian Oil/HP, etc.).

Following additional points must be taken into account:

1. Retro-fitment of Diesel Particulate Filter (DPF): These filters have a PM emission reduction efficiency of 60-90%. If the diesel vehicle entering the city has been equipped with DPF, there is a reduction of 40% emission. This option must be explored as Bharat Stage VI fuel is now available.
2. Industries must be encouraged by the transportation department to use Bharat Stage IV or Bharat Stage VI vehicles for transportation of the raw and finished products.
3. Restriction on plying and phasing out of 10 years old commercial diesel-driven vehicles.
4. Introduction of cleaner fuels (CNG/ LPG) for vehicles.
5. Electric/Hybrid Vehicles should be encouraged and new residential and commercial buildings should have charging facilities.
6. No registration of Petrol 2-wheelers should be allowed after two years from now. Electric charging points in public buildings and parking lots should be implemented. Battery

swapping facility should be developed in coordination with companies like IOCL.

7. Check overloading: Expedited installation of weigh-in-motion bridges and machines at all entry points to Agra.
8. Route rationalization: Improvement of availability by rationalizing routes and fleet enhancement with requisite modification. Ensure integration of the existing metro system with bus services.
9. IT systems in buses, bus stops and control center and passenger information systems for the reliability of bus services and monitoring.
10. Improved public mobility systems.
11. Zero traffic zones may be considered in some areas (Sanjay Palace, Sadar Bazaar, Hospital Road, and Raja ki Mandi Market)

It is proposed that the above control options may be coordinated under the supervision of the State Transport Department.

Industries and Diesel Generator Sets

A coordinated effort under the supervision of UPPCB and Industries Departments is suggested to implement the following control measures:

- All efforts should be made to supply uninterrupted power supply to the industry so that use of DG sets is completely eliminated.
- All industries should run on natural gas and combustion-related emissions should be bare minimum.
- Ensure compliance with emission standards in industries: All industries causing air, water, and noise pollution shall be made compliant with respect to environmental regulations.
- Strict action to stop unscientific disposal of industrial waste in the surrounding areas.
- Industrial waste burning should be stopped immediately.
- Area and road in front of the industry should be free from any storage or disposal of any waste or raw material.
- Industries should follow best practices to minimize fugitive emission within the their premises; all leakages, transfer points, loading and unloading, and material handling within the industries should be controlled.
- There are many industries with induction furnaces, which are highly polluting, fitted with almost no pollution control devices. The maximum emissions occur when the furnace lids

and doors are opened during charging, back charging, alloying, oxygen lancing (if done), poking, slag removal, and tapping operations. These emissions escape from the sides and top of the building. The emissions should be collected, channelized and arrested through the bag filters.

- To address the pollution caused by fugitive emissions using induction furnaces a fume gas capturing device has been developed and commercially available. It is recommended that fume gas capturing hood followed by baghouse should be used to control air pollution.
- It is seen that industrial waste (hazardous in nature) is mixed with MSW and burnt in several parts of Agra. It is recommended that no industrial waste should be mixed with MSW. There should be separate Treatment, Storage, and Disposal Facilities (TSDFs) for hazardous waste that should be developed under the guidance of UPPCB.
- The area inside and outside the industry premises should be properly maintained. The respective industry should be held responsible for not maintaining the area properly.
- Industries located outside the city of Agra also contribute to the city pollution; this contribution is nearly 8-10%. Brick kilns located outside the Agra City are major contributors to all pollutants in the airshed. In PM_{10} (37 tons/d) and $PM_{2.5}$ (27 tons/d) the brick kilns' contribution is 66 – 69%. Brick kilns constitute a major economic activity and drive the construction industry, this sector needs to come under the formal sector with the best available technology and modern pollution control equipment. The priority is that all brick kilns in Agra and Firozabad districts should adopt ziz-zag and vertical shaft technology. Other districts should follow suit. Improvment in technology is expected to reduce the brick kiln emission by 25%.
- There are two large industries in the Agra airshed: oil refinery at Mathura (about 40 km from Agra city) and Harduaganj coal-based power plant in Aligarh, at about 80 km from Agra. These two industries have large emission of SO_2; the power plant accounts for 47% of total SO_2 emission and the refinery accounts for 24%. These two industries should reduce their emission in a time-bound manner.

5.2 Strengthening of Agra Regional Office

- New manpower recruitment for sampling, analysis, assessment, and surveillance
- Availability of Automated Stack Testing Kit
- The surveillance team should work in two shifts (day and night)
- Strict action against visible emission

– Proper documentation of violation of emission norms
– Capacity-building through regular training of personnel
– Laboratory upgradation

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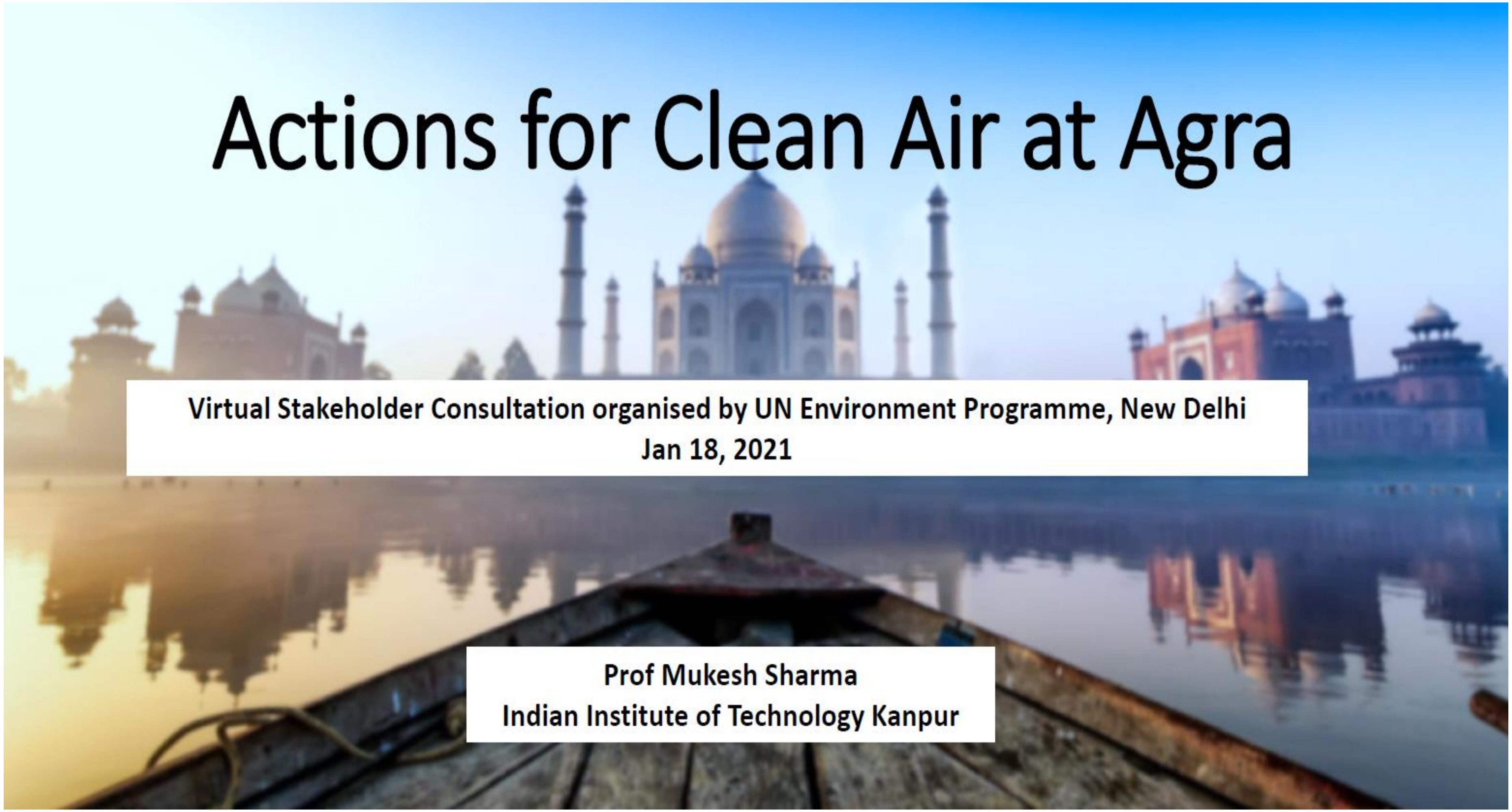
Annexure I: Virtual Stakeholder Consultation on August 18, 2020

Emission Inventory and Modelling of Air Pollution Sources in Agra Region: An Airshed Approach

Virtual Stakeholder Consultation for Clean Air Action in Agra organized by UN Environment Programme, New Delhi
August 18, 2020

Prof. Mukesh Sharma
IIT Kanpur

Annexure II: Virtual Stakeholder Consultation on January 18, 2021



Outcome of

- UNEP study
- Source apportionment study by UPPCB
- CPCB's study at Taj Mahal

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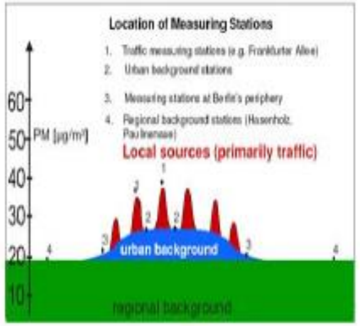
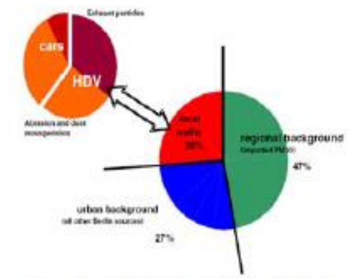
New Collaboration with Agra Municipal Corporation

Methodology

Case Study of Berlin

Challenges:



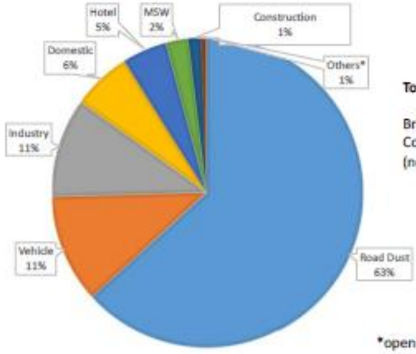


Clean Air and Action Plan for Berlin 2005-2010

TTZ boundary and Agra Airshed

Taj Trapezium Zone (TTZ) : 10,400 sq km
Agra Airshed: 20460 sq. km

$PM_{2.5}$: City Level Emission Inventory of Agra City

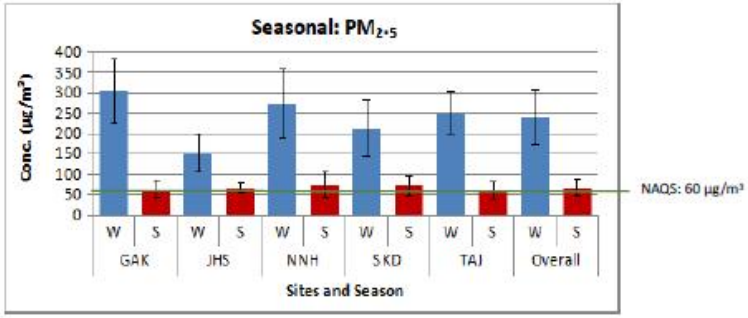


Total: 14.5 t/day

Brick Kiln outside city boundary
Contribution : 3t/day (18%)
(not mentioned in the graph)

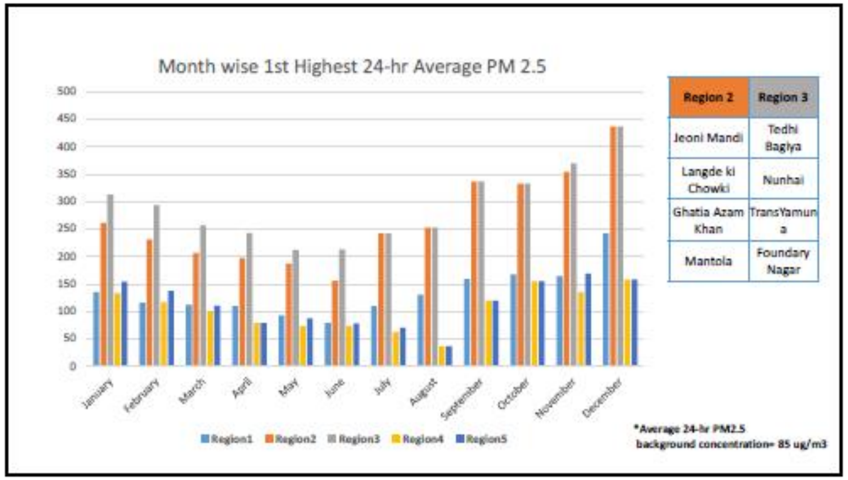
*open area, DG sets, Hospitals

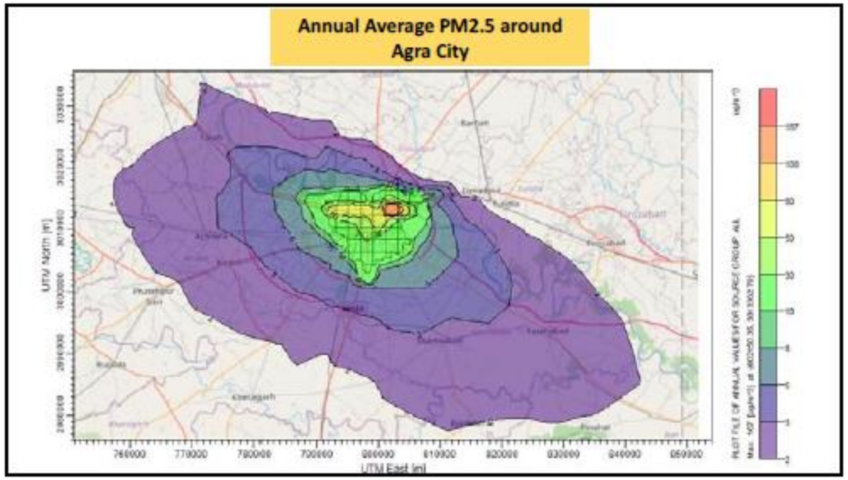
Seasonal Air Quality in Agra City (2018-2019)

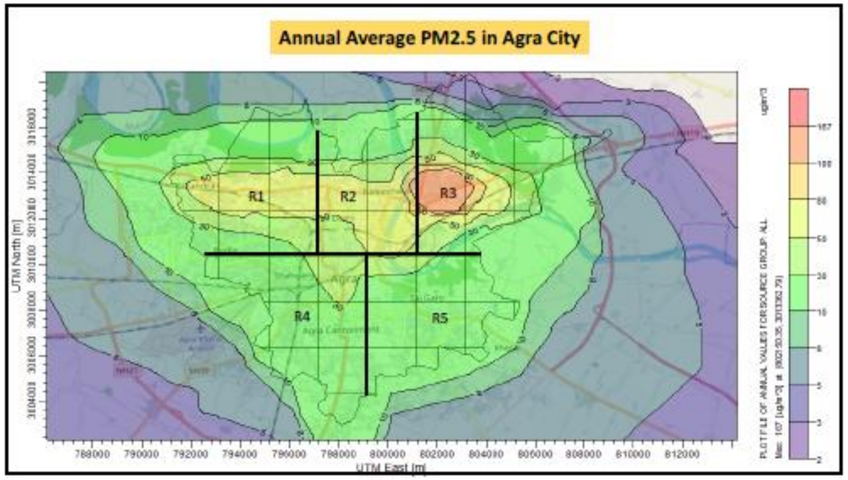


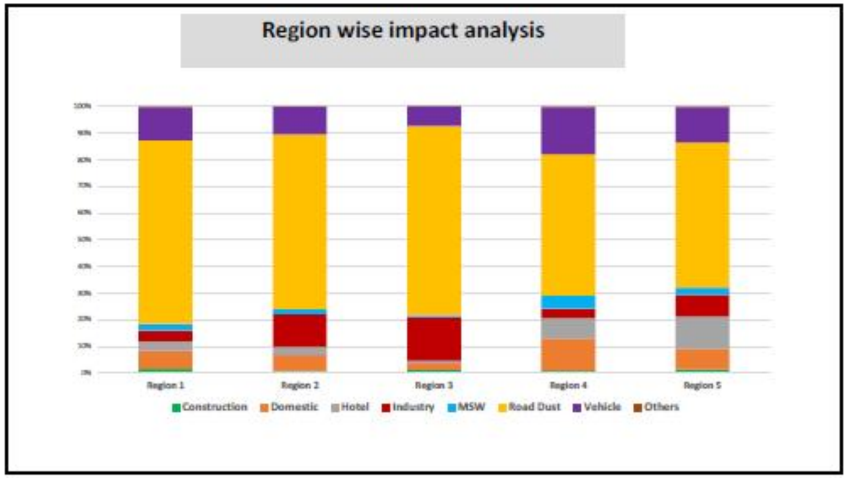
Region wise impact analysis

Region 1	Region 2	Region 3	Region 4	Region 5
Transport Nagar	Jeoni Mandi	Tedhi Bagiya	Shahganj	BijliGhar
Sikandra	Langde ki Chowki	Nunhai	Bhogipura	Tajganj
LohaMandi	Ghatia Azam Khan	TransYamuna	ChipiTola	Shaheed Nagar
Awas Vikas	Mantola	Foundary Nagar	Pachkuiyan	Shamsabad Road


Month wise 1st Highest 24-hr Average PM 2.5
Region 2
Region 3
Jeoni Mandi
Tedhi Bagiya
Langde ki Chowki
Nunhai
Ghatia Azam Khan
TransYamuna
Mantola
Foundary Nagar
January
February
March
April
May
June
July
August
September
October
November
December
Region1
Region2
Region3
Region4
Region5
*Average 24-hr PM2.5 background concentration= 85 ug/m3


Annual Average PM2.5 around Agra City
UTM East [m]
UTM North [m]


Annual Average PM2.5 in Agra City
R1
R2
R3
R4
R5
UTM East [m]
UTM North [m]


Region wise impact analysis
Region 1
Region 2
Region 3
Region 4
Region 5
Construction
Domestic
Hotel
Industry
MSW
Road Dust
Vehicle
Others

Region wise impact analysis

Rank	Region 1	Region 2	Region 3	Region 4	Region 5
1	Road Dust	Road Dust	Road Dust	Road Dust	Road Dust
2	Vehicle	Industry	Industry	Vehicle	Vehicle
3	Domestic	Vehicle	Vehicle	Domestic	Hotel
4	Industry	Domestic	Domestic	Hotel	Industry
5	Hotel	Hotel	Construction	MSW	Domestic
6	MSW	MSW	Hotel	Industry	MSW
7	Construction	Construction	MSW	Construction	Construction

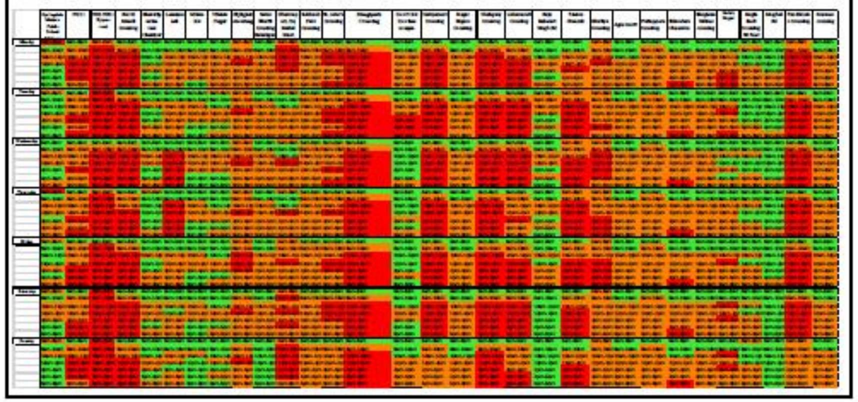
Traffic Congestion and Parking on Roadside

Guru ka Tal

Traffic conflict due to inappropriate U-turn on NH-2

Service lane road dust and unpaved shoulder

Typical Traffic Conditions at different locations in Agra



Major Traffic Bottleneck

Bhogipura Crossing	Nagar Nigam Intersection
Rakabganj Intersection	Deewani Intersection
Raja mandi Intersection	Sultanganj Intersection
Pachkuian Intersection	Jiwani Mandi Intersection
Hariparwat Intersection	Langre Ki chowki Intersection
Professor Colony Intersection	Bijali Ghar Intersection
RBS Crossing	Kinari Bazar Intersection
Lohamandi Intersection	Pipal Mandi Intersection
Madiakatra Intersection	Mantola Intersection
Church Road Khandari Intersection	Rambagh Intersection
Idgah Intersection	NH3 NH11 Bypass road
Shahganj Crossing	Rui Ki Mandi Crossing

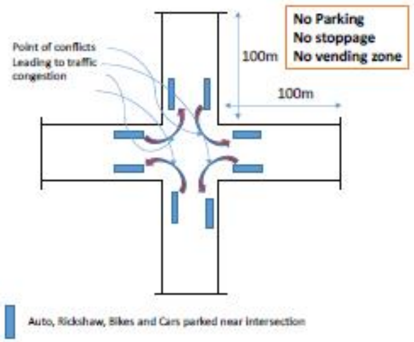
Decongestion Plan

Short-term

- No Parking (upto 100m) near congested intersection listed on Major Traffic Bottleneck slide above
- Parking policy in congestion area (high parking cost, at city centers, only parking is limited for physically challenged people, etc).
- Avoiding street parking on all roads of 8m width
- No encroachment on roads
- Introduction of one-way traffic routes (for e.g. Madiakatra, Jeoni Mandi)

Long-Term

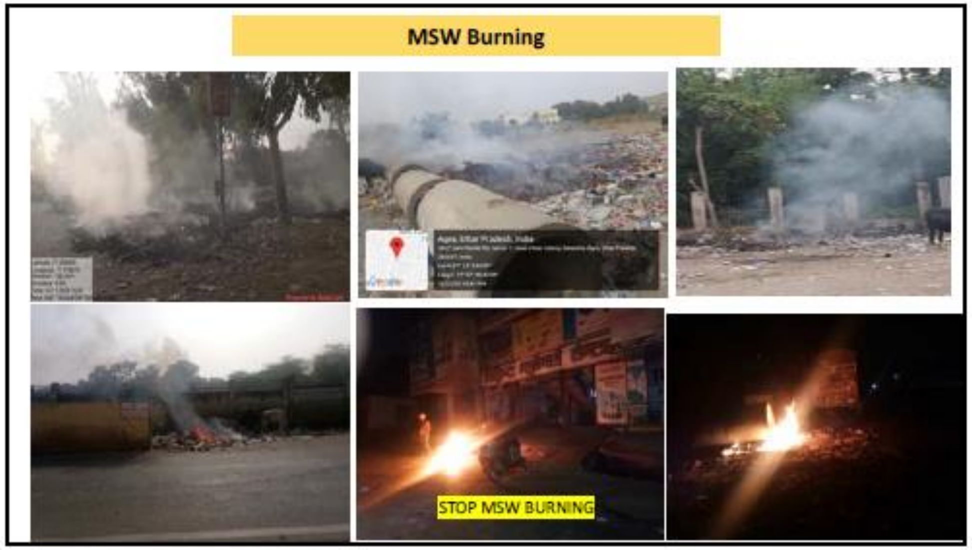
- Shifting of Transport Nagar outside city
- Bijlighar Bus stand may be shifted



Road Dust

Road Dust

- Maintain silt load of 3 gm/m2
- Vacuum Sweeping of major roads (Four Times a Month)
- Maintenance of all major roads
- Paved shoulders on all roads
- open fields should be kept slightly wet and small shrubs are planted to prevent drift of dust in summer
- No storage and disposal of material (construction, ash, etc) near roadside (up to 10 m from the edge of road).


MSW Burning
STOP MSW BURNING

Annexure III: Online Training Course Brochure

Participation

The training is open to all concerned interested in control of air pollution. Participation is expected from:

- Ministry of Environment, Forests and Climate Change
- Central Pollution Control Board.
- State Pollution Control Board
- Industries Associations.
- Urban Local Bodies
- Development Authorities
- Academic Institutions
- Non-govermental Organizations
- Air Quality Professionals

For participation and more information, please contact:

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Dr. Valentin Foltescu
Senior Programme Management Officer
UN Environment Programme India,
55, Lodhi Estate, New Delhi - 110003
Email - valentin.foltescu@un.org

For registration, please email (mukesh@iitk.ac.in) the following details by November 05, 2020.

Name:
Organization:
Address:
Email & Phone:

Selected candidates will be intimated by email.

DEPARTMENT OF CIVIL ENGINEERING
Indian Institute of Technology Kanpur
www.iitk.ac.in/ce

An Online Training Course

on

Emission Inventory, Air Dispersion & Receptor Modelling: Fundamentals and Applications

(November 07-11, 2020)

There is no course fee.

Online platform link will be shared with the participants.

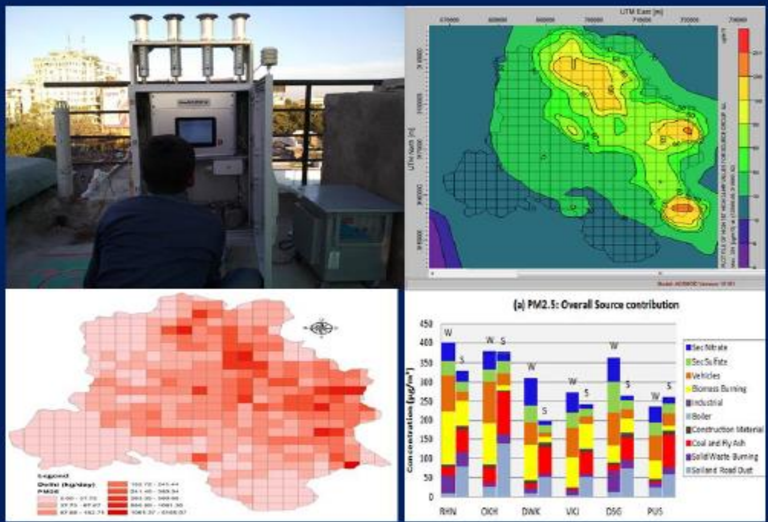
Indian Institute of Technology Kanpur
United Nations Environment Programme, New Delhi

Training Course Sponsored by:

United Nations Environment Programme (UNEP)

Course Contents

- Air Quality Management: Sources Effects and Standards
- Preparation of an Air Pollution Source Inventory
- Physical Properties of the Atmosphere and Meteorology
- Air Dispersion Models –Introduction to Gaussian Model
- Air Dispersion Modelling using AERMOD: Evaluation and Validation
- Receptor Source Models
- Weather Research Forecasting Model-Chemistry
- Problems for Practice



About the Training Course ...

Air pollution interferes with the healthy living of humans and other living entities. The problem becomes more complex due to the multiplicity and complexity of air polluting source mix (e.g., industries, automobiles, generator sets, domestic fuel burning, roadside dust, construction activities, etc.) in urban areas.

Until recently, traditional approaches to the problem of apportioning source impacts have been limited to dispersion, or source, models that use emission inventory data (gathered at emission source) with meteorological data to estimate impacts at the receptor. Most cities in the country still face continuing particulate non-attainment problems from aerosols of unknown origin (or those not considered for pollution control) despite the high level of control applied to many point sources. It is in the latter case that an improved understanding of source-receptor linkages is especially needed if cost-effective emission reductions are to be achieved.

Although there have been many advancements for understanding and abatement of air pollution, these advancements require high-end chemical analysis and high-performance computing. The greater problem faced by the pollution control board officials and other private and non-governmental personnel is the lack of exposure and induction into new and advanced arena of air quality management. To enhance the capacity of individuals, the proposed training course will benefit them to undertake large scale air quality studies, especially to build source -receptor linkage for effective air pollution control. The course content includes preparation of emission Inventory, atmosphere and meteorology, receptor source model (chemical mass balance and statistical models), simple box and Gaussian models, USEPA AERMOD model and introduction to Weather Research Forecasting Model.

Annexure IV: List of Participants

S.No.	Name	Designation	Organisation
1	Mr. Devvrat Mishra	Assistant Engineer	Chhattisgarh Env. Conservation Board, Raipur
2	Mr. Krishna Kedia	Student	IISER Bhopal
3	Ms. Deeksha Shukla	Student	IISER Bhopal
4	Mr. Utsav Sharma	R.O.	UPPCB, Ghaziabad
5	Ms. Priya	JRF	UPPCB, Ghaziabad
6	Mr. Susheel Kumar	SA	UPPCB, NOIDA
7	Mr. Ashish Chauhan	JRF	UPPCB, NOIDA
8	Mr. Kshitij Patel	SA	UPPCB, Lucknow
9	Mr. K.K. Chaudhary	SA	UPPCB, Lucknow
10	Mr. Sandeep Soniyal	JRF	UPPCB, Kanpur
11	Mr. Sanjeev Mishra	MA	UPPCB, Kanpur
12	Mr. R.V. Singh	ASO	UPPCB, Agra
13	Dr. Vishwanath Sharma	ASO	UPPCB, Agra
14	Mr. Bhalendra Srivastava	SA	UPPCB, Varanasi
15	Mr. Shivam Tripathi	JRF	UPPCB, Varanasi
16	Mr. Subhash Gautam	JRF	UPPCB, Bijnor
17	Ms. Divya Agrawal	JRF	UPPCB, Bijnor
18	Dr. Neeraj Chaturvedi	ASO	UPPCB, Bulandshahar
19	Ms. Nisha Fatima	JRF	UPPCB, Bulandshahar
20	Mr. Raj Bahadur	JRF	UPPCB, Meerut
21	Mr. Sashi Binbkar	AEE	UPPCB, Bareilly
22	Mrs. Poojika Bahadur	JRF	UPPCB, Bareilly
23	Mr. Alok Sharma	JRF	UPPCB, Moradabad
24	Ms. Kavita Saxena	JRF	UPPCB, Moradabad
25	Mr. Anmol Rathore	JRF	UPPCB, Sonbhadra
26	Dr. J.P. Singh	ASO	UPPCB, Firozabad
27	Mr. Deepak Singh	JRF	UPPCB, Firozabad
28	Dr. Anup Gupta	JRF	UPPCB, Prayagraj
29	Mr. Ramjas	SA	UPPCB, Prayagraj
30	Mr. Manish Tripathi	SA	UPPCB, Raebareli
31	Mr. Ramdas	SA	UPPCB, Jhansi
32	Shri. AshishTiwari	Member Secectary	UPPCB, Head Office, Lucknow
33	Mr. Shubham Mishra	JRF	UPPCB, Head Office, Lucknow
34	Ms. ParulGahoi	JRF	UPPCB, Head Office, Lucknow
35	Shri Devendra Kr. Sharma	Chief Engineer	Develoment Authority, Agra
36	Shri Kamal Kumar	Scientist, D	CPCB, Agra
37	Shri Rakesh Chandra	Forest Officer	Social Forestry Forest Department,Agra
38	Shri Rajeev Rathi	Environmental Engineer	Nagar Nigam, Agra

39	Shri Bhuwan Prakash Yadav	Regional Officer	UPPCB, Agra
40	Dr. Ranjit Kumar	Assist. Professor	Dyalbagh Education Institute, Agra
41	Shri U.C. Sharma	Chairman	Env. Cell, Laghu Udyog Bharti, Agra
42	Mr. Rishabh Singh		CSIR-National Physical Laboratory, Delhi
43	Mr. Dheeraj Mehra		The Energy and Resources Institute, New Delhi
44	Dr. Arindam Datta		The Energy and Resources Institute, New Delhi
45	Ms. KankshiSahu	JRF	UPPCB,Varanasi
46	MS. Subhadarsini Das	Environmental Engineer	OSPCB, Odisha
47	Mr. Krishna Mohan	JRF	Regional Office, UPPCB, Varanasi
48	Ms. Pratima Gupta	Student	Dyalbagh Education Institute, Agra
49	Mrs. Mithila Sankpal	Environmental Engineer	Agra Smart City Limited,Agra
50	Smt. Vidullatha	Assistant Environmental Scientist	TSPCB, RO, Hyderabad
51	Kum. Thaslim Begum	Assistant Environmental Engineer	TSPCB, RO, Hyderabad
52	Smt. P.Padma	Assistant Environmental Engineer	TSPCB, RO-I, Rangareddy District
53	Smt. C.Sravanthi	Asst. Scientist	TSPCB, RO-I, Rangareddy District
54	Smt. E.Kanaka Jyothi	Asst. Scientist	TSPCB, RO, Medchal
55	Sri P.Sravan Kumar	Assistant Environmental Engineer	TSPCB, RO, Warangal
56	Sri. P.Narshimha	Asst. Scientist	TSPCB, Zonal Lab, Warangal
57	Sri. B.Shaskar Babu	Assistant Environmental Engineer	TSPCB, RO, Kothagudem
58	Smt. N.Jayasri	Asst. Environmental Scientist	TSPCB, Board Office
59	Sri. M.Ramakrishna	Asst. Scientist	TSPCB, Board Office
60	Kum. S.Swathy	NCAP Consultant	TSPCB, Board Office

Annexure V: Short Training Course Module

Submitted separately.