

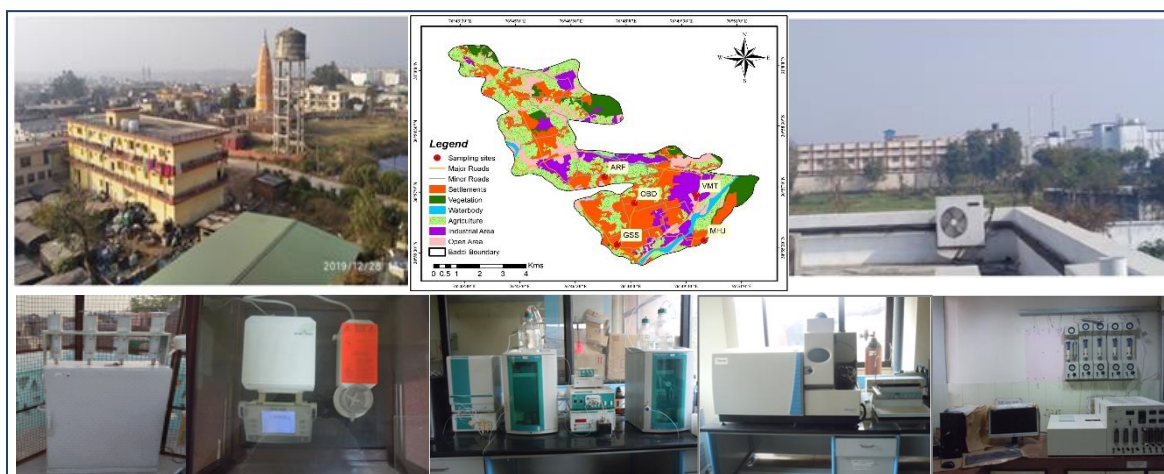
Source Apportion-based Action Plans for Restoring Air Quality in Non- Attainment Cities in the State of Himachal Pradesh in respect of PM₁₀, PM_{2.5} and other Notified Pollutants

City: Baddi

(Final Report)

Submitted to

Himachal Pradesh State Pollution Control Board, Shimla



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Executive Summary

Since the enactment of the Air Act of 1981, air pollution control programs have focused on point and area source emissions, and many communities have benefited from these control programs. The burgeoning population coupled with rapid growth in terms of vehicles for tourism and transportation of man and material, pharmaceuticals industries, construction, and energy consumption has resulted in air pollution issues in the state, particularly, a few cities have come under the category of non-attainment of air quality standards.

To address the air pollution issues in Baddi city in the state, HP State Pollution Control Board (HPSPCB), Shimla has sponsored the study “Source Apportion-based Action Plans for Restoring Air Quality in Non- Attainment Cities in the State of Himachal Pradesh” to the Indian Institute of Technology Kanpur (IITK). The study commenced on June 06, 2019. The main objectives of the study are preparation of emission inventory, air quality monitoring, chemical composition of PM₁₀ (particulate matter of size less than and equal to 10 µm diameter) and PM_{2.5} (particulate matter of size less than and equal to 2.5 µm diameter), apportionment sources to ambient air quality, preparation of action plan for cities and trend analysis in historical air quality data. The project has the following specific major objectives:

- Identify and inventorize emission sources (industry, traffic, power plants, local power generation, small-scale industries, etc.) in Baddi.
- Chemical speciation of particulate matter (PM) and measurement of other air pollutants;
- Perform receptor modeling to establish the source-receptor linkages for PM in ambient air;
- Identification of various control options and assessment of their efficacies for air quality improvements and development of control scenarios consisting of combinations of several control options; and
- Selection of best control options from the developed control scenarios and recommend implementation of control options in a time-bound manner.

- This study has five major components (i) air quality measurements, (ii) emission inventory, (iii) air quality modeling, (iv) control options and (v) action plan. The highlights of these components are presented below.

Air Quality: Measurements

A total of five air quality sites were categorized based on the predominant land-use pattern (Table 1) to cover varying land-use prevailing in the city. PM₁₀, PM_{2.5}, SO₂, NO₂, VOCs (volatile organic compounds), OC (organic carbon), EC (elemental carbon), Ions, Elements, PAHs (polyaromatic hydrocarbons), molecular markers, CO and ozone were considered for sampling and measurements. The air quality sampling was conducted during the winter season (2019-2020).

Table 1: Description of sampling sites in Baddi

S. No.	Sampling Site-City	Site Code	Description of the site	Type of sources
1.	Marice Hotel Jharmajri	MHJ	Industrial	Industries, DG sets, vehicles, road dust, garbage/industrial waste burning, coal
2.	HPSPCB Office Sai Road	OBD	Commercial	DG sets, vehicles, road dust, garbage/waste burning, hotels, coal uses
3.	Aristo Pharma	ARF	Industrial	Industries, DG sets, vehicles, road dust, garbage/industrial waste burning, coal
4.	Govt School Sandoli	GSS	Residential and Commercial	Domestic cooking, vehicles, road dust, garbage/MSW burning, restaurants
5.	Vardhman Textile	VMT	Industrial	Industries, DG sets, vehicles, road dust, garbage/industrial waste burning, coal

Based on the air quality measurements in the winter months and critical analyses of air quality data (Chapter 2), the following inferences and insights are drawn for understanding the current status of air quality. The site-specific average air concentrations of PM₁₀, PM_{2.5} and their compositions have been referred to bring important inferences to the fore.

- The mean PM₁₀ levels were 142 – 286 µg/m³ and the mean PM_{2.5} levels were 87 – 210 µg/m³.

- Particulate pollution is the main concern in the city, where PM_{10} levels are 1.4 – 2.9 times higher than the national ambient air quality standards (NAAQS) and $PM_{2.5}$ levels are 1.4 – 3.5 times higher than the national standard in the winter months. It is observed that the air quality in terms of PM_{10} and $PM_{2.5}$ falls in the poor to severe category of air quality index (AQI).
- The chemical composition of PM_{10} and $PM_{2.5}$ carries the signature of sources and their harmful contents. The chemical composition is variable depending on the size fraction of particles.

PM_{10}

The overall average concentration of PM_{10} is $218 \pm 55 \mu\text{g}/\text{m}^3$ against the acceptable level of $100 \mu\text{g}/\text{m}^3$. The highest levels were observed at MHJ and the lowest at VMT.

The important components are the secondary particles ($\text{NO}_3^- + \text{SO}_4^{2-} + \text{NH}_4^+$), which account for about 21% of total PM_{10} and combustion-related total carbon ($\text{TC} = \text{EC} + \text{OC}$) accounts for about 22%; both fractions of secondary particles and combustion-related carbons account for 44% of PM_{10} in winter months.

The crustal component ($\text{Si} + \text{Al} + \text{Fe} + \text{Ca}$) accounts for about seven percent in PM_{10} . This suggests soil and road dust have significant contributions. The coefficient of variation (CV) is about 0.21 (of the fraction of crustal component), which suggests the crustal source contributes consistently in the winter months.

The Cl^- content in PM_{10} is not consistent and varies between 7 – 21%, which is an indicator of the burning of municipal and plastic solid waste (MSW); recall poly vinyl chloride (PVC) is a major part of MSW. The highest Cl^- content is observed at OBD at $42 \mu\text{g}/\text{m}^3$ compared to the overall city level of $25 \mu\text{g}/\text{m}^3$. The high level at OBD signifies some local burning of waste either in industrial processes as a means of disposal of solid waste.

$PM_{2.5}$

The overall average concentration of PM_{2.5} in winter is 141±40 µg/m³ against the acceptable level of 60 µg/m³. The highest levels are observed at MHJ and the lowest at VMT.

The important components are the secondary particles (NO₃⁻ + SO₄⁻² + NH₄⁺), which account for about 23% of total PM_{2.5} and combustion-related total carbon (TC = EC + OC) accounts for about 25%; both fractions of secondary particles and combustion-related carbons account for 48% of PM_{2.5} in winter months. The highest levels of secondary particles were observed at VMT (30%) and TC at ARF (29%).

The Cl⁻ content in PM_{2.5} is not consistent and varies between 8 – 22%, which is an indicator of the burning of MSW and plastic waste.

Gaseous pollutant levels

NO₂ and SO₂ levels meet the national air quality standard of 80 µg/m³. The highest NO₂ and SO₂ levels were at MHJ with some high peaks, an industrial site having high coal combustion in nearby areas. In addition, high levels of NO₂ and SO₂ are expected to undergo chemical transformation to form fine secondary particles in the form of nitrates and sulfates, adding to high levels of existing PM₁₀ and PM_{2.5}. NH₃ levels in the city were well within the air quality standard.

The VOCs (benzene, toluene, and xylene) are generally quite low at all sites and maximum at ARF. The annual benzene levels are expected to be well below the NAAQS (National Ambient Air Quality Standards) of 5µg/m³ and within the safe limit in the city.

The mean 8-hourly ozone and CO levels are within the acceptable limits of NAAQS (8-hourly O₃:100 µg/m³; CO: 2 mg/m³). The diurnal pattern of CO and ozone are consistent as expected.

General inferences

It is to be noted that OC3/TC ratio is above 0.23 and the highest ratio of the fraction of OC to TC. It suggests a significant component of secondary organic aerosol is formed

in the atmosphere due to condensation and nucleation of volatile to semi-volatile organic compounds, which suggests emissions within and outside of Baddi.

Total PAH levels (17 compounds; particulate phase) had high variability in the range of 11 to 40 and B(a)P at 1.9 ng/m³ (annual standard is one ng/m³); the comparison with the annual standard is not advisable due to different averaging times. The highest PAH levels were observed at GSS.

The concentrations of molecular markers in PM_{2.5} (total of 6 compounds) vary in the range of 32 to 78 ng/m³, indicating the presence of common sources of emissions from coal, gasoline and domestic fuel.

In a broad sense, the air is toxic in the winter months as it contains a much larger contribution of fine particulates emitted from combustion sources. Fractions of secondary particles of both PM₁₀ and PM_{2.5} were consistent and needed to be controlled for better air quality. Combustion sources (vehicles, coal, and MSW burning) are consistent and require a strategy to control these sources.

Trend analysis

The long-term (2010-2019) temporal PM₁₀ and NO₂ levels were analyzed for annual and monthly variations and trends. The air quality data were obtained for 2010–2019 from HPSPCB. The results provide information in terms of trends such as (i) Significant downward, (ii) Significant upward, (iii) Firstly decreasing and then increasing, (iv) Firstly increasing then decreasing and (iv) No trend.

There is no specific trend in PM₁₀ and NO_x at Housing Board and A.H.C. Barotiwala. However, some months show an increasing trend, and some months indicate no trend. At the DIC site, PM₁₀ shows an increasing trend in all months, and NO_x also shows an increasing trend in all months except March. The annual levels of PM₁₀ show an increasing trend at all sites and NO_x at DIC and housing board. There is no trend in NO_x at A.H.C. Barotiwala both in monthly mean and annual levels.

Emission Inventory

Emission inventory (EI) is a basic necessity for planning air pollution control activities. The overall baseline EI for Baddi City is developed for the base year 2020. The pollutant-wise contribution is shown in Figures 1 to 5. Spatial distribution of pollutant emissions (for PM₁₀, NO_x, SO₂ and CO) from all sources is presented in Figure 6.

The total PM₁₀ emission load in the city is estimated to be 51482 kg/day. The top four contributors to PM₁₀ emissions are soil and road dust (89%), industries (textile, pharmaceutical, pulp and paper, food processing, induction furnaces, boilers, metal works; 5%), vehicles (3%), and industrial DG sets (1%); these are based on annual emissions. 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.

PM_{2.5} emission load in the city is estimated to be 15493 kg/day. The top four contributors to PM_{2.5} emissions are soil and road dust (68%), industries (16%), vehicles (10%), and industrial DG sets (4%); these are based on annual emissions. Seasonal and daily emissions could be highly variable.

SO₂ emission load in the city is estimated to be 7235 kg/day. Industrial (54%) and vehicular (29%) emissions account for 2/3rd of the total emission. Other sources which contribute for SO₂ emissions are Brick Kilns (9%) and Industrial DG sets (8%).

NO_x emissions load in the city is estimated to be 27812 kg/day. The majority of total emissions are attributed to Vehicular (56%), Industrial DG set (32%), and Industries (11%). Vehicular emissions occur at ground level, probably making it the most important emission. NO_x, apart from being a pollutant itself, is an important component in the formation of secondary particles (nitrates) and ozone. NO_x from vehicles and industry are potential sources for controlling NO_x emissions.

The estimated CO emission is about 60608 kg/day. The major contributors to CO emissions are Industries (68%), Vehicles (26%), Industrial DG sets (3%), and Brick Kiln (2%). Industries and Vehicles could be the main target for controlling CO for improving air quality concerning CO. The estimated emissions are for benzene: 2514 g/d, Pb: 7561 g/d, As: 119 g/d, Ni: 1319 g/d and BaP: 73 g/d from all sources.

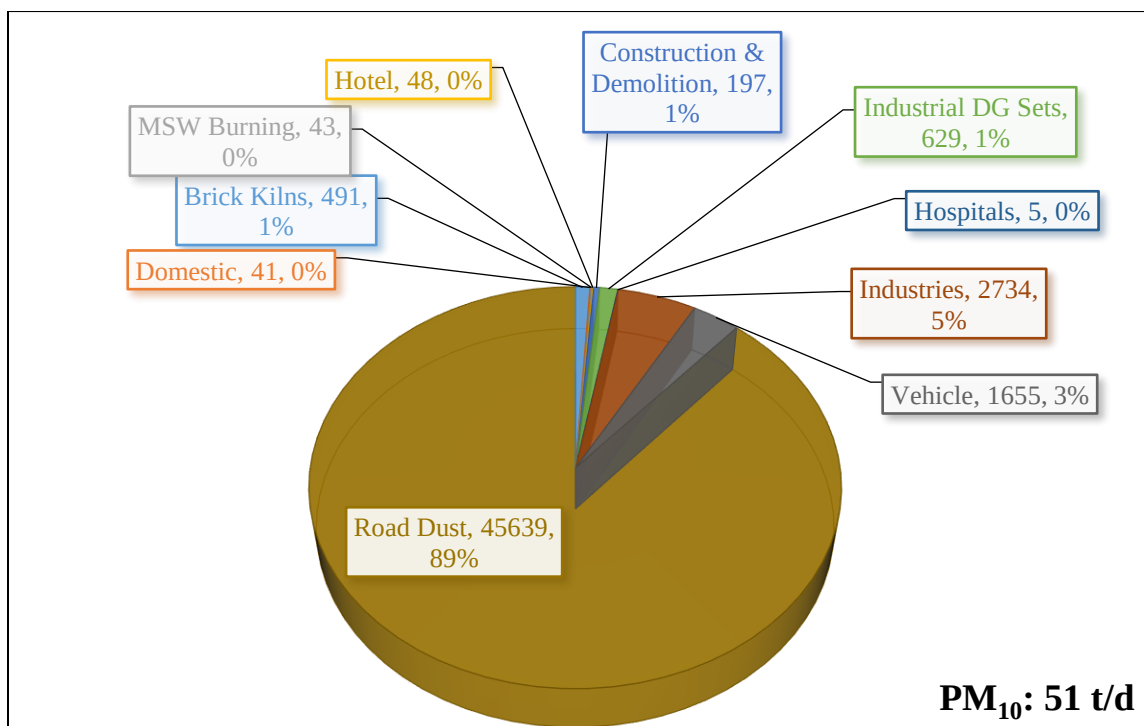


Figure 1: PM₁₀ emission Inventory of different sources in Baddi (kg/d)

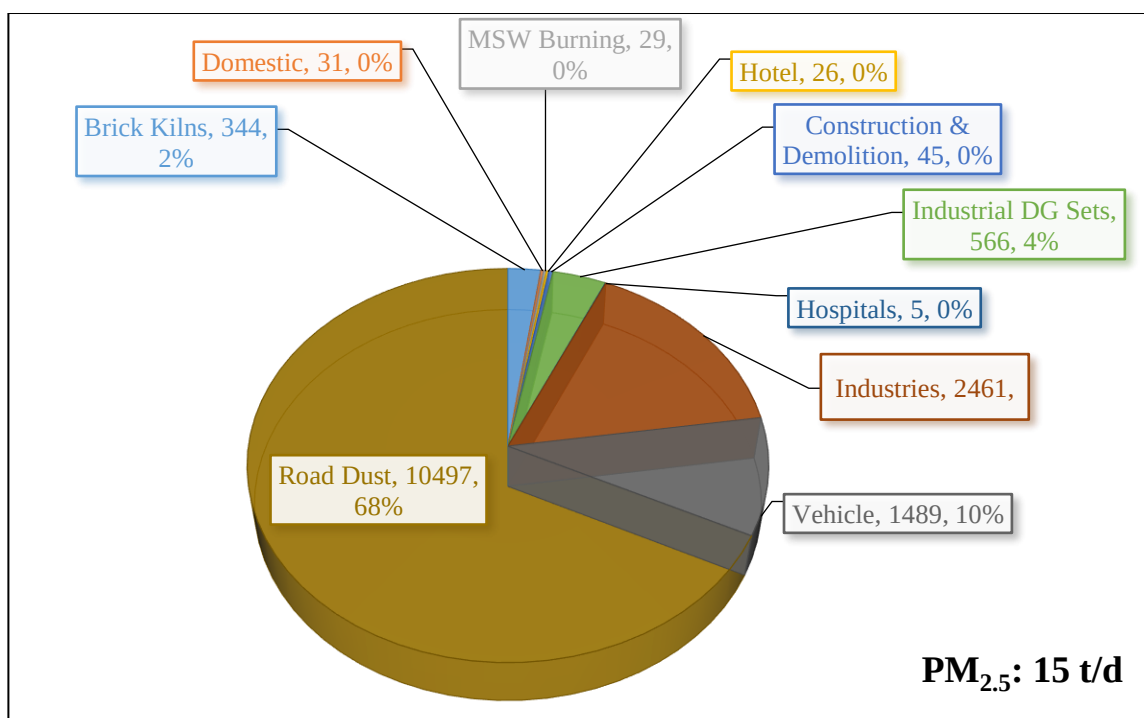


Figure 2: PM_{2.5} emission load of different sources in Baddi (kg/d)

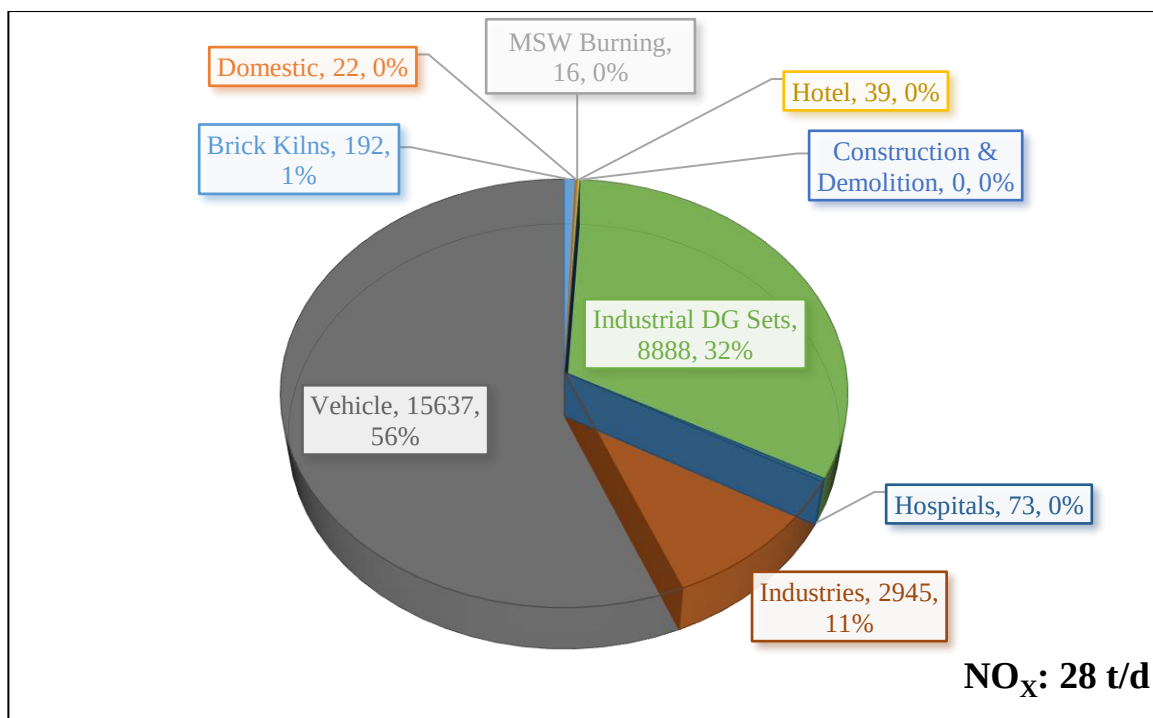


Figure 3: NO_x emission load of different sources in Baddi (Kg/d)

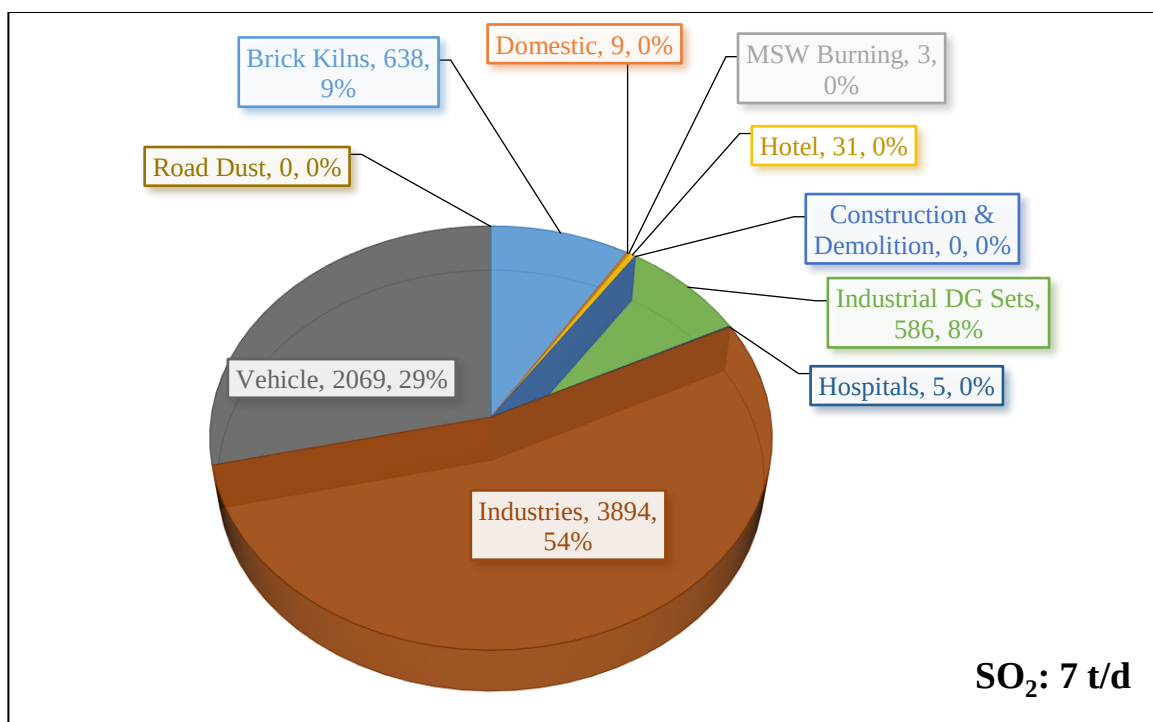


Figure 4: SO₂ emission load of different sources in Baddi (kg/d)

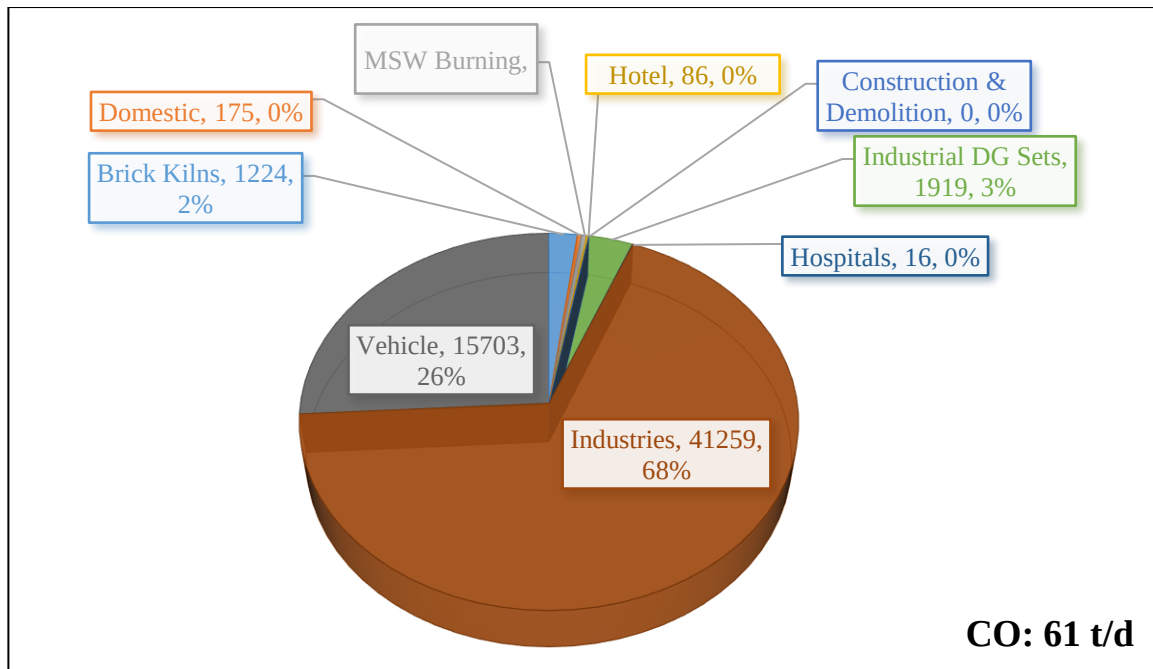


Figure 5: CO emission load of different sources in Baddi (kg/d)

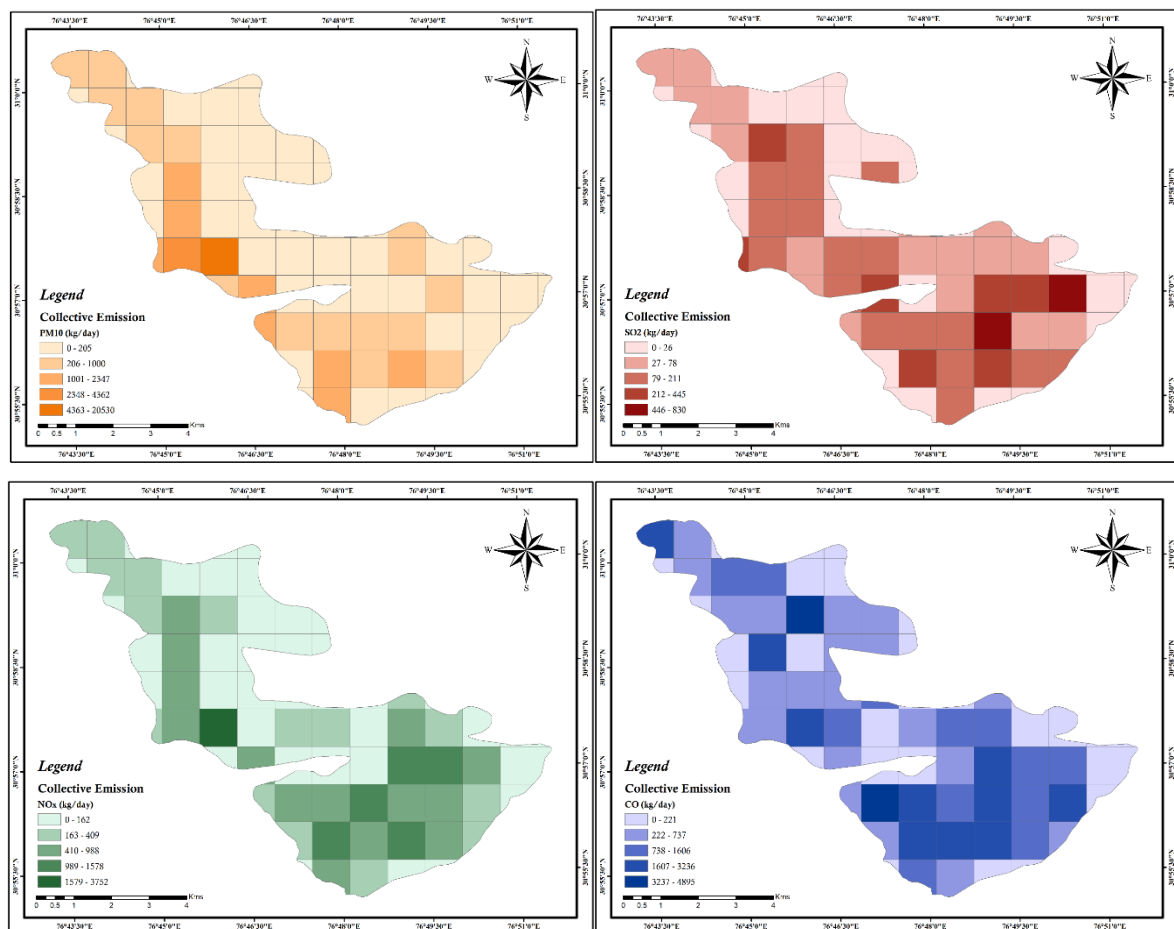


Figure 6: Spatial distribution of PM₁₀, NO_x, SO₂ and CO emissions in the city

Air Quality Modeling

Receptor Modeling

Based on the PMF (positive matrix factorization; USEPA's PMF5.0) modeling results (Figures 7 and 8) and their critical analyses, the following inferences and insights are drawn to establish quantified source-receptor impacts and to pave the path for the preparation of an action plan. The important inferences are:

- The relative sources contributions of PM_{10} and $PM_{2.5}$ in ambient air quality are generally the same. The sources (% contribution given in parenthesis for PM_{10} - $PM_{2.5}$ to the ambient air levels) include secondary inorganic aerosol (SIA) (13 – 14%), industrial and combustion (21 – 22%), soil and road dust (24 – 17%), MSW burning (8 – 8%), vehicles (12 – 15%), and biomass burning (14 – 17%).
- The most consistent sources of PM_{10} and $PM_{2.5}$ are vehicles, soil and road dust and industrial emissions. On average, the other sources may contribute more (or less), but their contributions vary from day to day. The most variable source was MSW burning, followed by SIA. Biomass burning was consistent in $PM_{2.5}$, but it was not true for PM_{10} .
- Soil and road dust contribute 24% in PM_{10} and 17% in $PM_{2.5}$, showing high variability in the city, which infers that the road condition in the city is not up to the mark. It indicates that most parts of roads and kerb-sides were poorly maintained.
- The contribution of biomass burning is relatively high at 14% (for PM_{10}) and 17% (for $PM_{2.5}$). Sizeable biomass is consistent in PM, indicating local sources present in Baddi and nearby areas. Biomass burning is because of arboriculture activities, agricultural residue burning, high energy crop burning for fuel, etc.
- From the uncollected solid waste, the major part would be burned. It is seen that MSW burning is a major source that contributes to both PM_{10} and $PM_{2.5}$ (8%). This emission is expected to be large in the regions of economically lower strata of the society, which do not have proper infrastructure for collection and disposal of MSW.
- MHJ site was surrounded by several industries. Therefore, it has the movement of large trucks ferrying raw material and finished products. Poor road conditions were spotted and dumping and burning of MSW and plastic waste along the roadsides was

a routine practice. The MSW/plastic burning contribution is exceptionally high at 31% both in PM_{10} and $PM_{2.5}$ which indicates improper management of waste generated from industries.

- Industrial contribution (22%) in the city is high for both PM_{10} and $PM_{2.5}$, which are in conformance with the fact that the city has a large number of industries. Industrial emission affirms that the fuels used both in domestic and industries are not of the clean category. Most industrial emissions are from combustion and process emissions. It may be noted that industrial emissions are only 5% in PM_{10} but their contribution is much higher at the breathing level.
- Secondary inorganic aerosol is significant in both PM_{10} (13%) and $PM_{2.5}$ (14%).
- Vehicles' contribution is consistent in PM_{10} (12%) and $PM_{2.5}$ (15%) in the city.

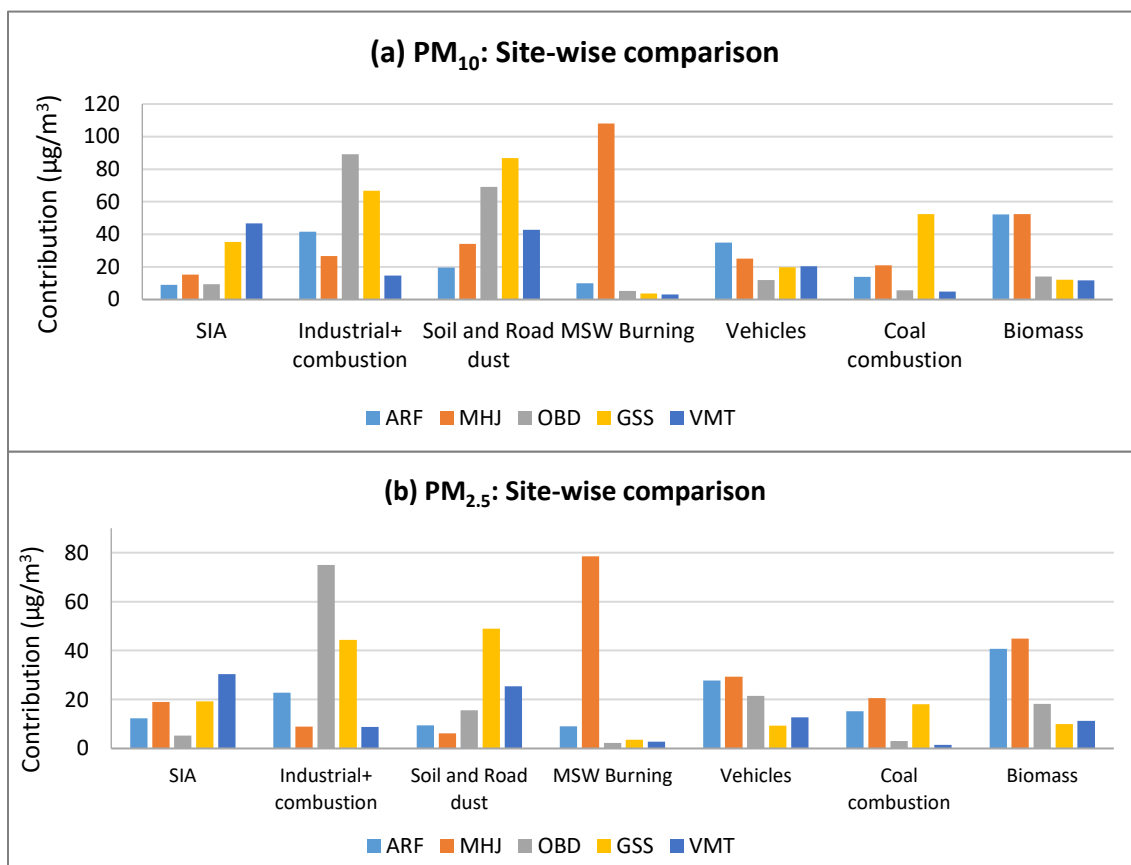


Figure 7: Site-specific source-wise contribution to PM_{10} and $PM_{2.5}$

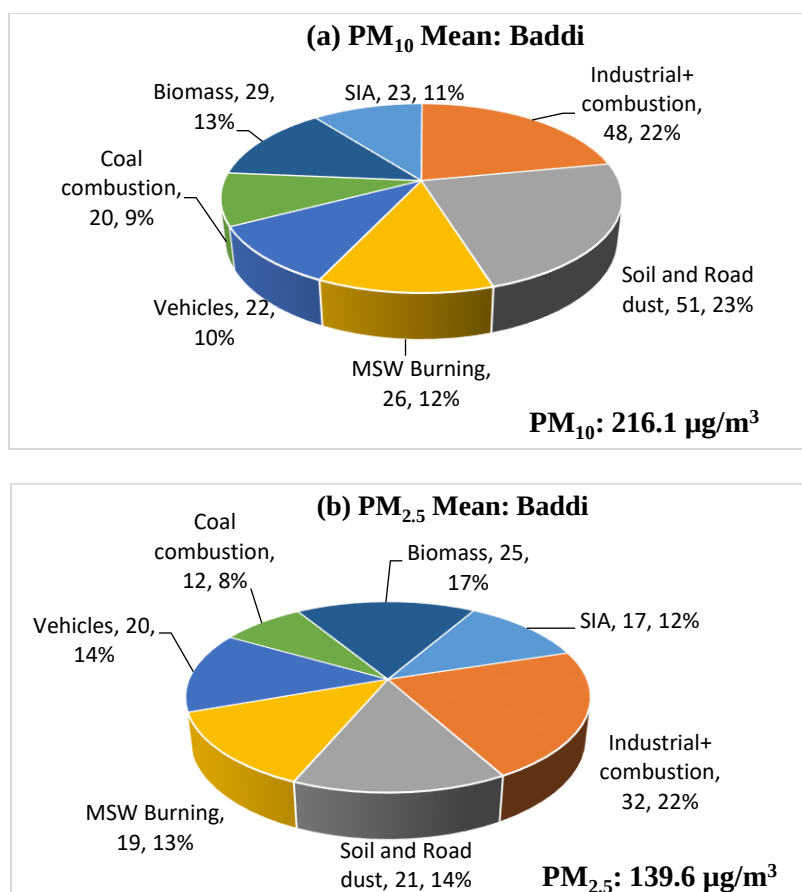


Figure 8: City level source contributions to PM₁₀ and PM_{2.5} levels

Control Options and Actions

A detailed analysis of control options for PM is given in Chapter 6. The proposed control options are summarized below and in Table 2.

- Hotels/Restaurants/Banquet Halls**

The total number of big hotels and restaurants was approximately 50, mainly situated in the central part of the city and along with the National Highway-105. It was observed that coal/wood is being used as fuel in the tandoor; the common fuel other than wood is LPG. The banquet halls (BHs) also use diesel generator sets at the time of power failure and coal, especially in tandoor and other cooking.

The Municipal Council Baddi should enforce coal-free cooking in the hotels and restaurants, BHs and marriage places. The ash must be stored in leak-free bags and properly disposed of. One may consider linking the commercial license to clean fuel,

which may be enforced by Municipal Council Baddi, Department of Food, Civil Supplies and Consumer Affairs, and oil companies (Indian Oil, HP, etc.).

- MSW Burning

MSW and other residue burning is a common practice in Baddi. Any form of garbage burning should be strictly stopped and strictly monitored for its compliance. The Municipal Council Baddi should have the provision of penalties and fines to deter the people from burning any residue and improve the collection and disposal of the MSW.

Proper disposal of MSW will require the development of infrastructure (including access to remote and congested areas) for effective collection of MSW and disposal at the scientific landfill site. The Municipal Council Baddi should prioritize the MSW collection mechanism starting systematically in each ward with an emphasis on public awareness. Special attention is required for fruits and vegetable markets, commercial areas, mandis and high-rise residential buildings. Industrial waste burning is dealt with separately.

A mechanism should be developed to carry out a mass balance of MSW generation, collection and disposal on a weekly and monthly basis. Major commercial areas identified for this issue were Sai Road, Rotary Chowk, Labour Chowk, and NRI Chowk. Major residential areas (having high density) were Housing Board Colony, Haripur Sandoli, Jhar Majri and Barotiwala.

Desilting and cleaning of municipal drains by Municipal Council Baddi should be undertaken on a regular interval, as the silt with biological activities can cause emission of air pollutants like H₂S, NH₃, VOCs, etc.

The official MSW dumping sites are located in Kainduwal and have undisposed waste. The MSW treatment and disposal sites should be developed and operated in compliance with MSW waste management rules. The treatment and rightful disposal of fresh waste should not take more than 7 days i.e., as storage becomes a major source of VOCs.

Sensitize people and media through workshops and literature distribution to prevent waste burning and its unauthorized disposal; this activity may be undertaken by Municipal Council Baddi, HPSPCB, NGOs and municipal corporators. A helpline

Number (for reporting complaints about air pollution viz., open burning, fugitive emission due to construction activities, etc.) should be created and advertised.

- **Brick Kilns**

Brick kilns are one of the major contributors to air pollution from the surrounding areas of Baddi. It is important to cover this sector in terms of emissions, although the majority of brick kilns lie outside the city boundary. These brick kiln (outside the city boundary) affects the local air quality of the city. There are approximately 12 brick kilns present in Baddi. Some brick kilns were present just at the border of the city, it is important to consider these brick kilns, as they contribute to the city's air pollution. These kilns used wood and coal as prominent fuels.

It has been found that most of the brick kilns were on conventional (Bull-trench) technology and only a few on Zig-Zag technology (emissions vary for two technologies).

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 with modern pollution control equipment.

- **Construction and Demolition**

The construction and demolition (C&D) emission can be classified as temporary or short-term. In a developing urban area, these temporary or short-term construction activities are frequent. This source is one of the significant ground-level emission sources. Nearly at all the construction sites, the construction material and their debris (lying open, without cover) are being stored outside the construction premises, near the road.

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

- Wet suppression
- wind speed reduction (for large construction sites)
- Waste should be properly disposed of and not stored on the premises or the roadside.

- Proper handling and raw material storage: covered the storage and provided the windbreakers.
- Vehicle cleaning and specific fixed wheel washing on leaving the site and damping down of haul routes.
- A fine screen covers the actual construction area.
- No storage (no matter how small) of construction material near the roadside (up to 10 m from the edge of the road).

The above control measures should be coordinated and supervised by Baddi-Barotiwala-Nalagarh Development Authority (BBNDA), Himachal Pradesh Housing Board, Municipal Council Baddi, Urban Development Department, PWD, and HPSPCB.

- Domestic sector

The fuel consumption pattern shows LPG (79%) consumption (CRISIL report, 2015), wood (12%), dung (2%), coal (2%), kerosene (4%) and crop residue (1%). The LPG for the urban area appears small as most large cities have over 95% LPG coverage. It appears that the labourers or daily wagers use solid fuel and may not have access to LPG. 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 to have LPG. There is a sizable floating population working in industries that must also have an LPG supply. For new residential societies, buildings should have a good infrastructure for PNG.

- Soil and Road Dust

It can be seen from Chapters 4 and 5, that the soil and road dust emissions and their contributions to ambient air concentration are consistent and it is one of the largest sources of PM₁₀ and PM_{2.5} emissions. The silt load, an important factor in PM emissions from the road varied from 8.2 to 62.7 g/m², which is very high (typical in developed countries less than 1 g/m²). The industrial area, where heavy vehicle movement is seen, also shows the high road dust emission. It is suggested that high traffic density roads should be properly maintained, paved from one end to another, have sidewalks through interlocking blocks for the pedestrians, proper drainage from the road, and shrubs should be planted on on-road dividers. Out of the total road

network, about 60% of surface quality is poor. The following control measures are suggested to reduce the dust emissions from the major roads:

- Convert all unpaved, partially paved roads to fully paved roads.
- Municipal Council should carry out vacuum-assisted sweeping.
- If the silt load is greater than 3 gm/m², the vacuum-assisted sweeping should be carried out along with washing and there should be regular surveillance for maintaining low silt content on road.
- NHAI should ensure that the silt load on highways maintained by them should have a silt load of less than 3 gm/m² across the road in the entire stretch in the city.
- The condition of the roads must be maintained properly with no potholes and shoulders paved by interlocking concrete to have a proper sidewalk.
- The truck carrying construction material or any airborne material should be covered.
- Vacuum sweeping of roads with high silt load locations (Sai Road, Baddi-Barotiwala Road, Haripur-Sandoli Road and other major roads) should be carried out at least four times a month also carpeting of shoulders, maintenance of the road, dividers, and kerbs should be carried out at regular intervals. This activity should have proper documentation, including the quantity of dust collected from the roads.
- Shrubs and perennial forages or grass covers should be planted on the medians wherever possible.

The above control measures should be coordinated and supervised by BBNDA, Himachal Pradesh Housing Board, Municipal Council Baddi, NHAI, PWD, and State Forest Department (for increasing green cover and plantation) as per their jurisdictions.

- **Vehicle Emission Control and Traffic Management**

The vehicle emission contribution is significant for CO, NO_x, PM₁₀, and PM_{2.5}. There is a relatively large contribution of diesel vehicles (trucks, buses, LCVs, cars, etc.) to PM₁₀, PM_{2.5} and NO_x. Out of about 1.5 tonnes/d emissions of PM_{2.5} from vehicles, about 70% is from diesel vehicles, especially trucks and buses. Therefore, control measures must focus on advanced technological intervention for diesel vehicles like

Diesel Particulate Filter (DPF). The general recommendations for vehicular emission control are enumerated below (specific recommendations are discussed later).

- Retro-fitment of DPF: This option must be explored as Bharat stage VI fuel is available and this technology can be adopted.
- Industries should encourage employing trucks and heavy-duty vehicles of Bharat stage-VI or IV with DPF for transportation of the raw and finished products at and from the industry.
- By the end of 2024, a target of 50% of the total registration of vehicles in the city should be electric vehicles (EVs) in the sector of 2Ws, 3Ws and passenger cars. Strong and plug-in hybrid electrified vehicles may also be encouraged. Charging infrastructure should come up quickly at multiple places (As per Ministry of Petroleum guidelines, Charging infrastructure for EV- Revised guidelines and standards, Oct 1, 2019, MoP), including public buildings and parking lots and battery swapping facilities should be planned to avoid long charging periods, especially for two-wheelers.
- Emissions from in-use vehicles also depend on the maintenance and upkeep of vehicles. In this regard, it is suggested that each vehicle manufacturing company should have its authorized service centres in sufficient numbers to cater to the need of their vehicles in the city. Every vehicle at least once a year should undergo a thorough check-up and compliance with pollution control devices and their proper functioning from an authorized centre.
- 4 - 8 PUC Centres are required per 1,00,000 vehicles (5mins/vehicle and 12 hrs/day). Maintenance and calibration of equipment must be ensured by regular surveillance.
- Restriction on plying and phasing out of 10 years old commercial diesel-driven vehicles.
- Check the overload vehicles: Expedite installation of weigh-in-motion bridges and machines at all entry points to Baddi to ensure that vehicles are not overloaded.
- Himachal Road Transport Corporation (HRTC) should plan and install multiple electric charging facilities in its depots (in Baddi and other destinations) to quickly move towards electric buses.

- The local public transport in the city should also move to electric buses. It is suggested that buses should be medium size of 30 seating capacity and provide better frequency for easy maneuvering in the city to avoid difficult turning and congestion.
 - Route rationalization: Improvement of availability by rationalizing routes and fleet enhancement with requisite modifications. Ensure integration of the existing metro system with bus service.
 - IT systems in buses, bus stops, and control centre and passenger information systems should be introduced for the reliability of bus services and monitoring.
 - The intersections are poorly designed. There is a need to improve the intersections of roads at many places in Baddi city. The traffic signal, wherever installed, does not function properly which leads to slow traffic movement and reduced road safety. Steps shall be taken to install traffic signals on all the major intersections and traffic police shall enforce smooth traffic.
 - Other than a few roads, there is a lack of footpath availability and marking of zebra crossing for the pedestrian movements and people are forced to walk on the road. Proper footpaths and ease of crossing should be available for the pedestrians.
- Decongestion of Roads

To increase the average speed and get full advantage of BS-VI, decongestion, removing encroachments from the roads, and stopping unauthorized and improper parking is essential. The off-street parking is inadequate in the city causing jams and permanent congestion because of on-street haphazard parking. The specific points that will help in decongestion are elaborated below.

- Strict action on roadside encroachment.
- The operation of unauthorized vehicle service centres should be stopped
- The important points of congestion are Hotel Legend, Maluk Majara, Vardhman Chowk, Samsung Plaza, Gol Market Chauraha, Nagar Nigam and Sikka Hotel Chowk. The city's main road is Sai Road and this is also Haripur-Sandoli Bypass Road; As a result, these routes within the city will also be congested.
- Areas that are adjacent to the market centers like Gol Market, Samsung Plaza, Nagar Nigam, and Sikka Hotel Chowk experience heavy traffic congestion due to

the unregulated parking and encroachment by local shop owners. The on-street parking has to be removed and if required multistorey parking is developed.

- Parking spaces: Off-street parking is inadequate in the city. There must be no parking zone (up to 50 m including auto, electric and hand-pulled rickshaw) near the intersections. It will help the smooth traffic flow.
- Certain parking policies in congestion areas (high parking costs, at city centers, only parking should be limited for physically challenged people.
- The city should strictly follow recommendations from IRC 12-2015 of prohibiting on-street parking as detailed below:
 - Near Intersections: the capacity of an intersection is greatly reduced if vehicles are allowed to park on the approaches.
 - Narrow Streets: Narrow streets with heavy traffic require that all possible measures should be taken to remove obstacles to traffic flow. Prohibition of parking can have a salutary effect on traffic flow & congestion.
 - Pedestrian Crossings: Desirable to prohibit parking within about 8.0 m from the pedestrian crossings.
 - Parking prices: Since on-street parking has been a major concern within the city, strict guidelines need to be adopted to discourage private vehicles in the settlements.
 - Promoting public transport travel: Increasing the efficiency of public transport can deliver benefits of enhanced road capacities, accessibility and safety, and security.

- Industries and Diesel Generator Sets

There are more than 300 polluting units that are claimed to have control devices installed. The devices are inadequate or poorly operated with very low collection efficiency. It is suggested that these industries must control PM with highly efficient capture devices and suitable disposal of collected particles.

It is also observed that the majority of industries use coal, wood, pet coke, rice husk and HSD as fossil fuels, in the industries. Since the residential areas are surrounded by many industrial clusters within the city, the industry should shift to PNG or LDO or other cleaner fuels in a time-bound manner acceptable to industry and regulatory agencies.

A coordinated effort under the supervision of HPSPCB and Industries Departments (i.e., BBNDA) is suggested to implement the following control measures:

- The majority of industries use multi-cyclones as air pollution control devices. It is recommended that these cyclones should be replaced by baghouses for effective control of particulate emissions.
- Ensuring compliance with emission standards in industries: All industries causing Air, Water, and Noise pollution shall be made compliant w.r.t environmental regulations.
- Strict action to stop unscientific disposal of industrial waste in the surrounding area.
- Industrial waste burning should be stopped immediately, which is seen in the industrial area especially packing materials and soiled papers and clothes.
- The area and road in front of the industry should be free from any storage or disposal of any waste or raw material all times.
- The industry should follow best practices to minimize fugitive emissions within the industry premises; all leakages, transfer points, loading and unloading, and material handling within the industry should be controlled and comply with USEPA regulation LDAR (Leak detection and repairs).
- Adequate and quality electric supply should be available to the industries for an effective industrial operation and avoidance of the DG sets.
- It is seen that industrial waste (hazardous) is mixed with MSW and burnt in several parts of Baddi. It is recommended that no industrial waste should be mixed with MSW but rather disposed of at TSDF for hazardous waste disposal.
- There are industries with induction furnaces, which is a very pollution process, 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.
- To address the pollution caused by fugitive emissions using induction furnaces a fume gas capturing device has been developed and is commercially available (details in Chapter 6).

- It is recommended that a fume gas capturing hood followed by baghouse should be used to control air pollution.
- Strict compliance and surveillance are required that hazardous waste goes to TSDF under the supervision of Municipal Council Baddi and HPSPCB.

Strengthening of HPSPCB Baddi, Regional Office

- New manpower recruitment for sampling, analysis, assessment, and surveillance
- Automated stack testing kit
- The surveillance team should work in two shifts (day and night)
- Strict action against visible emission and reporting mechanism
- Proper documentation of violation of emission norms
- Capacity-building should be done through regular training of personals
- Laboratory upgradation

It may be noted that this study on air quality management is comprehensive that provides insight into air quality measurements, emission inventory, source-receptor impact analyses, identification of control options, their efficacies and action plan for attaining air quality standards.

Table 2: Control Options and Action Plan for Baddi

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
Hotels/ Restaurants/ Banquet Halls	All Restaurants small or large should not use coal and shift to gas-based or electric (for sitting capacity of more than 10 persons) appliances.	Municipal Council Baddi	1 year
	Link Commercial license to clean fuel	Municipal Council Baddi, Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian Oil/HP, etc.)	1 year
	Ash/residue from the tandoor and other activities should not be disposed of near the roadside. Requires ward-level surveillance.	Municipal Council Baddi	1 year
Domestic Sector	LPG to all. Slums and about 21% of the population are still using wood, biomass and dung as cooking fuel.	Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian Oil/HP, etc.)	1 year
	No new building complex or society be allowed without a PNG supply distribution network	Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian Oil/HP, etc.)	1 year
	By 2030, the city may plan to shift to electric	Department of Food, Civil Supplies and	10 years

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
	cooking (common in western countries) or PNG at the minimum	Consumer Affairs and Oil Companies (Indian Oil/HP, etc.)	
Municipal Solid Waste (MSW) Burning	Any type of garbage burning should be strictly stopped. Current waste collection and surveillance are poor.	Municipal Council Baddi	Immediate
	Surveillance is required that hazardous waste goes to TSDF.	Municipal Council Baddi, HPSPCB, BBNDA	
	Desilting and cleaning of municipal drains	Municipal Council Baddi	
	Waste burning in Industrial areas should be stopped.	HPSIDC, HPSPCB	
	Daily, Monthly mass balance of MSW generation and disposal	Municipal Council Baddi	
	Sensitize people and media through workshops and literature distribution so as not to burn the waste.	Municipal Council Baddi, HPSPCB, and NGO	
Construction and Demolition	Wet suppression	Baddi, Barotiwala, Nalagarh Development Authority (BBNDA), Municipal Council Baddi, Urban Development Department, PWD	Immediate
	Wind speed reduction (for large construction sites)	BBNDA, Municipal Council Baddi, Urban	

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
		Development Department, PWD	
	Enforcement of C&D Waste Management Rules. The waste should be sent to a construction and demolition processing facility	BBNDA, Municipal Council Baddi, Urban Development Department, PWD	Immediate
	Proper handling and storage of raw material: covered the storage and provide the windbreakers.	BBNDA, Municipal Council Baddi, Urban Development Department, PWD	
	Vehicle cleaning and specific fixed wheel washing on leaving the site and damping down of haul routes.	BBNDA, Municipal Council Baddi, Urban Development Department, PWD	
	The actual construction area should be covered by a fine screen.	BBNDA, Municipal Council Baddi, Urban Development Department, PWD	
	No storage (no matter how small) of construction material near the roadside (up to 10 m from the edge of the road)	BBNDA, Municipal Council Baddi, Urban Development Department, PWD	
	Builders should leave 25% area for green belt in residential colonies to be made mandatory.	BBNDA, Municipal Council Baddi, Urban Development Department, PWD	

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
	Sensitize construction workers and contract agencies through workshops.	BBNDA, Municipal Council Baddi, Urban Development Department, PWD, HPSPCB, and NGO	
Road Dust	The silt load in Baddi varies from 8.2 to 62.7 g/m ² . The silt load on each road should be reduced to under 3 gm/m ² . Regular vacuum sweeping should be done on the road having a silt load above 3 gm/m ² .	BBNDA, Municipal Council Baddi, National Highway Authority, PWD, HPSPCB (for silt load compliance)	Immediate
	Convert unpaved roads to paved roads. Maintain pothole-free roads.	BBNDA, Municipal Council Baddi, National Highway Authority, PWD, HPSPCB to carry out surveillance	
	Implementation of truck loading guidelines; use appropriate enclosures for haul trucks and gravel paving for all haul routes.	BBNDA, Municipal Council Baddi, National Highway Authority, PWD	
	Increase green cover and plantation. Undertake the green of open areas, community places, schools, and housing societies.	BBNDA, Municipal Council Baddi, National Highway Authority, State Forest Department, PWD	

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
	vacuum-assisted sweeping is carried out four times a month on major roads with road washing.	BBNDA, Municipal Council Baddi, National Highway Authority, PWD	
Vehicles	Diesel vehicles entering the city should be equipped with DPF which will bring a reduction of 40% in emissions (This option can be implemented with vehicles of the BS-IV category as well)	State Transportation Department	3 years
	Industries must be encouraged to use BS-VI or BS-IV (with DPF) vehicles for the transportation of raw and finished products	Industrial Associations and State transport Department	Immediate
	Restriction on plying and phasing out of 10 years old commercial diesel-driven vehicles.	Transport Department	2 years
	Introduction of cleaner fuels (CNG/ LPG) for all vehicles (other than 2-W).	Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian Oil/HP, etc.)	2 years
	Check to overload: Expedited installation of weigh-in-motion bridges and machines at all entry points to Baddi.	Transport Department, Traffic Police, Baddi, NHAI, Toll agencies	Six-months

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
	Electric/Hybrid Vehicles should be encouraged; New residential and commercial buildings to have charging facilities. All new city buses should be electric.	Transport Department, ARTO Baddi	1 year
	Bus stop and their parking should be rationalized to ensure more efficient utilization. The depots should include well-equipped maintenance workshops. Adequate charging stations.	Transport Department, ARTO Baddi	1 year
	Enforcement of bus lanes and keeping them free from obstruction and encroachment.	Municipal Council Baddi, ARTO Baddi	1 year
	Route rationalization: Improvement of availability by rationalizing routes and fleet enhancement with requisite modification.	BBNDA, ARTO Baddi, Traffic Police, Baddi	1 year
	IT systems in buses, bus stops, control centers, and passenger information systems for the reliability of bus services and monitoring.	Baddi Barotiwala Nalagarh Development Authority, ARTO Baddi, Traffic Police, Baddi	1 year
	Movement of materials (raw and product) within the	Transport Department, Baddi, BBNDA, ARTO	1 year

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
	city should be allowed between 10 PM to 5 AM.	Baddi, Traffic Police, Baddi	
Industries and DG Sets	Ensuring emission standards in industries. Shifting of polluting industries.	HPSPCB, Industries Department	1 year
	Strict action to stop unscientific disposal of hazardous waste in the surrounding area	Municipal council and HPSPCB	
	There should be separate Treatment, Storage, and Disposal Facilities (TSDFs) for hazardous waste.	Industrial Associations, BBNDA, HPSIDC, Industries Department, HPSPCB	2 years
	Industrial waste burning should be stopped immediately	Industrial Associations, HPSIDC, HPSPCB	Immediate
	Following best practices to minimize fugitive emissions within the industry premises, all leakages within the industry should be controlled	Industrial Associations, HPSIDC, HPSPCB	Immediate
	Area and road in front of the industry should be the responsibility of the industry	Industrial Associations, HPSIDC, HPSPCB	
	Category A Industries (using coal and other dirty fuels)		
	About 299 boilers, Heater and furnaces in Baddi are	Department of Food, Civil Supplies and	2 years

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
	running over coal, wood, and other dirty solid fuels which should be shifted to natural gas and electricity	Consumer Affairs and Oil Companies (Indian Oil/HP, etc.), Industrial Associations, HPSPCB	
	Almost all rotary furnaces having significant emissions are running on coal that needs to be shifted to natural gas and electricity	Industrial Associations, HPSPCB	2 years
	Multi-cyclones should be replaced by baghouses. Ensure installation and operation of air pollution control devices in industries.	Industrial Associations, HPSPCB	2 years
	Category B Industries (Induction Furnace)		
	Recommended Fume gas capturing hood followed by Baghouse should be used to control air pollution	Industrial Associations, HPSPCB	2 years
	Diesel Generator Sets		
	Strengthening of grid power supply, uninterrupted power supply to the industries	State Energy Department, HPSEBL	2 years
	Renewable energy should be used to cater to the need of office requirements in the absence of power failure to stop the use of DG Set	Industrial Associations	2 years

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
Decongestion of Roads in high traffic areas	Strict action on roadside encroachment. Disciplined movement of tempos to stop only at designated spots. Action on driving in the wrong lane	BBNDA, Municipal Council Baddis, ARTO Baddi, Traffic Police, Baddi	6 months
	Disciplined Public transport (designate one lane stop).	ARTO Baddi., Traffic Police, Baddi	
	Removal of the free parking zone. No parking within 50 m of any major crossing and or chaurahs, rotaries. Strictly follow Indian Road Congress guidelines	BBNDA, Municipal Council Baddi, ARTO Baddi, Traffic Police, Baddi	
	Examine the existing framework for removing broken vehicles from roads and create a system for speedy removal and ensure minimal disruption to traffic.	BBNDA, ARTO Baddi, NHAI, Traffic Police, Baddi	
	Synchronize traffic movements or introduce intelligent traffic systems for lane-driving.	BBNDA, ARTO Baddi, NHAI, Traffic Police, Baddi	
	Mechanized multi-story parking at bus stands, and big commercial areas.	BBNDA, ARTO Baddi, Municipal Council Baddi, NHAI, Traffic Police, Baddi	

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
	Remove at least 50 percent of on-street parking in the city.		
	Identify traffic bottleneck intersections and develop a smooth traffic plan. For example, Hotel Legend, Maluk Majara, Vardhman Chowk, Samsung Plaza, Gol Market Chauraha, Nagar Nigam and Sikka Hotel Chowk are the main bottlenecks for traffic.	BBNDA, ARTO Baddi, Municipal Council Baddi, Traffic Police, Baddi	
	Parking policy in congestion areas (high parking cost, at city centers, only parking is limited for physically challenged people, etc).	BBNDA, ARTO Baddi, Municipal Council Baddi, NHAI, Traffic Police, Baddi	
	The important point of congestion is Gol market Chaburah. Parking on the Sai Road should be strictly prohibited.	ARTO Baddi, Traffic Police	2 years
*The above steps should not only be implemented in Baddi municipal limits rather these should be extended up to at least 10 km beyond the boundary. This will need support from the central government.			

Table of contents

Executive Summary	iii
Table of contents.....	xxxiv
List of Figures	xxxviii
List of Tables	xliv
Acknowledgments.....	xlvi
1 Introduction.....	1
1.1 Background	1
1.2 General Description of Baddi City	1
1.2.1 Geography and Demography	2
1.2.2 Climate.....	2
1.2.3 Emission Source Activities	2
1.3 Need for the Study.....	3
1.3.1 Air Pollution Levels: Earlier Studies	3
1.4 Objectives and Scope of Work.....	3
1.5 Approach to the Study	4
1.5.1 Selection of sampling sites.....	5
1.5.2 Identification and Grouping of Sources for Emission Inventory	6
1.5.3 Emission Source Profiles	6
1.5.4 Application of Receptor modeling.....	6
1.5.5 Time Series Analysis	7
1.6 Report Structure	7
2 Air Quality: Measurements, Data Analyses and Inferences	9
2.1 Methodology	9
2.1.1 Site Selection and details	9

2.1.2	Instruments and Accessories.....	12
2.2	Quality Assurance and Quality Control (QA/QC) Quality Control.....	13
2.3	Ambient Air Quality – Results.....	16
2.3.1	Particulate Matter (PM ₁₀ , PM _{2.5}).....	18
2.3.2	Gaseous pollutants	23
2.3.3	Volatile Organic Compounds (VOCs: BTX).....	26
2.3.4	Elemental and Organic Carbon Content (EC/OC) in PM _{2.5}	28
2.3.5	PAHs in PM _{2.5}	33
2.3.6	Molecular Markers in PM _{2.5}	34
2.3.7	Chemical Composition of PM ₁₀ and PM _{2.5} and their correlation matrix	35
2.3.8	Comparison of PM ₁₀ and PM _{2.5} Composition.....	46
2.3.9	Carbon monoxide (CO).....	48
2.3.10	Ozone (O ₃)	50
2.4	Interpretations and Inferences	53
3	Time Series Analysis and Trend.....	57
3.1	Introduction	57
3.2	Methodology	57
3.3	Results and Interpretations	58
3.3.1	Annual pattern in PM ₁₀ and NO ₂	58
3.3.2	Variation in the slope: Trend analyses.....	63
4	Emission Inventory	65
4.1	Introduction	65
4.2	Methodology	65
4.2.1	Categorization of Sources	66
4.2.2	Data Collection	66
4.2.3	Digital Data Generation	67
4.2.4	Emission Factor	73

4.2.5	Domestic Sector	74
4.2.6	Construction and Demolition.....	80
4.2.7	Industrial Diesel Generator Sets (Industrial DG sets).....	83
4.2.8	Hotels, Restaurants, Guest Houses (GHs), and Banquet Halls (BHs).....	87
4.2.9	Brick Kilns	91
4.2.10	Municipal Solid Waste Burning.....	95
4.2.11	Hospitals	99
4.2.12	Industries.....	101
4.2.13	Parking Lot Survey	109
4.2.14	Vehicular-Line Sources	110
4.2.15	Traffic Congestion	117
4.2.16	Paved and Unpaved Road Dust.....	118
4.3	City Level Emission Inventory	122
5	Receptor Modelling and Source Apportionment	129
5.1	Receptor Modeling.....	129
5.2	PMF Modeling: Source Apportionment of PM ₁₀ and PM _{2.5}	130
5.3	PMF Modeling Results and interpretation (Baddi)	131
5.3.1	MHJ.....	133
5.3.2	OBD	136
5.3.3	ARF.....	138
5.3.4	GSS	139
5.3.5	VMT.....	141
5.3.6	Overall.....	143
5.4	Interpretations and Inferences	148
6	Control options, Analyses and Prioritization for Actions.....	151
6.1	Air Pollution Scenario in the City of Baddi	151
6.2	Controlling of sources within the city	151

6.2.1	Hotels/Restaurants/Banquet Halls	151
6.2.2	Municipal Solid Waste (MSW) Burning	153
6.2.3	Brick Kilns.....	155
6.2.4	Construction and Demolition.....	156
6.2.5	Domestic sector.....	157
6.2.6	Soil and Road Dust	158
6.1.1	Vehicle Emission Control, Congestion and Traffic Management	160
6.2.7	Industries.....	167
6.3	Summary of Actions and Control Options.....	170
6.4	Strengthening of HPSPCB Baddi, Regional Office	170
	References.....	181
	Annexure 1.....	184
	Annexure 2.....	185

List of Figures

Figure 1: PM ₁₀ emission Inventory of different sources in Baddi (kg/d)	ix
Figure 2: PM _{2.5} emission load of different sources in Baddi (kg/d).....	ix
Figure 3: NO _x emission load of different sources in Baddi (Kg/d).....	x
Figure 4: SO ₂ emission load of different sources in Baddi (kg/d)	x
Figure 5: CO emission load of different sources in Baddi (kg/d)	xi
Figure 6: Spatial distribution of PM ₁₀ , NO _x , SO ₂ and CO emissions in the city	xi
Figure 7: Site-specific source-wise contribution to PM ₁₀ and PM _{2.5}	xiii
Figure 8: City level source contributions to PM ₁₀ and PM _{2.5} levels.....	xiv
Figure 1.1: Annual average levels of PM ₁₀ from 2013-14 to 2017-18 (HPSPCB, 2018).....	3
Figure 1.2: Approach to the Study and Major Tasks	5
Figure 2.1: Photographs of Sampling Sites.....	10
Figure 2.2: Land-use Pattern and Locations of Sampling Sites.....	10
Figure 2.3: Photographs of the Instruments	13
Figure 2.4: PM Concentrations at MHJ	18
Figure 2.5: PM Concentrations at OBD.....	19
Figure 2.6: PM Concentrations at ARF	19
Figure 2.7: PM Concentrations at GSS.....	20
Figure 2.8: PM Concentrations at VMT	21
Figure 2.9: Comparison of PM levels at all sites	22
Figure 2.10: Comparison of PM _{2.5} /PM ₁₀ ratio for all sites	22
Figure 2.11: SO ₂ , NO ₂ and NH ₃ concentrations at MHJ.....	23
Figure 2.12: SO ₂ , NO ₂ and NH ₃ concentrations at OBD	24
Figure 2.13: SO ₂ , NO ₂ and NH ₃ concentrations at ARF	24
Figure 2.14: SO ₂ , NO ₂ and NH ₃ concentrations at GSS	25
Figure 2.15: SO ₂ , NO ₂ and NH ₃ concentrations at VMT	25
Figure 2.16: Comparison of gaseous pollutants levels at all sites	26
Figure 2.17: VOCs Concentrations at different sites in Baddi	27
Figure 2.18: Comparison of gaseous pollutants levels at all sites	27
Figure 2.19: EC and OC Content in PM _{2.5} at MHJ.....	28
Figure 2.20: EC and OC Content in PM _{2.5} at OBD	29
Figure 2.21: EC and OC Content in PM _{2.5} at ARF	30

Figure 2.22: EC and OC Content in PM _{2.5} at GSS	31
Figure 2.23: EC and OC Content in PM _{2.5} at VMT	31
Figure 2.24: Comparison of EC and OC in PM _{2.5} for all Sites	32
Figure 2.25: PAHs Concentrations in PM _{2.5}	34
Figure 2.26: Molecular Markers in PM _{2.5}	35
Figure 2.27: Concentrations of species in (a) PM ₁₀ and (b) PM _{2.5} at Baddi	36
Figure 2.28: Percentage distribution of species in PM ₁₀ at Baddi	38
Figure 2.29: Percentage distribution of species in PM _{2.5} at Baddi	40
Figure 2.30: Compositional comparison of species in PM _{2.5} vs PM ₁₀	47
Figure 2.31: Hourly average concentration ($\mu\text{g}/\text{m}^3$) of CO at MHJ	48
Figure 2.32: Hourly average concentration ($\mu\text{g}/\text{m}^3$) of CO at OBD	49
Figure 2.33: Hourly average concentration ($\mu\text{g}/\text{m}^3$) of CO at GSS	49
Figure 2.34: Hourly average concentration ($\mu\text{g}/\text{m}^3$) of CO at VMT	50
Figure 2.35: Hourly average concentration ($\mu\text{g}/\text{m}^3$) of O ₃ at MHJ	51
Figure 2.36: Hourly average concentration ($\mu\text{g}/\text{m}^3$) of O ₃ at OBD	52
Figure 2.37: Hourly average concentration ($\mu\text{g}/\text{m}^3$) of O ₃ at GSS	52
Figure 2.38: Hourly average concentration ($\mu\text{g}/\text{m}^3$) of O ₃ at VMT	53
Figure 3.1: Stepwise methodology and major tasks (Nagar et al., 2019)	58
Figure 3.2: Variation in PM ₁₀ at various sites in Baddi	60
Figure 3.3: Time series variation in NO _x at various sites	61
Figure 3.4: Timeseries of annual mean levels of PM ₁₀ at various sites	62
Figure 3.5: Timeseries of annual mean levels of NO _x at various sites	63
Figure 4.1: Stepwise Methodology adopted for the Study	65
Figure 4.2: Source Category and type of sources	66
Figure 4.3: Baddi City Boundary	67
Figure 4.4: Ward Map	67
Figure 4.5: Agricultural Area Map	68
Figure 4.6: Green Area Map	68
Figure 4.7: Industrial Area Map	69
Figure 4.8: Waterbodies Area Map	69
Figure 4.9: Major Road Network Map	70
Figure 4.10: Minor Road Network Map	70
Figure 4.11: Settlement Area Map	71

Figure 4.12: Open Area Map	71
Figure 4.13: Land use Map of Baddi City	72
Figure 4.14: Grid Map of Baddi City showing Grid Identity Numbers.....	73
Figure 4.15: Emission Load from Domestic Sector.....	75
Figure 4.16: PM ₁₀ Emission load from Domestic Sector (Kg/day, %).....	75
Figure 4.17: PM _{2.5} Emission load from Domestic Sector (Kg/day, %)	76
Figure 4.18: SO ₂ Emission load from Domestic Sector (Kg/day, %).	76
Figure 4.19: NO _x Emission load from Domestic Sector (Kg/day, %)	77
Figure 4.20: CO Emission load from Domestic Sector (Kg/day, %).	77
Figure 4.21: Spatial Distribution of PM ₁₀ Emissions from Domestic Sector	78
Figure 4.22: Spatial Distribution of PM _{2.5} Emissions from Domestic Sector.....	78
Figure 4.23: Spatial Distribution of SO ₂ Emissions from Domestic Sector	79
Figure 4.24: Spatial Distribution of NO _x Emissions from Domestic Sector.....	79
Figure 4.25: Spatial Distribution of CO Emissions from Domestic Sector	80
Figure 4.26: Construction material and debris near construction sites	81
Figure 4.27: Location of Construction and Demolition sites at Baddi city	81
Figure 4.28: Emission Load from Construction and Demolition activities	82
Figure 4.29: Spatial Distribution of PM ₁₀ Emissions from Construction/Demolition.....	82
Figure 4.30: Spatial Distribution of PM _{2.5} Emissions from Construction/Demolition	83
Figure 4.31: Location of Industrial DG Sets.....	84
Figure 4.32: Emission Load from Industrial DG sets	84
Figure 4.33: Spatial Distribution of PM ₁₀ Emissions from Industrial DG sets	85
Figure 4.34: Spatial Distribution of PM _{2.5} Emissions from Industrial DG sets	85
Figure 4.35: Spatial Distribution of SO ₂ Emissions from Industrial DG sets	86
Figure 4.36: Spatial Distribution of NO _x Emissions from Industrial DG sets	86
Figure 4.37: Spatial Distribution of CO Emissions from Industrial DG sets	87
Figure 4.38: Location of Hotels, Restaurants, GHs and BHs	88
Figure 4.39: Emission Load from Hotels, Restaurants, GHs and BHs.....	88
Figure 4.40: Spatial Distribution of PM ₁₀ Emissions from Hotels, Restaurants, GHs and BHs.....	89
Figure 4.41: Spatial Distribution of PM _{2.5} Emissions from Hotels, Restaurants, GHs and BHs.....	89

Figure 4.42: Spatial Distribution of SO ₂ Emissions from Hotels, Restaurants, GHs and BHs.....	90
Figure 4.43: Spatial Distribution of NO _x Emissions from Hotels, Restaurants, GHs and BHs.....	90
Figure 4.44: Spatial Distribution of CO Emissions from Hotels, Restaurants, GHs and BHs.....	91
Figure 4.45: Location of Brick kilns in Baddi	92
Figure 4.46: Emission Load from Brick kilns	92
Figure 4.47: Spatial Distribution of PM ₁₀ Emissions from Brick kilns	93
Figure 4.48: Spatial Distribution of PM _{2.5} Emissions from Brick kilns	93
Figure 4.49: Spatial Distribution of SO ₂ Emissions from Brick kilns	94
Figure 4.50: Spatial Distribution of NO _x Emissions from Brick kilns.....	94
Figure 4.51: Spatial Distribution of CO Emissions from Brick kilns.....	95
Figure 4.52: MSW Burning in several parts of Baddi city	96
Figure 4.53: Emission Load from MSW Burning	96
Figure 4.54: Spatial Distribution of PM ₁₀ Emissions from MSW Burning	97
Figure 4.55: Spatial Distribution of PM _{2.5} Emissions from MSW Burning	97
Figure 4.56: Spatial Distribution of SO ₂ Emissions from MSW Burning	98
Figure 4.57: Spatial Distribution of NO _x Emissions from MSW Burning.....	98
Figure 4.58: Spatial Distribution of CO Emissions from MSW Burning.....	99
Figure 4.59: Locations of Hospitals in Baddi City	100
Figure 4.60: Emission Load from Hospitals	100
Figure 4.61: Location of Industries in Baddi city	101
Figure 4.62: Emission Load from Industries as Area Source	103
Figure 4.63: Spatial Distribution of PM ₁₀ Emissions from Industries as area source	103
Figure 4.64: Spatial Distribution of PM _{2.5} Emissions from Industries as area source.....	104
Figure 4.65: Spatial Distribution of SO ₂ Emissions from Industries as area source	104
Figure 4.66: Spatial Distribution of NO _x Emissions from Industries as area source.....	105
Figure 4.67: Spatial Distribution of CO Emissions from Industries as area source	105
Figure 4.68: Emission Load from Industrial Point Source	106
Figure 4.69: Spatial Distribution of PM ₁₀ Emissions from Industries as point source.....	106
Figure 4.70: Spatial Distribution of PM _{2.5} Emissions from Industries as point source	107
Figure 4.71: Spatial Distribution of SO ₂ Emissions from Industries as point source.....	107

Figure 4.72: Spatial Distribution of NO _x Emissions from Industries as point source	108
Figure 4.73: Spatial Distribution of CO Emissions from Industries as point source.....	108
Figure 4.74: Distribution of 2-Ws in the study area (parking lot survey).....	109
Figure 4.75: Distribution of 4-Ws in the study area (parking lot survey).....	110
Figure 4.76: Traffic location considered for vehicle emission in the city of Baddi.	111
Figure 4.77: Emission Load from Vehicles	111
Figure 4.78: PM ₁₀ Emission Load contribution of each vehicle type (kg/day)	112
Figure 4.79: PM _{2.5} Emission Load contribution of each vehicle type (kg/day).....	112
Figure 4.80: SO ₂ Emission Load contribution of each vehicle type (kg/day)	113
Figure 4.81: NO _x Emission Load contribution of each vehicle type (kg/day).....	113
Figure 4.82: CO Emission Load contribution of each vehicle type (kg/day)	114
Figure 4.83: Spatial Distribution of PM ₁₀ Emissions from Vehicles.....	114
Figure 4.84: Spatial Distribution of PM _{2.5} Emissions from Vehicles.....	115
Figure 4.85: Spatial Distribution of SO ₂ Emissions from Vehicles.....	115
Figure 4.86: Spatial Distribution of NO _x Emissions from Vehicles	116
Figure 4.87: Spatial Distribution of CO Emissions from Vehicles	116
Figure 4.88: Typical Traffic conditions at different locations in Baddi	117
Figure 4.89: Road Dust Sampling Locations	119
Figure 4.90: Road Dust Sampling in the City of Baddi.....	119
Figure 4.91: Road dust deposition on the road	120
Figure 4.92: Emissions from road dust in Baddi city	120
Figure 4.93: Spatial Distribution of PM ₁₀ Emissions from Road Dust Re-suspension	121
Figure 4.94: Spatial Distribution of PM _{2.5} Emissions from Road Dust Re-suspension	121
Figure 4.95: PM ₁₀ Emission Load of Different Sources.....	124
Figure 4.96: PM _{2.5} Emission Load of Different Sources	124
Figure 4.97: SO ₂ Emission Load of Different Sources.....	125
Figure 4.98: NO _x Emission Load of Different Sources	125
Figure 4.99: CO Emission Load Contribution of Different Sources	126
Figure 4.100: Spatial Distribution of PM ₁₀ Emissions in the City of Baddi.....	126
Figure 4.101: Spatial Distribution of PM _{2.5} Emissions in the City of Baddi.....	127
Figure 4.102: Spatial Distribution of SO ₂ Emissions in the City of Baddi.....	127
Figure 4.103: Spatial Distribution of NO _x Emissions in the City of Baddi	128
Figure 4.104: Spatial Distribution of CO Emissions in the City of Baddi	128

Figure 5.1: PMF-based Source profiles for PM ₁₀ and PM _{2.5}	132
Figure 5.2: PMF modeling Results for PM ₁₀ at all sites	132
Figure 5.3: PMF modeling Results for PM _{2.5} at all sites	133
Figure 5.4: PMF modeling for (a) PM ₁₀ and (b) PM _{2.5} at MHJ	135
Figure 5.5: Backward trajectories at MHJ	135
Figure 5.6: PMF modeling for (a) PM ₁₀ and (b) PM _{2.5} at OBD	137
Figure 5.7: Backward trajectories at OBD.....	137
Figure 5.8: PMF modeling for (a) PM ₁₀ and (b) PM _{2.5} at ARF	139
Figure 5.9: Backward trajectories at ARF	139
Figure 5.10: PMF modeling for (a) PM ₁₀ and (b) PM _{2.5} at GSS.....	140
Figure 5.11: Backward trajectories at GSS.....	141
Figure 5.12: PMF modeling for (a) PM ₁₀ and (b) PM _{2.5} at VMT	142
Figure 5.13: Backward trajectories at VMT	143
Figure 5.14: source concentration comparison at sites for (a) PM ₁₀ and (b) PM _{2.5} at all sites.....	144
Figure 5.15: PMF modeling for (a) PM ₁₀ and (b) PM _{2.5} at Baddi	145
Figure 6.1: Location of Hotels, Restaurants, GHs and BHs in Baddi City.....	152
Figure 6.2: MSW Burning in several parts in Baddi City.....	153
Figure 6.3: Solid waste burning in the area	154
Figure 6.4: Location of Brick Kilns in Baddi City	156
Figure 6.5: Construction material and debris near construction sites.....	157
Figure 6.6: Road Dust is prominent on various roads	159
Figure 6.7: Quality of dust-free Roads, footpaths and dividers with dust control (Courtesy Greater Hyderabad Municipal Corporation)	160
Figure 6.8: Location of traffic bottlenecks	164
Figure 6.9: Conflicts due to on-street parking near intersections	165
Figure 6.10: Multi-level car parking (example).....	166
Figure 6.11: Proposed Suction Hood (Pic courtesy: Electrotherm).....	168
Figure 6.12: Side-based Suction Hood (Pic courtesy: Electrotherm)	169
Figure 6.13: Working on side-based Suction Hood (Sharma, 2020).....	169

List of Tables

Table 1: Description of sampling sites in Baddi	iv
Table 2: Control Options and Action Plan for Baddi	xxiv
Table 2.1: Description of sampling sites in Baddi	9
Table 2.2: Details of Samplers/Analyzers and Methods.....	11
Table 2.3: Chemical Components for PM Characterization	11
Table 2.4: Sampling Days of Various Pollutants at MHJ	15
Table 2.5: Sampling Days of Various Pollutants at OBD	15
Table 2.6: Sampling Days of Various Pollutants at ARF	16
Table 2.7: Sampling Days of Various Pollutants at GSS.....	16
Table 2.8: Sampling Days of Various Pollutants at VMT	16
Table 2.9: National Ambient Air Quality Standards	17
Table 2.10: Statistical Results of PM _{2.5} and PM ₁₀ in (µg/m ³) at Baddi	22
Table 2.11: Statistical results of gaseous pollutants (µg/m ³) at Baddi	26
Table 2.12: Statistical Results of VOCs Contents (µg/m ³) at Baddi	28
Table 2.13: Statistical Results of Carbon Contents (µg/m ³) in PM _{2.5} at MHJ.....	29
Table 2.14: Statistical Results of Carbon Contents (µg/m ³) in PM _{2.5} at OBD	29
Table 2.15: Statistical Results of Carbon Contents (µg/m ³) in PM _{2.5} at ARF.....	30
Table 2.16: Statistical Results of Carbon Contents (µg/m ³) in PM _{2.5} at GSS	31
Table 2.17: Statistical Results of Carbon Contents (µg/m ³) in PM _{2.5} at VMT.....	32
Table 2.18: Overall summary of Carbon Contents (µg/m ³) in PM _{2.5}	33
Table 2.19: Overall summary of average concentration (ng/m ³) of PAHs in PM _{2.5} all sites.....	41
Table 2.20: Overall summary of average concentration (ng/m ³) of molecular markers in PM _{2.5} all sites	41
Table 2.21: Statistical results of chemical characterization (µg/m ³) of PM ₁₀ at sites.....	42
Table 2.22: Statistical results of chemical characterization (µg/m ³) of PM _{2.5} at all sites	43
Table 2.23 : Overall statistical results of chemical characterization (µg/m ³) of PM ₁₀ in Baddi	44
Table 2.24: Overall statistical results of chemical characterization (µg/m ³) of PM _{2.5} in Baddi	44
Table 2.25: Correlation matrix for PM and its composition at Baddi	45

Table 2.26: Mean of major components: PM ₁₀ , winter (µg/m ³).....	47
Table 2.27: Statistical summary of major components: PM _{2.5} , winter (µg/m ³).....	47
Table 2.28: 8 Hourly Statistical Results of CO (µg/m ³) at BADDI	50
Table 2.29: 8 Hourly Statistical Results of O ₃ (µg/m ³) at BADDI.....	53
Table 3.1: Comparison of mean PM ₁₀ slopes (in µg/m ³ /day) and trends at various sites in monthly slots during 2008-2019	64
Table 3.2: Comparison of mean NO _x slopes (in µg/m ³ /day) and trends at various sites in monthly slots during 2008-2019	64
Table 4.1: Hospitals Details in Baddi city (emissions in kg/day and g/day)	100
Table 4.2: Furnace/Boiler Details in Baddi city (emissions in kg/day and g/day)	102
Table 4.3: Major Traffic Bottleneck at Baddi.....	117
Table 4.4: Baddi City Level Inventory (emissions in kg/day and g/day)	123
Table 5.1: Summary of source concentration of PM ₁₀ : BADDI.....	146
Table 5.2: Summary of source concentration of PM _{2.5} : BADDI.....	147
Table 6.1: Major Traffic Bottleneck at Baddi City.....	163
Table 6.2: A Glance of Control Options and Action Plan for City of Baddi (for details read section 6.2)	171

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 air polluting source mix (e.g., industries, automobiles, generator sets, domestic fuel burning, roadside dust, construction activities, etc.). The state of Himachal Pradesh is a major centre of tourism and attracts large number of floating populations. The other activities in the state include textiles, education, pharmaceuticals and food processing and growth in all sectors has been phenomenal in recent years. The burgeoning population coupled with rapid growth in terms of vehicles for tourism and transportation of man and material, pharmaceuticals industries, construction, and energy consumption has resulted in air pollution issues in the state, particularly, a few cities have come under the category of nonattainment of air quality standards.

To address the air pollution issues of seven cities (Kala Amb, Paonta Sahib, Parwanoo, Baddi, Nalagarh, Sunder Nagar and Damtal) in the state, HP State Pollution Control Board (HPSPCB), Shimla has sponsored the study “Source Apportion-based Action Plans for Restoring Air Quality in Non- Attainment Cities in the State of Himachal Pradesh in respect of PM₁₀ (particulate matter of size 10 µm or less), PM_{2.5} (particulate matter of size 2.5 µm or less) and other Notified Pollutants” to the Indian Institute of Technology Kanpur (IITK). The study has commenced in June 06, 2019 but has been delayed considerably due to lockdown. The main objectives of the study are preparation of emission inventory, air quality monitoring, chemical composition of PM₁₀ and PM_{2.5}, apportionment of sources to ambient air quality, preparation of action plan for cities and trend analysis in historical air quality data.

This report presents the source apportionment and action plan for Baddi, a city in Himachal Pradesh having a large number of industries in different sectors, i.e., textile, pulp and paper, fast-moving consumer goods, pharmaceuticals and food processing.

1.2 General Description of Baddi City

1.2.1 Geography and Demography

Baddi is an industrial town and Nagar parishad in the southwestern Solan district of Himachal Pradesh situated at 30.928°N and 76.796°E. The city lies on the border of Himachal Pradesh and Haryana states in the Shivalik Hills, distanced about 35 kilometers in the west of Solan city.

In Baddi, the key business activities are trade, commerce and industries. The industry sectors are categorized as textile, pulp and paper, fast-moving consumer goods, pharmaceuticals, food processing and engineering industries. Baddi houses more than 2100 industries in different sectors.

As per the 2011 census, the population of Baddi city is 29,911; of which males and females are 19,332 and 10,579 respectively (Census-India, 2012). The city is governed by Municipal Council, which has 14 wards.

1.2.2 Climate

The climate of Baddi features humid subtropical (warm and temperate) nature and the temperature varies from 8°C to 42°C. The city features mild winters, hot and dry summers and a monsoon season. The total average rainfall in Baddi area is about 1050 mm with occasionally foggy weather. The relative humidity in the city varies between 10% to 85%.

1.2.3 Emission Source Activities

The source activities for air pollution in the city can be broadly classified as: the transport sector (motor vehicles), commercial activities, industrial activities, domestic activities, institutional and office activities and fugitive non-point sources. For transport of men, mostly public transport, tempos and buses fulfill the transport requirement for the city. The combustion of fuels like coal, liquefied petroleum gas (LPG) and wood come under the source of domestic activities. As far as industrial activities are concerned, mostly small and medium scale industries are responsible for industrial air pollution. In most institutions and offices, diesel generators are used at the time of power failure. The industries generating air pollution are mainly due to the use of induction furnaces/boilers/ thermic fluid heaters etc. (having Particulate Matter - PM, Oxides of Sulphur and Oxides of Nitrogen as a pollutant).

1.3 Need for the Study

1.3.1 Air Pollution Levels: Earlier Studies

The annual average levels of SO₂ and NO_x were observed well below the permissible limit at stations of the national air quality monitoring programme (NAMP) (HSPCB, 2019). PM_{2.5} and PM₁₀ concentrations varied seasonally with atmospheric processes and anthropogenic activities.

A report (HPSPCB, 2019) submitted to the Hon'ble National Green Tribunal (NGT) by HPSPCB, showed the annual average levels of PM₁₀ for the years 2013-14 to 2017-18 (Figure 1.1). The average PM₁₀ levels in 2017-18 was 168 µg/m³. Sharma and Dikshit (2014) have reported levels of PM₁₀ (98 – 478 µg/m³), PM_{2.5} (51 – 124 µg/m³), SO₂ (6 – 90 µg/m³) and NO_x (8 – 39 µg/m³).

Although Baddi city faces air pollution problems due to the number of sources, no detailed study of the chemical composition of PM₁₀ and PM_{2.5} in recent years has been undertaken to identify the sources and their contributions to air pollution.

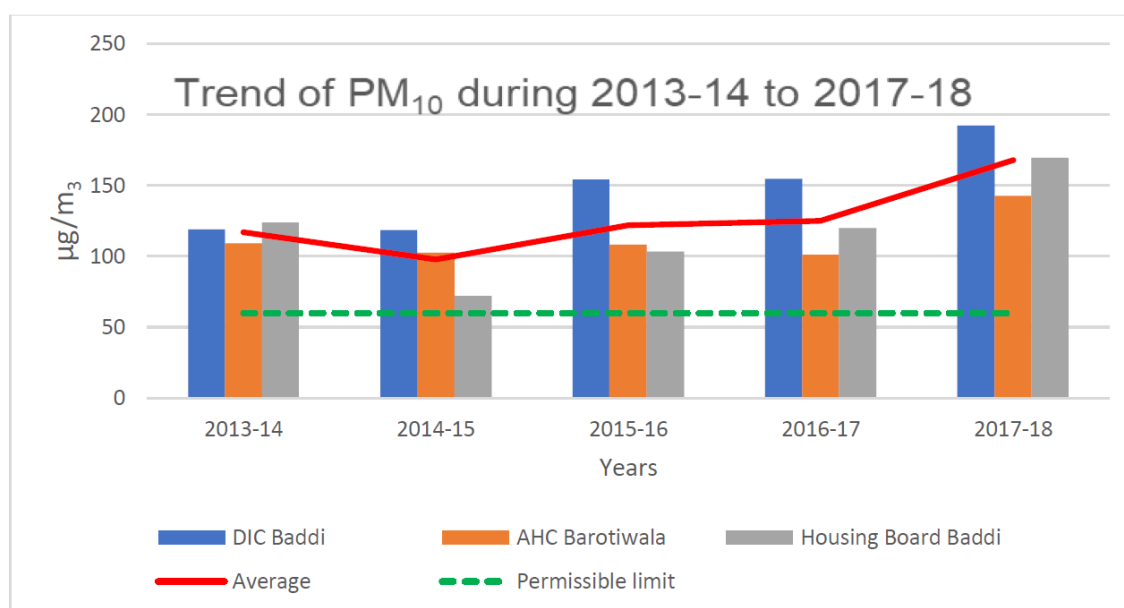


Figure 1.1: Annual average levels of PM₁₀ from 2013-14 to 2017-18 (HPSPCB, 2018)

1.4 Objectives and Scope of Work

Objectively the project aims to achieve the following:

- Development of GIS-based gridded (i.e., 2 km × 2 km resolution) emission inventory for air pollutants PM₁₀, PM_{2.5}, SO₂, NO₂, NH₃, CO, O₃, VOCs (Benzene), PAHs (BaP), Ni, As and Pb for the base year, 2020.
- Compilation of emission factors for all sources, parking lot surveys through questionnaires for vehicle technology, model, engine capacity and measurement of driving patterns of various classes of vehicles operating on roads.
- Compilation and interpretation of ambient air quality data for PM₁₀, PM_{2.5}, SO₂, NO₂ and other pollutants being monitored by HPSPCB. The time-series analyses will identify trends such as: (i) significant downward, (ii) significant upward, (iii) firstly decreasing and then increasing, (iv) firstly increasing then decreasing (iv) no trend.
- Monitoring of air pollutants PM₁₀, PM_{2.5}, SO₂, NO₂, NH₃, and VOCs. Analyze collected PM₁₀ and PM_{2.5} mass for elemental composition, ions, elemental carbon, organic carbon, PAHs (Benzo[a]pyrene, Fluorene, Acenaphthene, Phenanthrene, Anthracene, Fluoranthene, Pyrene, Chrysene, Benzo(b)f, Benzo(k)f, Dibenz(a,h)a, Inp, and B(ghi)) and molecular markers.
- Reconstruction of PM based on chemical species (of PM) and assessment for primary and secondary sources of air pollutants.
- Application of receptor model to establish source-receptor linkages of PM₁₀, and PM_{2.5} using state-of-the-art modeling to arrive at source apportionments at sampling sites.
- Identification of various control options and assessment of their efficacies for air quality improvements and development of control scenarios (in a techno-economical perspective) consisting of combinations of several control options.
- Selection of most effective control options for implementation and development of time-bound action plan.

1.5 Approach to the Study

The approach to the study is based on the attainment of its objectives within the scope of work, as explained in section 1.4. The summary of the approach to the study and major tasks are presented in Figure 1.2. The overall approach to the study is broadly described below.

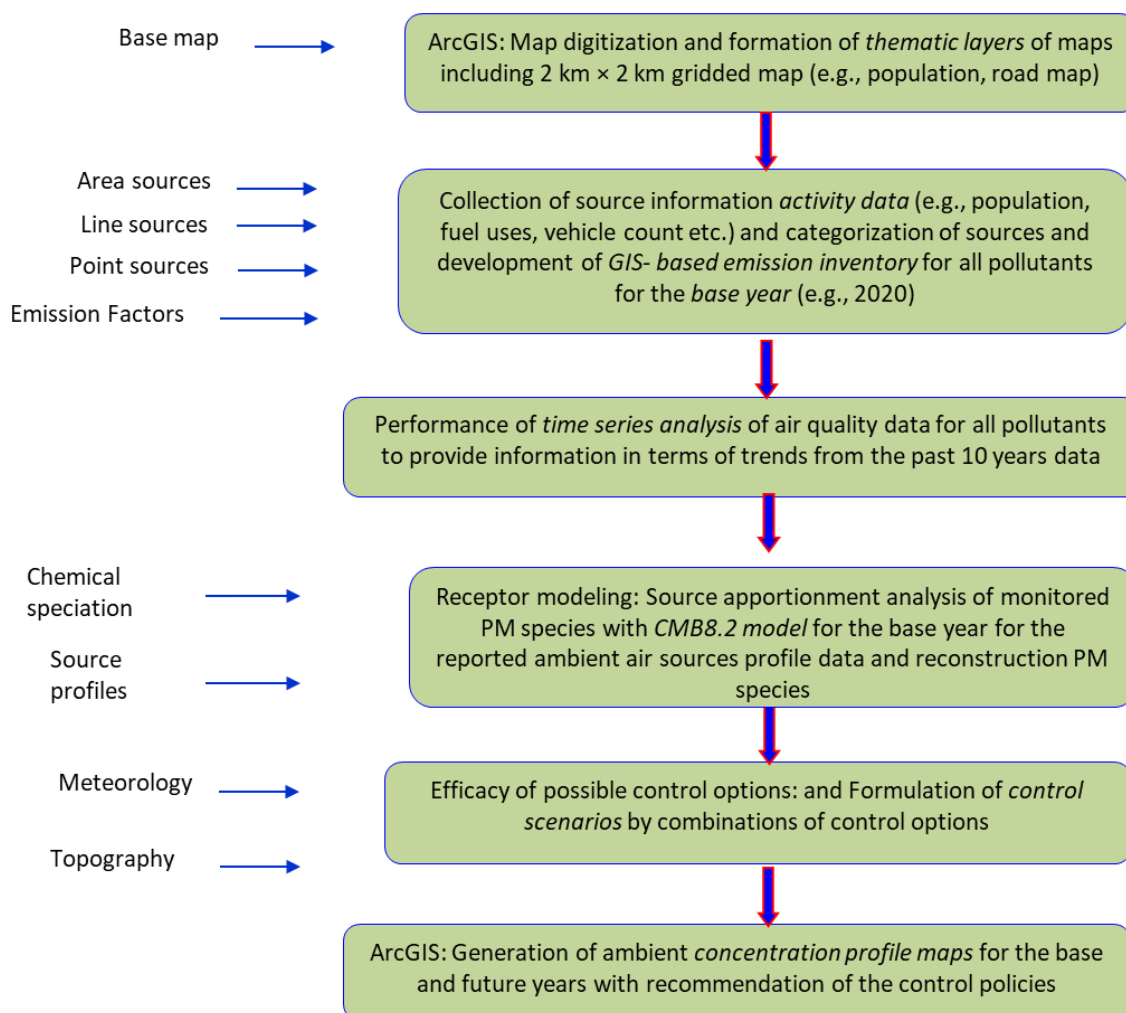


Figure 1.2: Approach to the Study and Major Tasks

1.5.1 Selection of sampling sites

It was considered appropriate that five sites in a city like Baddi can represent typical land-use patterns. It needs to be ensured that at all sites, there is a free flow of air without any obstruction (e.g., buildings, trees, etc.). In view of the safety of the stations, most public buildings could be better choices as sampling sites. Sites were finalized in consultation with the officials of HPSPCB, Baddi.

1.5.2 Identification and Grouping of Sources for Emission Inventory

An on-the-field exercise was taken up to physically identify all small and large sources around the sampling sites. This exercise included the presence of emission sources like refuses and biomass burning, road dust, and coal/coke burnt by street vendors/small restaurants to large units like power generation units and various vehicle types. It was necessary to group some of the similar sources to keep the inventory exercise manageable. It needs to be recognized that particulate emission sources change from one season to another. Finally, the collected data were developed into emission inventory for the following pollutants: SO₂, NO_x, CO, PM₁₀, PM_{2.5} on a GIS platform and other pollutants NH₃, VOCs (benzene, Pb, As, Ni and B(a)P) are given in tables.

1.5.3 Emission Source Profiles

PMF model does not require emission source profiles. Instead, it generates the local profiles based on the matrix database. First, however, a database is developed to find source-specific fingerprint chemical species for assigning the source to the factor generated from the PMF model.

Since for PM_{2.5}, Indian or Himachal Pradesh specific source profiles are not available except for vehicular sources (ARAI, 2009), the source profiles for this study were taken from ‘SPECIATE version 3.2’ of USEPA (2006). For vehicular sources, profiles were taken from ARAI (2009). ‘SPECIATE’ is a repository of Total Organic Compound (TOC) and PM speciated profiles for a variety of sources for use in source apportionment studies (USEPA, 2006); care has been exercised in adopting the profiles for their applicability in the local environment of Baddi city. For the sake of uniformity, source profiles for non-vehicular sources for PM₁₀ and PM_{2.5} were adopted from USEPA (2006).

1.5.4 Application of Receptor modeling

There are several methods and available commercial software that can be used for apportioning the sources if the emission profiles and measurements are available in the ambient air particulate in terms of elemental composition. The most common software is USEPA PMF 5.0 (USEPA, 2014). This model should be able to provide the contribution of each source in the particulate in ambient air. The modeling results should help identify major

sources for pollution control. It was important to note that along with source contribution, the model could also provide the associated uncertainties in estimated source contributions.

1.5.5 Time Series Analysis

Several techniques provide trends including simple plotting of data to more complex autoregressive integrated moving average (ARIMA) models. This analysis was done for all pollutants and the results provide information in terms of trends such as: (i) Significant downward, (ii) Significant upward, (iii) Firstly decreasing and then increasing, (iv) Firstly increasing then decreasing (iv) No trend. This analysis clearly establishes the benefits of air pollution control measures and need for future measures.

1.6 Report Structure

The report is divided into six chapters. The brief descriptions of the chapters are given below.

Chapter 1

This chapter presents the background of the study, a general description of the city, including geography and demography, climate and sources of air pollution. The current status of the city in terms of air pollution is described by reviewing the previous studies. The objectives, scope and approach to this study are also briefly described in this chapter.

Chapter 2

This chapter presents the air quality status of the city based on the monitoring and chemical characterization results of various air pollutants of all sampling sites for two seasons, i.e., winter and summer. In addition to the above information, this chapter also describes methodologies adopted for monitoring, laboratory analyses, quality assurance and quality control (QA/QC). Finally, this chapter also compares the results of all sites both diurnally and seasonally.

Chapter 3

This chapter presents the methodology used for trend analyses in long-term time series and the results of trends in historical pollution data of the last 10 years.

Chapter 4

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. The QA/QC approaches for emission inventory are also explained in this chapter.

Chapter 5

This chapter presents the methodology used for PMF5.0 modeling for source apportionment study for PM₁₀ and PM_{2.5} in the summer and winter. The contribution of various sources at receptor sites and the overall scenario of sources that influences the air quality in the city is presented.

Chapter 6

This chapter describes, explores and analyzes emission control options and analysis for various sources based on the modeling results from Chapters 4 and 5.

This chapter discusses alternatives for controlling the prominent sources in the city from the management, administrative and technology points of view.

2 Air Quality: Measurements, Data Analyses and Inferences

Air pollution continues to remain a public health concern despite various actions taken to control air pollution. There is a need to take stock of benefits that have accrued and ponder on 'Way Forward'. Further analysis of actions and future needs become even more important in view of the revised air quality standards that have been notified ([http://www.cpcb.nic.in/National Ambient Air Quality Standards.php](http://www.cpcb.nic.in/National_Ambient_Air_Quality_Standards.php) (CPCB, 2009). The first step to accomplish future action is to assess the current air pollution status.

This chapter presents and discusses the current status of the air quality of seven cities in Himachal Pradesh for the winter season from the sampling and chemical analysis results carried out under the present study.

2.1 Methodology

2.1.1 Site Selection and details

A total of five air quality sites have been selected to cover various land-use patterns prevailing in the city. It was ensured that all sites had a free flow of air without any obstruction (e.g., buildings, trees, etc.). In view of the safety of the stations, general public buildings (institutions, office buildings, schools, etc.) were selected in consultation with HPSPCB. Table 2.1 describes the sampling sites with prevailing land-use and other features.

Table 2.1: Description of sampling sites in Baddi

S. No.	Sampling Site-City	Site Code	Description of the site	Type of sources
1.	Marice Hotel Jharmajri	MHJ	Industrial	Industries, DG sets, vehicles, road dust, garbage/industrial waste burning, coal
2.	HPSPCB Office Sai Road	OBD	Commercial	DG sets, vehicles, road dust, garbage/waste burning, hotels, coal uses
3.	Aristo Pharma	ARF	Industrial	Industries, DG sets, vehicles, road dust, garbage/industrial waste burning, coal
4.	Govt School Sandoli	GSS	Residential and Commercial	Domestic cooking, vehicles, road dust, garbage/MSW burning, restaurants

5.	Vardhman Textile	VMT	Industrial	Industries, DG sets, vehicles, road dust, garbage/industrial waste burning, coal
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Figure 2.1 shows the physical features (photographs) of the sampling sites. Figure 2.2 shows the locations of the sampling sites on the map and overall land-use pattern of the city.

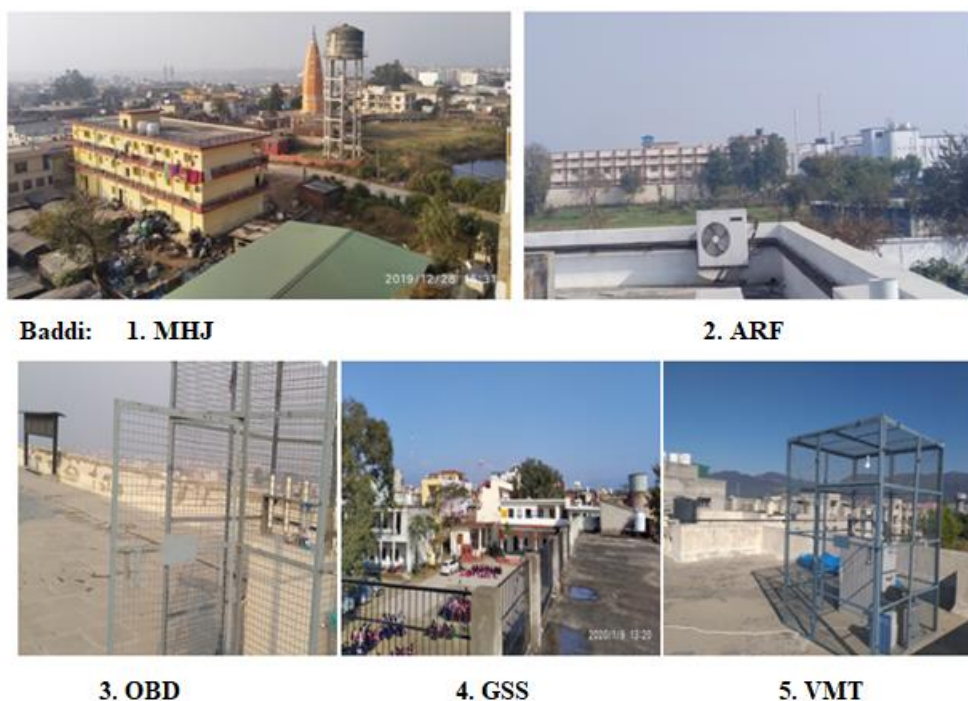


Figure 2.1: Photographs of Sampling Sites

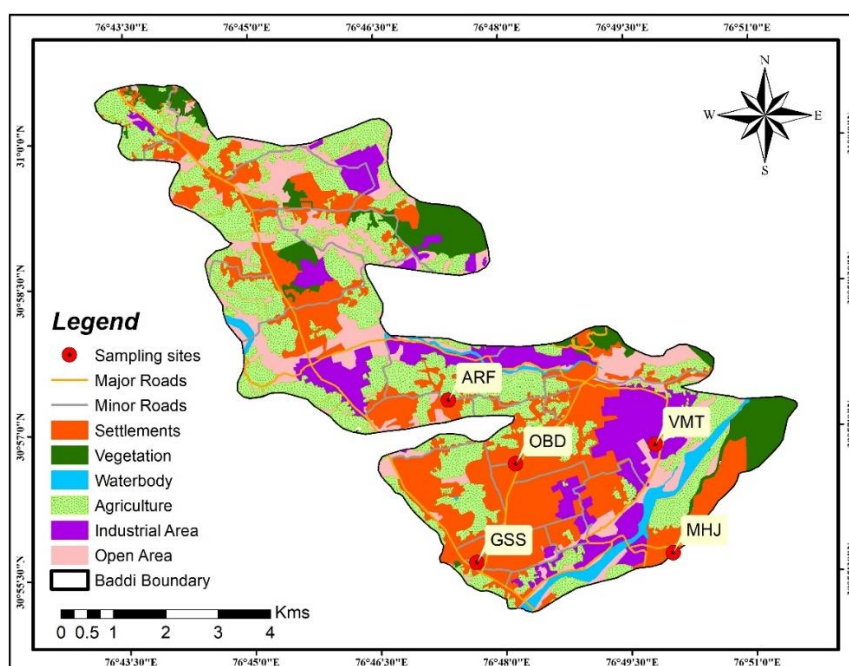


Figure 2.2: Land-use Pattern and Locations of Sampling Sites

The parameters for sampling and their monitoring methods including the type of filter papers/chemicals and calibration protocols are adopted from CPCB, Delhi (www.cpcb.nic.in). The entire monitoring programme is divided into two groups, i.e. (i) gaseous sampling: nitrogen dioxide (NO₂), Sulphur dioxide (SO₂), carbon monoxide (CO), ozone (O₃), ammonia (NH₃) and volatile organic compounds (VOCs) and (ii) particulate matter sampling (PM₁₀ and PM_{2.5}). The monitoring parameters for this study along with sampling and analytical methods are presented in Table 2.2 and chemical components for PM characterization are presented in Table 2.3.

Table 2.2: Details of Samplers/Analyzers and Methods

Sr. No.	Parameter	Sampler/Analyzing Instrument	Method
1.	PM ₁₀	4-Channel Speciation Sampler (4-CSS)	Gravimetric
2.	PM _{2.5}	4-Channel Speciation Sampler (4-CSS)	Gravimetric
3.	SO ₂	Bubbler/Spectrophotometer	West and Gaek
4.	NO ₂	Bubbler/Spectrophotometer	Jacob & Hochheiser modified
5.	NH ₃	Bubbler/Spectrophotometer	Indo phenol method
5.	CO	Continuous online CO analyzer	Sensor-based technique
6.	O ₃	Continuous online O ₃ analyzer	Sensor based technique
7.	OC/EC	OC/EC Analyzer	Thermal Optical Reflectance
8.	Ions	Ion-Chromatograph	Ion-Chromatography
9.	Elements	ICP-MS	USEPA
10.	PAHs	GC-MS	Mass spectrometry
11.	Markers	GC-MS	Mass spectrometry

Table 2.3: Chemical Components for PM Characterization

Components	Required filter matrix	Analytical methods
PM ₁₀ /PM _{2.5}	Teflon filter paper.	Gravimetric
Elements (Be, B, Na, Mg, Al, Si, P, K, Ca, Cr, V, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Rb, Sr, Cd, Cs, Ba and Pb)	Teflon filter paper	ED-XRF or ICP-MS
Ions (F ⁻ , Cl ⁻ , NO ₃ ⁻ , SO ₄ ²⁻ , K ⁺ , NH ₄ ⁺ , Na ⁺ , Mg ²⁺ , and Ca ²⁺)	Teflon filter paper	Ion-chromatography
Carbon Analysis (OC, EC and Total Carbon)	Quartz filter (Prebaked at 600°C)	TOR/TOT method

2.1.2 Instruments and Accessories

As indicated in Table 2.2, the 4-channel speciation samplers (Umwelttechnik MCZ GmbH, Germany) were used for the sampling studies for monitoring particulate matter (Figure 2.3 (a)). The flow rate was 16.7 LPM. Three channels of the sampler are utilized: The first channel for PM₁₀, second channel for PM_{2.5} (Teflon filters - Whatman grade PTFE filters of 47 mm diameter) and third for collection of PM_{2.5} on quartz fiber filter (Whatman grade QM-A quartz filters of 47 mm Diameter). PTFE filters are used for the analysis of ions and elements and quartz filters are used for OC-EC and PAHs. Gaseous sampler (AAS 118, Ecotech, India, flow rate of 1.0 LPM; Figure 2.3(h)) is used for gaseous pollutants (SO₂, NO₂ and NH₃), Continuous online gaseous analyzer (Airshed planning professional Pvt Ltd, India, Figure 2.3(i)) used for CO and O₃, and low flow pump (Pocket pump 210 series; SKC Inc., USA, Figure 2.3(g)) is used for measurement of VOCs (flow rate - 40 ml/min) through adsorption in tenex tubes and analysis on GC-MS using ATD.

PM₁₀ and PM_{2.5} concentrations are determined gravimetrically by weighing the PTFE filters before and after the sampling using a digital microbalance (Metler-Toledo MX-5, USA; sensitivity of 1µg; Figure 2.3(b)) in controlled room having temperature 22±2°C and relative humidity less than 45%. OC and EC are analyzed by thermal optical transmittance (DRI Model 2001A Thermal/Optical Carbon Analyzer; Figure 2.3(c)).

Water-soluble ions are extracted from the teflon filters in ultra-pure Milli-Q water following the reference method (USEPA, 1999a). Ions analysis of extracted sampled is carried out using Ion Chromatography (Merohm 882 compact IC, Switzerland; Figure 2.3(e)). Ion recovery efficiencies were determined by spiking the known quantity of ion mass and reproducibility tests were performed by replicate analysis. Recovery was found between 90% and 106%, which was within ±10% for all species analyzed.

For elemental analysis, PTFE filters were digested in hydrochloric/nitric acid solution using the microwave digestion system (Anton-Paar, Austria) as per the USEPA method (USEPA, 1999b). The digested samples were filtered and diluted to 25 mL with deionized (ultra-pure) water. The digested samples for elements were analyzed using ICP-MS (Thermo fisher Scientific Inc, USA; Figure 2.3(f)) (USEPA, 1999c).

PAHs were extracted in hexane and dichloromethane (DCM) solvent (1:1v/v) followed by passing it through silica cartridge (Rajput et al., 2011, USEPA, 1999d). The extracted

samples were concentrated using rotary evaporator (up to 10 mL) and Turbo Vap (Work Station-II, Caliper Life Sciences, Hopkinton, USA) for final volume of 1 mL. Extracted samples were analyzed for PAHs using the Gas chromatography-Mass spectrophotometer (Model Clarus 600 S, Perkin Elmer, USA; Figure 2.3(d)).

To analyze the molecular markers, QMA filters were used. In view of small quantity of molecular markers on filters, filter papers of seven days were combined and extracted. Extractions were carried out in DCM and acetone (1:1) solution in soxhlet apparatus followed by concentration of extract using a rotary evaporator and nitrogen purging on turbovap; the extract volume was reduced to 2 ml. The samples were analyzed for alkanes and hopanes on GCMS (Zhang et al., 2009).



(a) 4-Channel Speciation Sampler (b) Microbalance (c) OC/EC Analyzer



(d) GC-MS with ATD (e) Ion Chromatography (f) ICP-MS



(g) Low flow pump (h) gaseous sampler (i) Online gas analyzer

Figure 2.3: Photographs of the Instruments

2.2 Quality Assurance and Quality Control (QA/QC) Quality Control

Quality assurance and quality control (QA/QC) in entire project planning and its implementation at all levels were designed and the hands-on training was imparted to the project team before the beginning of any sampling and analysis. During sampling and analysis, a coding system has been adopted to eliminate any confusion. Separate codes for parameters, and time slots are adopted.

For parameters like SO₂, NO₂, NH₃, CO, O₃, PM₁₀, PM_{2.5}, analyses were done regularly just after the sampling following the standard operating procedures (SOPs). The analyses for elements and ions were done at the laboratories of IIT Kanpur. The calibrations for all samplers were done at regular intervals at the time of sampling. The calibrations of overall analyses were established by cross-checking with known concentrations of the pollutants. The major features of QA/QC are briefly described here.

- SOPs for entire project planning and implementation were developed, and peer-reviewed by other experts and project personnel have been trained in the field and the laboratory. Whenever necessary, the SOPs were adjusted to meet the field challenges.
- SOPs include type of equipment (with specifications), sampling and calibration methods with their frequency and height and distance of measurement from the source.
- SOPs for chemical analysis includes a description of methods, standards to be used, laboratory and field blanks, internal and recovery standards, database, screening of data, record-keeping including backups, traceability of calculations and standards.

There are dedicated computers for instruments and data storage with passwords. To ensure that the computers do not get infected, these computers are not hooked to Internet connections.

Sampling periods: The ambient air sampling has been completed for 7 days at each site during winter (December 29, 2019 – January 19, 2020). The analysis of SO₂, NO₂ and NH₃ was carried out daily at the laboratory in Baddi while gravimetric analysis for particulate matters was done after completion of the sampling at IITK. All efforts were made for the 100% achievement of the sampling and analysis. Efforts were made to sample on extra days to cover the missing days of sampling, mostly because of rainy days. Tables 2.4 to 2.8 present the details of sampling days for all pollutants at all monitoring sites.

Table 2.4: Sampling Days of Various Pollutants at MHJ

MHJ - Baddi, Winter							
	30-Dec-19	31-Dec-19	1-Jan-20	2-Jan-20	3-Jan-20	4-Jan-20	5-Jan-20
PM10							
PM2.5							
OC							
EC							
VOC							
NO2							
NH3							
SO2							
CO							
O3							

Table 2.5: Sampling Days of Various Pollutants at OBD

OBD - Baddi, Winter							
	30-Dec-19	31-Dec-19	1-Jan-20	2-Jan-20	3-Jan-20	4-Jan-20	5-Jan-20
PM10							
PM2.5							
OC							
EC							
VOC							
NO2							
NH3							
SO2							
CO							
O3							

Table 2.6: Sampling Days of Various Pollutants at ARF

ARF - Baddi, Winter								
	29-Dec-19	30-Dec-19	31-Dec-19	1-Jan-20	2-Jan-20	3-Jan-20	4-Jan-20	5-Jan-20
PM10								
PM2.5								
OC								
EC								
VOC								
NO2								
NH3								
SO2								

Table 2.7: Sampling Days of Various Pollutants at GSS

GSS - Baddi, Winter								
	10-Jan-20	11-Jan-20	12-Jan-20	13-Jan-20	14-Jan-20	15-Jan-20	16-Jan-20	17-Jan-20
PM10								
PM2.5								
OC								
EC								
VOC								
NO2								
NH3								
SO2								
CO								
O3								

Table 2.8: Sampling Days of Various Pollutants at VMT

VMT - Baddi, Winter									
	10-Jan-20	11-Jan-20	12-Jan-20	13-Jan-20	14-Jan-20	15-Jan-20	16-Jan-20	17-Jan-20	18-Jan-20
PM10									
PM2.5									
OC									
EC									
VOC									
NO2									
NH3									
SO2									
CO									
O3									

2.3 Ambient Air Quality – Results

The air quality standards are legally binding numbers that must be attained in ambient air. Attainment of air quality standards should ensure safety (or acceptable risk) for human beings and other receptors. The Indian National Ambient Air Quality Standards (NAAQS) standards for 12 parameters as notified by Central Pollution Control Board (CPCB), Delhi are presented in Table 2.9. The air quality for twelve notified parameters is discussed in the next section.

Table 2.9: National Ambient Air Quality Standards

Pollutants	Time Weighted Average	Concentration in Ambient Air	
		Industrial, Residential, Rural and other Areas	Ecologically Sensitive Area (Notified by Central Government)
Sulphur Dioxide (SO ₂), µg/m ³	Annual * 24 Hours **	50 80	20 80
Nitrogen Dioxide (NO ₂), µg/m ³	Annual * 24 Hours **	40 80	30 80
Particulate Matter (Size less than 10µm) or PM ₁₀ , µg/m ³	Annual * 24 Hours **	60 100	60 100
Particulate Matter (Size less than 2.5µm) or PM _{2.5} , µg/m ³	Annual * 24 Hours **	40 60	40 60
Ozone (O ₃) µg/m ³	8 Hours * 1 Hour **	100 180	100 180
Lead (Pb) µg/m ³	Annual * 24 Hours **	0.50 1.0	0.50 1.0
Carbon Monoxide (CO), mg/m ³	8 Hours ** 1 Hour **	02 04	02 04
Ammonia (NH ₃), µg/m ³	Annual * 24 Hours **	100 400	100 400
Benzene (C ₆ H ₆), µg/m ³	Annual *	5	5
Benzo(a)Pyrene (BaP) Particulate phase only, ng/m ³	Annual *	1	1
Arsenic (As), ng/m ³	Annual *	6	6
Nickel (Ni), ng/m ³	Annual *	20	20
*Annual Arithmetic mean of minimum 104 measurements in a year at a particular site taken twice a week 24 hourly at uniform intervals. ** 24 hourly or 8 hourly or 1 hourly monitored values, as applicable, shall be complied with 98% of the time in a year. 2% of the time, they may exceed the limits but not on two consecutive days of monitoring. NOTE: Whenever and wherever monitoring results on two consecutive days of monitoring exceed the limits specified above for the respective category, it shall be considered an adequate reason to institute regular or continuous monitoring and further investigations.			

2.3.1 Particulate Matter (PM₁₀, PM_{2.5})

A statistical summary of PM levels is presented in Table 2.10 for all sites.

Marice Hotel Jharmajri (MHJ)

The time-series of 24-hr average concentrations of PM₁₀ and PM_{2.5} are shown in Figure 2.4. Average levels were $210 \pm 85 \mu\text{g}/\text{m}^3$ (for PM_{2.5}) and $286 \pm 107 \mu\text{g}/\text{m}^3$ (for PM₁₀). The levels of PM₁₀ and PM_{2.5} are non-complying with the NAAQS. The corresponding CPCB air quality Index (AQI) was less than 451 and 380 in the category *severe*. The ratio of PM_{2.5} to PM₁₀ was 0.73 at MHJ.

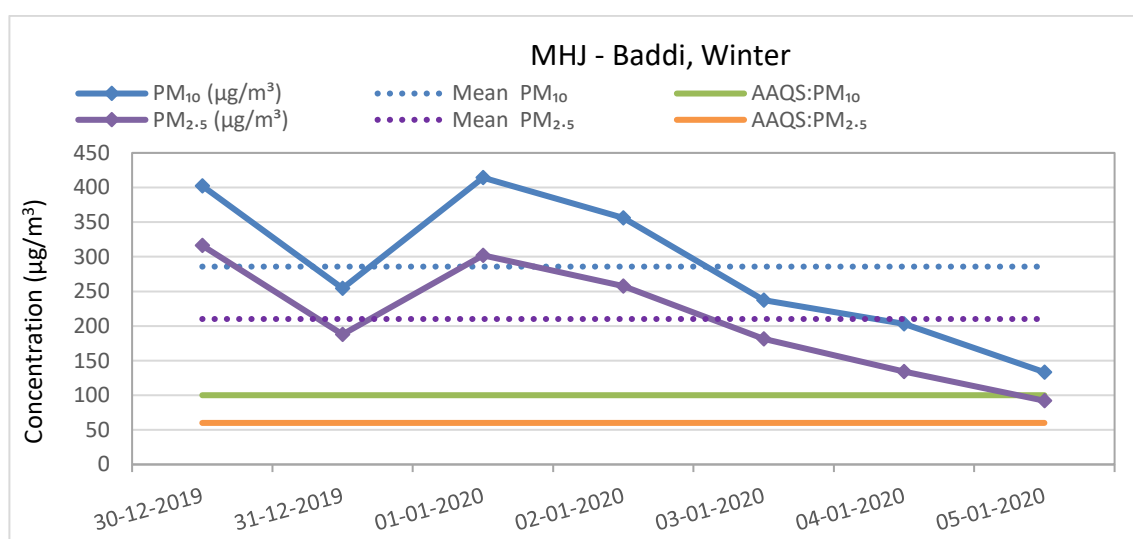


Figure 2.4: PM Concentrations at MHJ

HPSPCB Office Sai Road (OBD)

Time-series of 24-hr average concentrations of PM₁₀ and PM_{2.5} is shown in Figure 2.5. Average levels were $137 \pm 50 \mu\text{g}/\text{m}^3$ (for PM_{2.5}) and $205 \pm 63 \mu\text{g}/\text{m}^3$ (for PM₁₀). The levels of PM₁₀ and PM_{2.5} are non-complying with the NAQS. The corresponding CPCB air quality Index (AQI) was less than 378 and 256 in the category *very poor*. The ratio of PM_{2.5} to PM₁₀ was 0.66 at OBD.

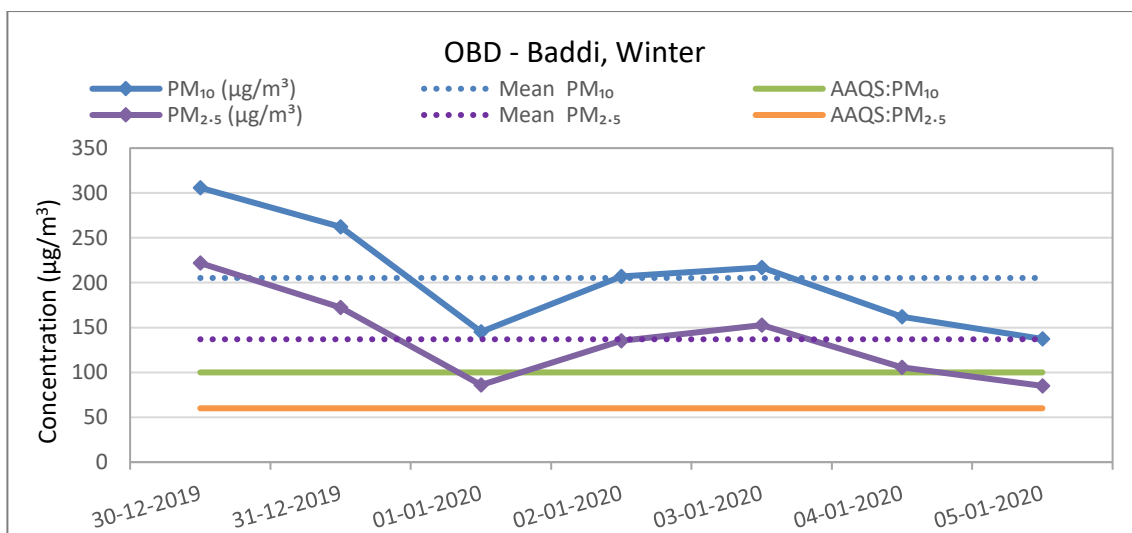


Figure 2.5: PM Concentrations at OBD

Aristo Pharma (ARF)

The time-series of 24-hr average concentrations of PM₁₀ and PM_{2.5} is shown in Figure 2.6. Average levels were $127 \pm 33 \mu\text{g}/\text{m}^3$ (for PM_{2.5}) and $181 \pm 43 \mu\text{g}/\text{m}^3$ (for PM₁₀). The levels of PM₁₀ and PM_{2.5} are non-complying with the NAQS. The corresponding CPCB air quality Index (AQI) was less than 358 and 221 in the category *very poor*. The ratio of PM_{2.5} to PM₁₀ was 0.70 at ARF.

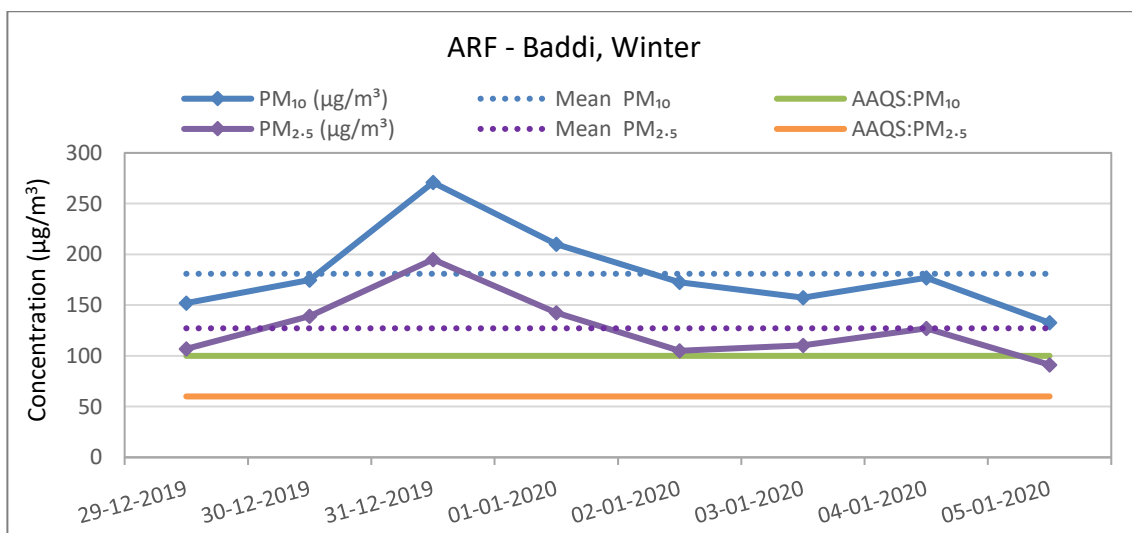


Figure 2.6: PM Concentrations at ARF

Govt. School Sandoli (GSS)

Time-series of 24-hr average concentrations of PM₁₀ and PM_{2.5} is shown in Figure 2.7. Average levels were 146±63 µg/m³ (for PM_{2.5}) and 274±104 µg/m³ (for PM₁₀). The levels of PM₁₀ and PM_{2.5} are non-complying with the NAQS. The corresponding CPCB air quality Index (AQI) was less than 428 and 465 in the category *severe*. The ratio of PM_{2.5} to PM₁₀ was 0.53 at GSS.

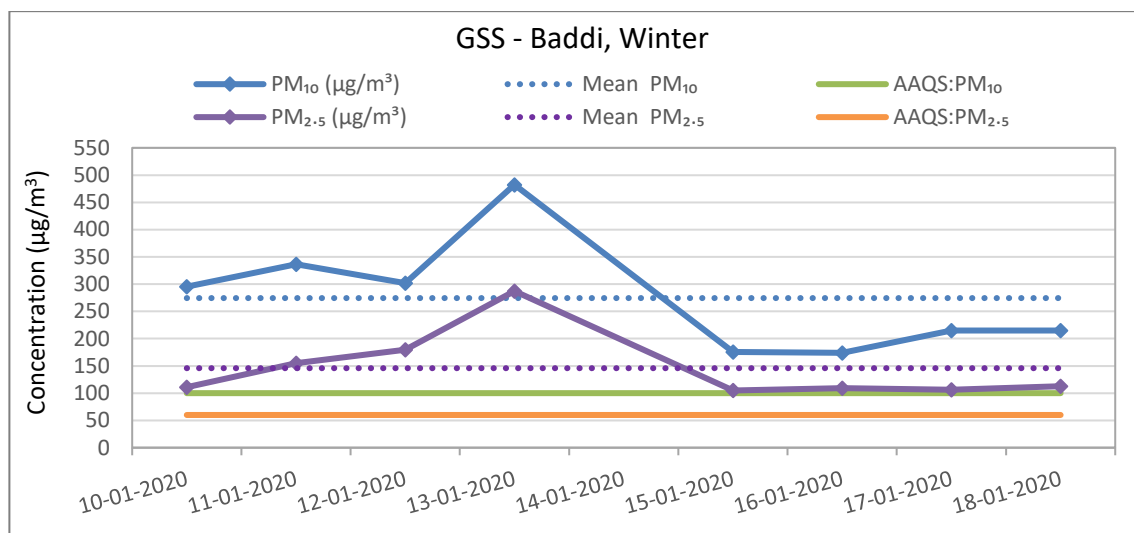


Figure 2.7: PM Concentrations at GSS

Vardhman Textile (VMT)

Time-series of 24-hr average concentrations of PM₁₀ and PM_{2.5} is shown in Figure 2.8. Average levels were 87±26 µg/m³ (for PM_{2.5}) and 142±28 µg/m³ (for PM₁₀). The levels of PM₁₀ and PM_{2.5} are non-complying with the NAQS. The corresponding CPCB air quality Index (AQI) was less than 304 and 154 in the category *very poor*. The ratio of PM_{2.5} to PM₁₀ was 0.61.

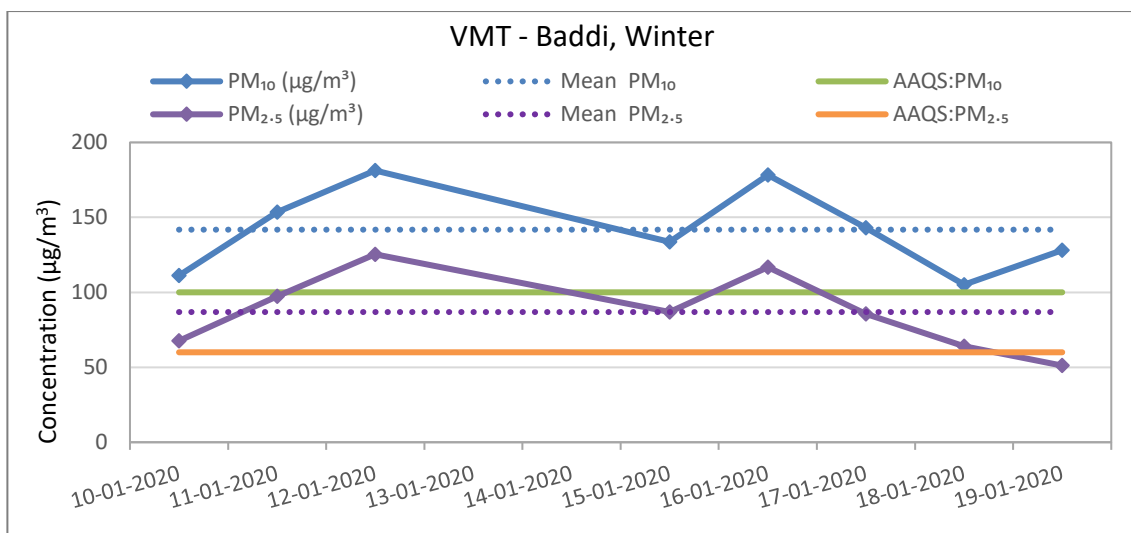


Figure 2.8: PM Concentrations at VMT

Overall PM levels

The site-wise comparison is shown for PM₁₀ and PM_{2.5} (Figure 2.9) and the ratio of PM_{2.5} to PM₁₀ (Figure 2.10) for all sites. The overall summary of experimental results for PM is shown for Baddi (Table 2.10).

The overall city mean levels in winter were 141 ± 40 µg/m³ (for PM_{2.5}) and 218 ± 55 µg/m³ (for PM₁₀) and the ratio (PM_{2.5}/PM₁₀) was 0.65 ± 0.07 . The PM_{2.5} levels are about 2.3 times higher than the NAAQS (60 µg/m³) and PM₁₀ about 2.2 times higher than the standard (100 µg/m³). The PM₁₀ and PM_{2.5} levels were highest at MHJ (286 and 210 µg/m³) and lowest at VMT (142 and 87 µg/m³).

The ratio of PM_{2.5} to PM₁₀ is a useful parameter to indicate the relative abundance of fine particles (i.e., PM_{2.5}) and toxicity of particulate matter. The overall city ratio is 0.65 and it was highest at MHJ (0.73), followed by ARF (0.70). The relatively high PM_{2.5} at these sites could be attributed to high traffic and emissions from industrial units.

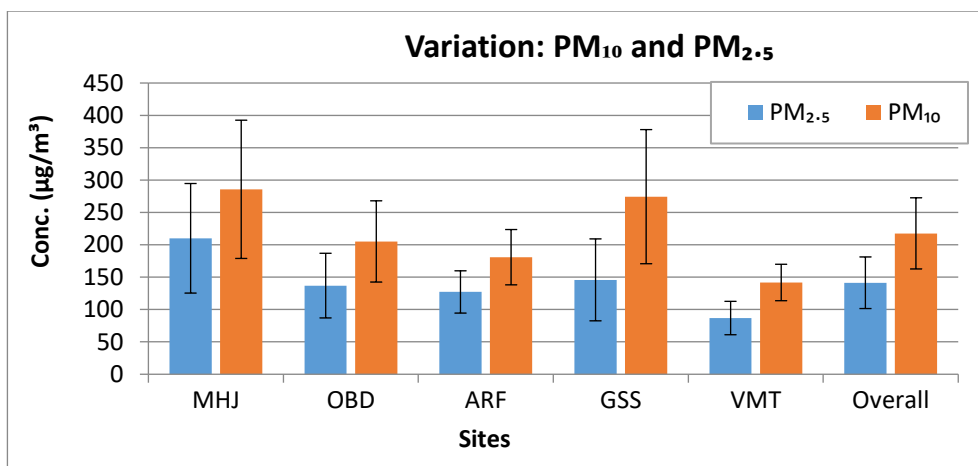


Figure 2.9: Comparison of PM levels at all sites

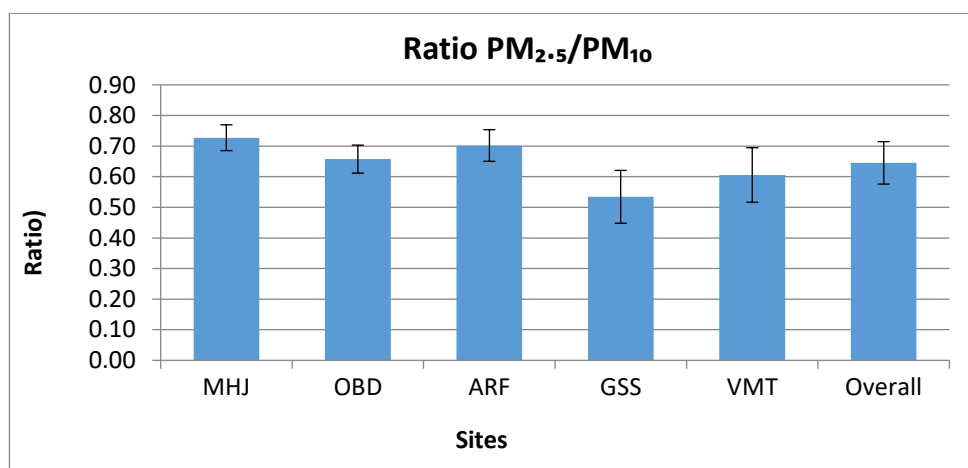


Figure 2.10: Comparison of PM_{2.5}/PM₁₀ ratio for all sites

Table 2.10: Statistical Results of PM_{2.5} and PM₁₀ in (µg/m³) at Baddi

Site		PM _{2.5}	PM ₁₀	PM _{2.5} /PM ₁₀
MHJ	Mean±SD	210±85	286±107	0.73±0.04
	Range	92-316	133-414	0.66-0.79
OBD	Mean±SD	137±50	205±63	0.66±0.05
	Range	85-222	137-306	0.59-0.73
ARF	Mean±SD	127±33	181±43	0.70±0.05
	Range	91-195	133-271	0.61-0.80
GSS	Mean±SD	146±63	274±104	0.53±0.09
	Range	105-287	174-482	0.38-0.63
VMT	Mean±SD	87±26	142±28	0.61±0.09
	Range	51-125	105-181	0.40-0.69
Overall	Mean±SD	141±40	218±55	0.65±0.07

2.3.2 Gaseous pollutants

The statistical summary for gaseous pollutant (SO_2 , NO_2 and NH_3) results are given in Table 2.11.

MHJ

The time-series of 24-hr average concentrations of SO_2 , NO_2 and NH_3 are shown in Figure 2.11. It was observed that NH_3 concentrations were low and met the air quality standard. Average SO_2 and NO_2 concentration are below NAAQS. SO_2 and NO_2 concentration are exceptionally high at one day of sampling.

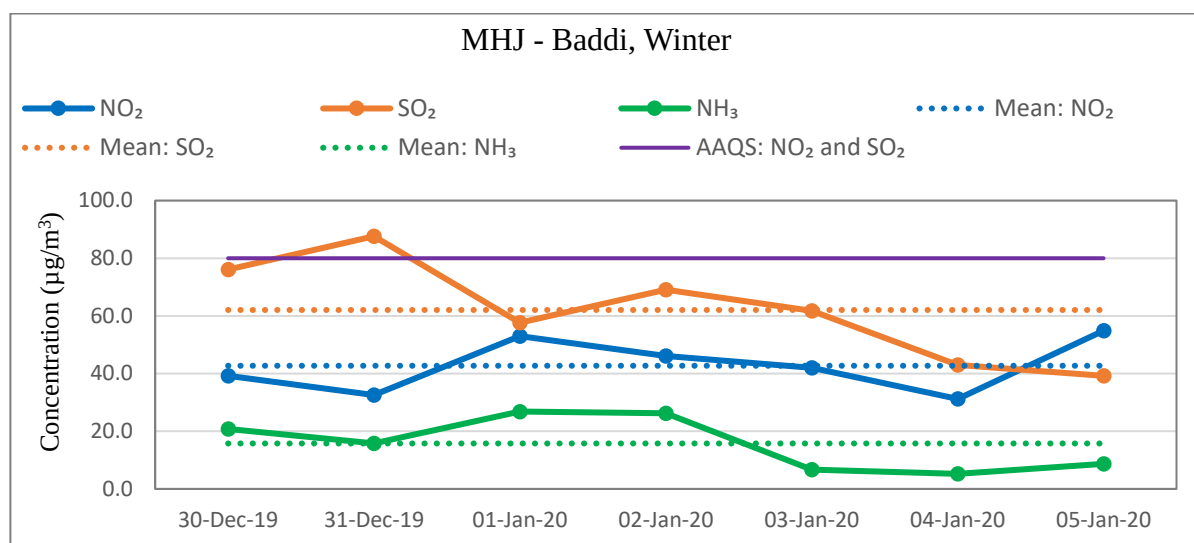


Figure 2.11: SO_2 , NO_2 and NH_3 concentrations at MHJ

OBD

Time-series of 24-hr average concentrations of SO_2 , NO_2 and NH_3 are shown in Figure 2.12. It was observed that SO_2 , NO_2 and NH_3 concentrations were low and met the air quality standard. SO_2 concentrations are lesser than NO_2 concentrations.

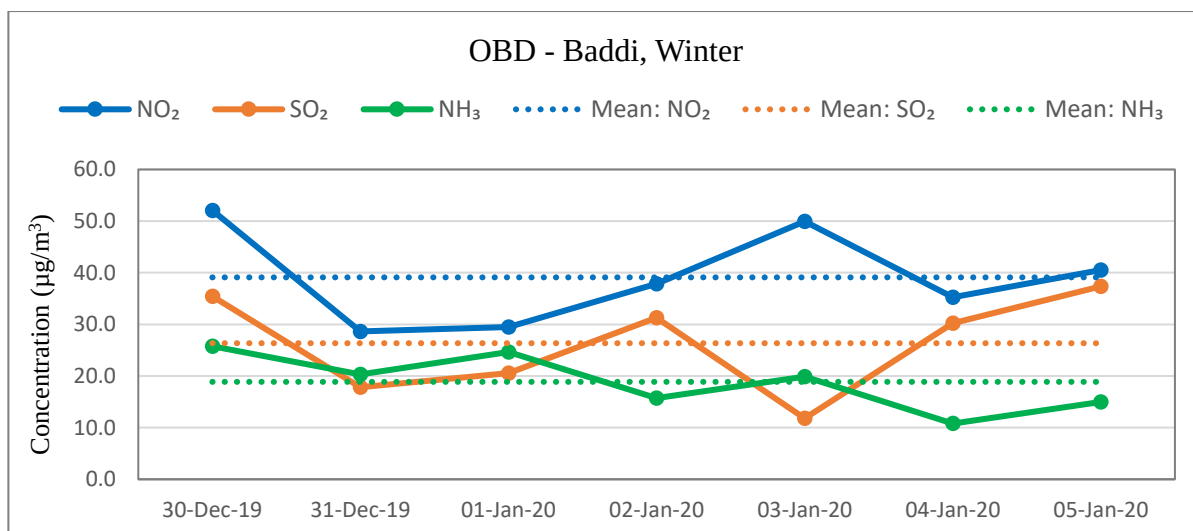


Figure 2.12: SO₂, NO₂ and NH₃ concentrations at OBD

ARF

Time-series of 24-hr average concentrations of SO₂, NO₂ and NH₃ are shown in Figure 2.13. It was observed that SO₂, NO₂ and NH₃ concentrations were low and met the air quality standard.

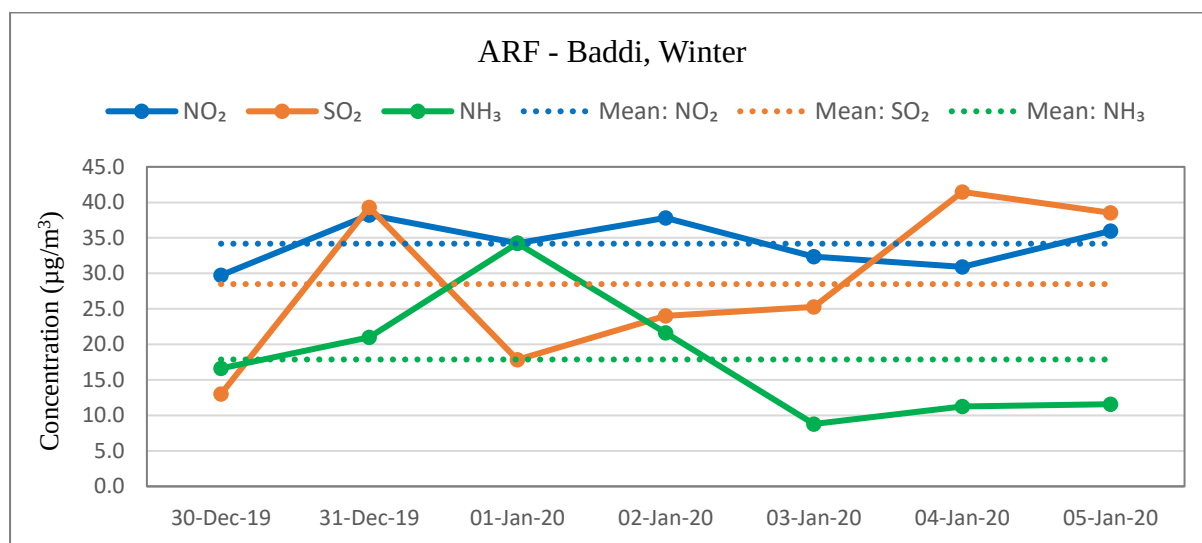


Figure 2.13: SO₂, NO₂ and NH₃ concentrations at ARF

GSS

Time series of 24-hr average concentrations of SO₂, NO₂ and NH₃ are shown in Figure 2.14. It was observed that SO₂, NO₂ and NH₃ concentrations were low and met the air quality standard.

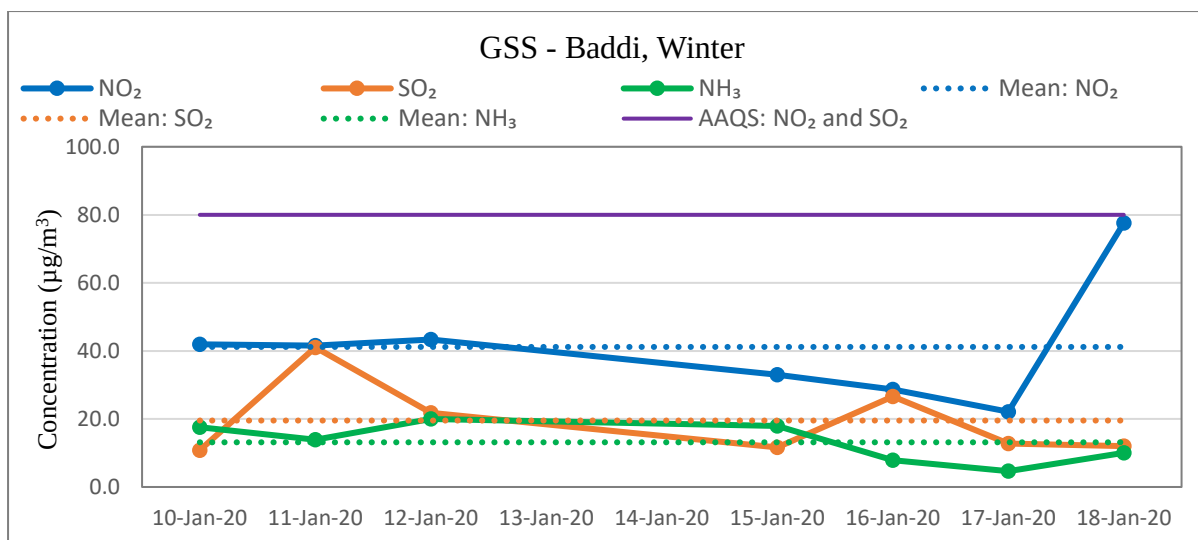


Figure 2.14: SO₂, NO₂ and NH₃ concentrations at GSS

VMT

Time series of 24-hr average concentrations of SO₂, NO₂ and NH₃ are shown in Figure 2.15. It was observed that NO₂ and NH₃ concentrations were low and meet the air quality standard. SO₂ concentration was not complying with NAAQS at a few sampling days and was higher than NO₂ concentrations.

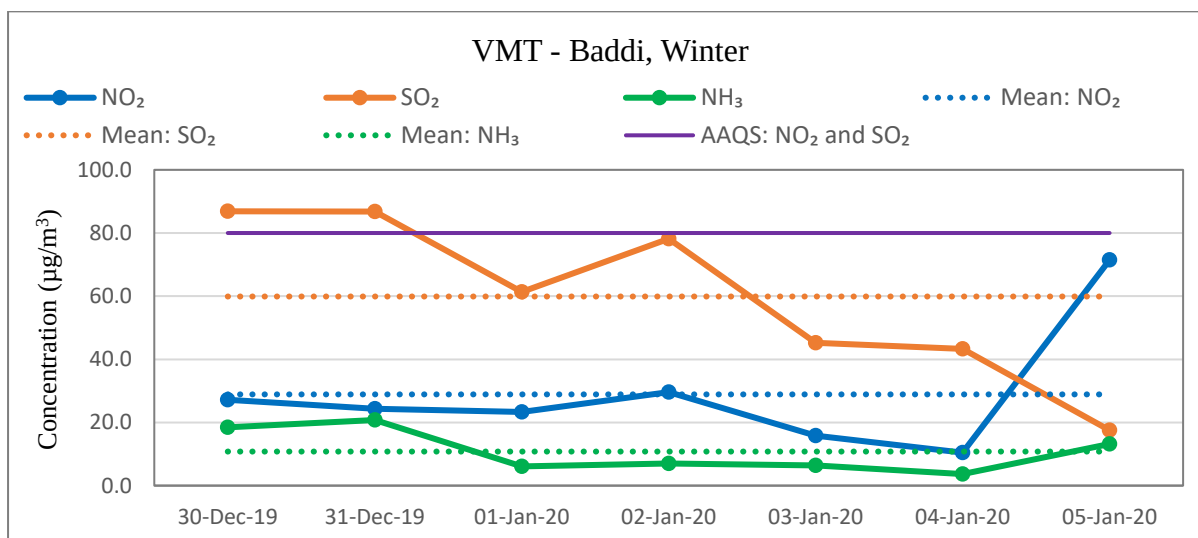


Figure 2.15: SO₂, NO₂ and NH₃ concentrations at VMT

Overall gaseous levels

The site-wise comparison is shown for NO₂, SO₂ and NH₃ (Figure 2.16) for all sites. The overall summary of experimental results for PM is shown for Baddi (Table 2.11).

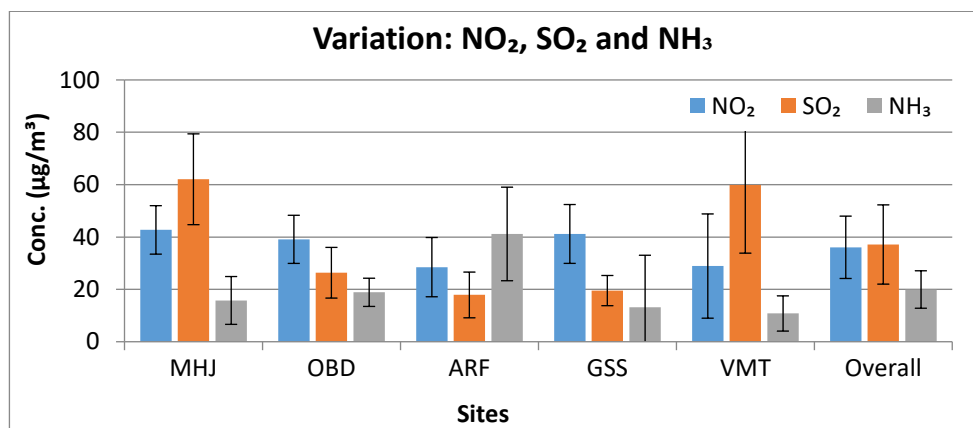


Figure 2.16: Comparison of gaseous pollutants levels at all sites

Table 2.11: Statistical results of gaseous pollutants (µg/m³) at Baddi

Site		NO ₂	SO ₂	NH ₃
MHJ	Mean±SD	42.7±9.3	62.1±17.3	15.8±9.1
	Range	31.2-54.9	39.2-87.6	5.2-26.8
OBD	Mean±SD	39.1±9.2	26.4±9.7	18.9±5.4
	Range	28.6-52.1	11.8-37.4	10.8-25.8
ARF	Mean±SD	34.2±3.3	28.5±11.3	17.9±8.7
	Range	29.7-38.2	13.0-41.5	8.8-34.2
GSS	Mean±SD	41.2±17.9	19.5±11.2	13.1±5.8
	Range	22.1-77.6	10.8-41.0	4.7-20.0
VMT	Mean±SD	28.9±19.9	59.9±26.0	10.8±6.7
	Range	10.5-71.5	17.5-86.9	3.7-20.8
Overall	Mean±SD	37.2±11.9	39.3±15.1	15.3±7.2

2.3.3 Volatile Organic Compounds (VOCs: BTX)

VOCs (benzene, toluene, p-xylene and o-xylene (BTX)) concentrations at all sites are shown in Figure 2.17 and the site-wise comparison is presented in Figure 2.18 for the winter season. Statistical Results of VOC levels at Baddi are presented in Table 2.12.

The overall city-level average of BTX levels is 0.52 ± 0.09 µg/m³ in winter. It is observed that the BTX concentrations are highest at ARF (1.03 µg/m³) could be due to the more industrial activity and the lowest at the VMT (0.07 µg/m³) could be due to the green campus and less organic solvent uses. The possible reason for higher concentrations in OBD could be more

vehicle movement in this area due to petrol pumps, main market, alongside the main road and which may cause large evaporative losses from fuel tanks of vehicles and petrol pumps.

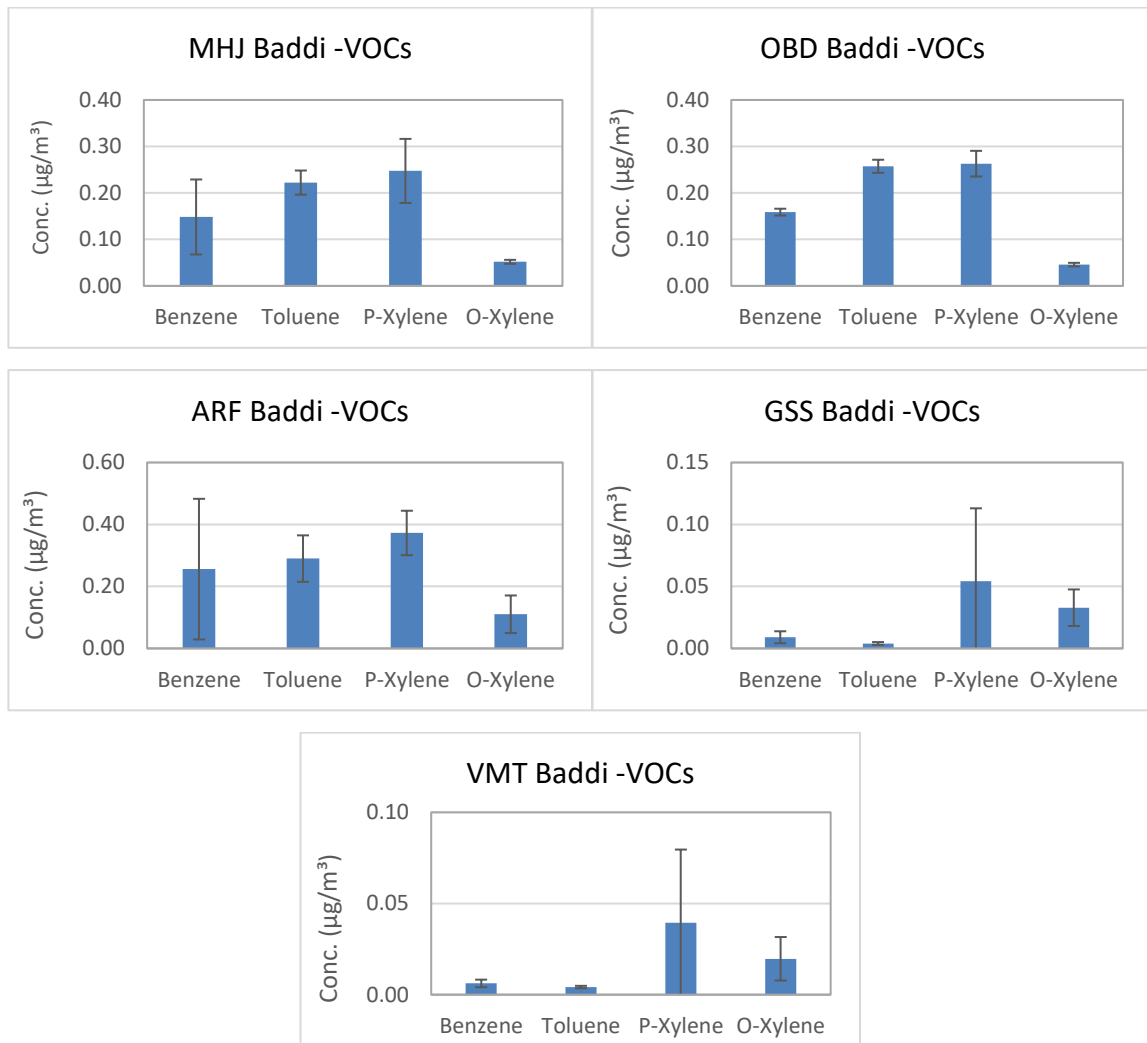


Figure 2.17: VOCs Concentrations at different sites in Baddi

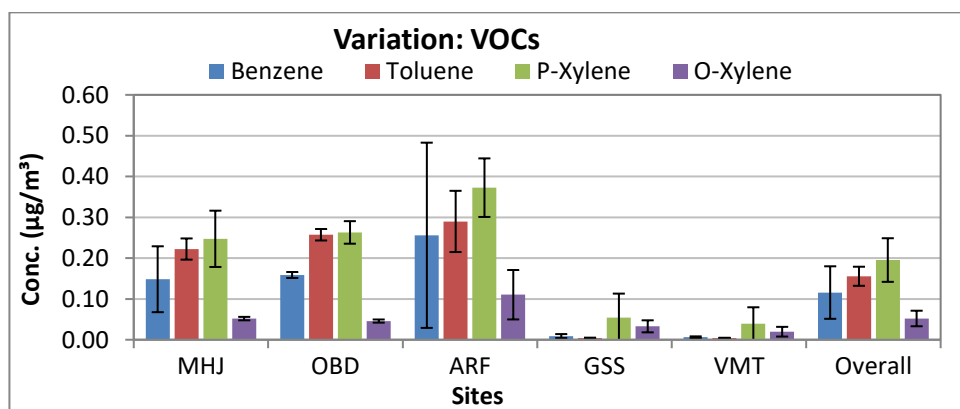


Figure 2.18: Comparison of gaseous pollutants levels at all sites

Table 2.12: Statistical Results of VOCs Contents ($\mu\text{g}/\text{m}^3$) at Baddi

Site		Benzene	Toluene	P-Xylene	O-Xylene	Total (BTX)
MHJ	Mean $\pm$ SD	0.15 $\pm$ 0.08	0.22 $\pm$ 0.03	0.25 $\pm$ 0.07	0.05 $\pm$ 0.00	0.67 $\pm$ 0.08
	Range	0.09-0.28	0.19-0.26	0.15-0.33	0.05-0.06	0.54-0.75
OBD	Mean $\pm$ SD	0.16 $\pm$ 0.01	0.26 $\pm$ 0.01	0.26 $\pm$ 0.03	0.05 $\pm$ 0.00	0.72 $\pm$ 0.02
	Range	0.15-0.17	0.24-0.28	0.23-0.29	0.04-0.05	0.71-0.75
ARF	Mean $\pm$ SD	0.26 $\pm$ 0.23	0.29 $\pm$ 0.07	0.37 $\pm$ 0.07	0.11 $\pm$ 0.06	1.03 $\pm$ 0.25
	Range	0.11-0.66	0.25-0.42	0.29-0.48	0.04-0.17	0.88-1.47
GSS	Mean $\pm$ SD	0.01 $\pm$ 0.00	0.00 $\pm$ 0.00	0.05 $\pm$ 0.06	0.03 $\pm$ 0.01	0.10 $\pm$ 0.07
	Range	0.00-0.02	0.00-0.01	0.01-0.16	0.01-0.05	0.03-0.23
VMT	Mean $\pm$ SD	0.01 $\pm$ 0.00	0.00 $\pm$ 0.00	0.04 $\pm$ 0.04	0.02 $\pm$ 0.01	0.07 $\pm$ 0.05
	Range	0.00-0.01	0.00-0.00	0.01-0.11	0.01-0.03	0.03-0.15
Overall	Mean $\pm$ SD	0.12 $\pm$ 0.06	0.16 $\pm$ 0.02	0.20 $\pm$ 0.05	0.05 $\pm$ 0.02	0.52 $\pm$ 0.09

2.3.4 Elemental and Organic Carbon Content (EC/OC) in $\text{PM}_{2.5}$

MHJ

Average concentrations of EC, OC (OC1, OC2, OC3 and OC4) and ratio of OC fraction to TC are shown in Figures 2.19 (a) and (b). Organic carbon is observed higher than elemental carbon. However, the ratio of OC3/TC is observed higher that indicating the formation of secondary organic carbon in the atmosphere at MHJ. Statistical Results of Carbon Contents ($\mu\text{g}/\text{m}^3$) in $\text{PM}_{2.5}$ at MHJ are presented in Table 2.13.

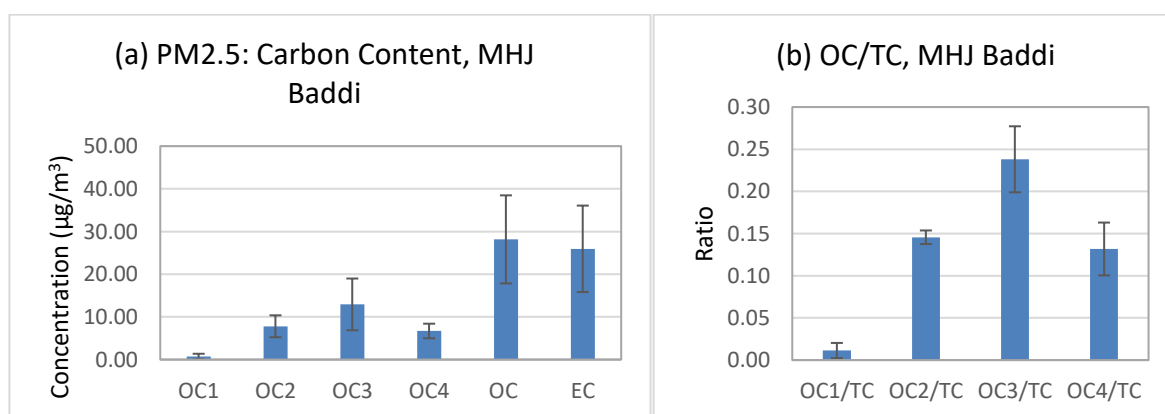
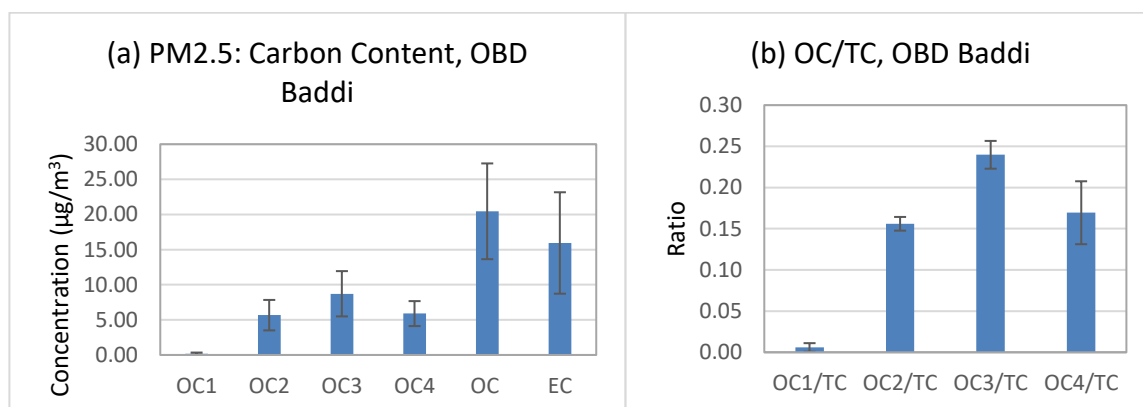
**Figure 2.19: EC and OC Content in $\text{PM}_{2.5}$ at MHJ**

Table 2.13: Statistical Results of Carbon Contents ($\mu\text{g}/\text{m}^3$) in $\text{PM}_{2.5}$ at MHJ

	OC1	OC2	OC3	OC4	OC	EC	TC	OC1/TC	OC2/TC	OC3/TC	OC4/TC
Mean	0.74	7.80	12.92	6.69	28.16	25.95	54.10	0.01	0.15	0.24	0.13
SD	0.62	2.57	6.06	1.71	10.32	10.13	19.60	0.01	0.01	0.04	0.03
CV	0.84	0.33	0.47	0.26	0.37	0.39	0.36	0.80	0.06	0.16	0.24
Max	1.42	10.82	25.48	9.73	47.36	36.07	83.44	0.02	0.15	0.31	0.18
Min	0.00	3.84	6.53	4.60	14.98	10.97	25.95	0.00	0.13	0.18	0.10

OBD

Average concentrations of EC, OC (OC1, OC2, OC3 and OC4) and ratio of OC fraction to TC are shown in Figures 2.20 (a) and (b). Organic carbon is observed higher than elemental carbon. However, the ratio of OC3/TC is observed higher that indicating the formation of secondary organic carbon in the atmosphere at OBD. Statistical Results of Carbon Contents ($\mu\text{g}/\text{m}^3$) in $\text{PM}_{2.5}$ at OBD are presented in Table 2.14.

**Figure 2.20: EC and OC Content in $\text{PM}_{2.5}$ at OBD****Table 2.14: Statistical Results of Carbon Contents ($\mu\text{g}/\text{m}^3$) in $\text{PM}_{2.5}$ at OBD**

	OC1	OC2	OC3	OC4	OC	EC	TC	OC1/TC	OC2/TC	OC3/TC	OC4/TC
Mean	0.18	5.66	8.71	5.89	20.45	15.94	36.39	0.01	0.16	0.24	0.17
SD	0.16	2.17	3.22	1.78	6.82	7.22	13.98	0.01	0.01	0.02	0.04
CV	0.87	0.38	0.37	0.30	0.33	0.45	0.38	0.90	0.05	0.07	0.23
Max	0.36	8.97	13.52	9.32	31.26	27.14	58.40	0.01	0.17	0.26	0.23
Min	0.00	3.48	4.49	3.85	13.00	8.40	21.40	0.00	0.14	0.21	0.12

ARF

Average concentrations of EC, OC (OC1, OC2, OC3 and OC4) and ratio of OC fraction to TC are shown in Figure 2.21 (a) and (b). Organic carbon is observed higher than elemental carbon. However, the ratio of OC3/TC is observed higher that indicating the formation of secondary organic carbon in the atmosphere at ARF. Statistical Results of Carbon Contents ($\mu\text{g}/\text{m}^3$) in $\text{PM}_{2.5}$ at ARF are presented in Table 2.15.

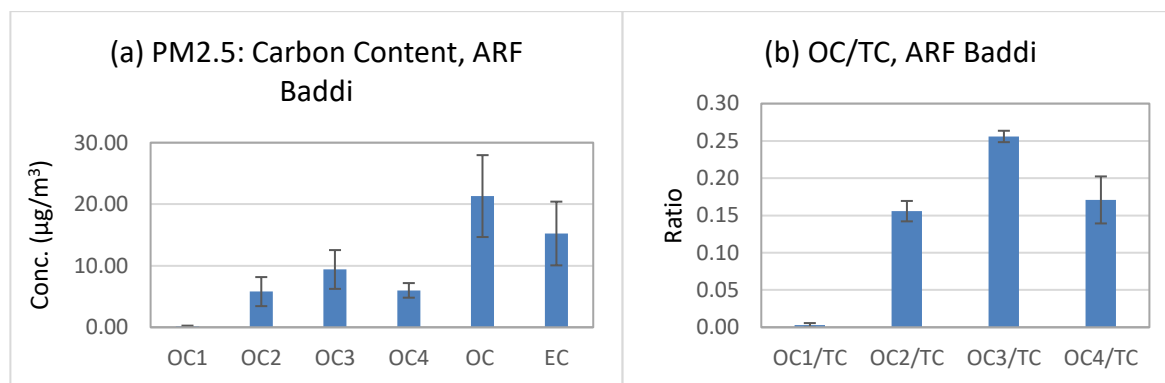


Figure 2.21: EC and OC Content in $\text{PM}_{2.5}$ at ARF

Table 2.15: Statistical Results of Carbon Contents ($\mu\text{g}/\text{m}^3$) in $\text{PM}_{2.5}$ at ARF

	OC1	OC2	OC3	OC4	OC	EC	TC	OC1/TC	OC2/TC	OC3/TC	OC4/TC
Mean	0.13	5.80	9.40	6.00	21.32	15.24	36.56	0.00	0.16	0.26	0.17
SD	0.14	2.36	3.15	1.19	6.65	5.18	11.72	0.00	0.01	0.01	0.03
CV	1.10	0.41	0.34	0.20	0.31	0.34	0.32	0.95	0.09	0.03	0.18
Max	0.36	10.87	15.63	8.72	35.58	24.61	60.19	0.01	0.18	0.27	0.21
Min	0.00	3.57	6.17	4.97	14.71	9.83	24.54	0.00	0.14	0.25	0.12

GSS

Average concentrations of EC, OC (OC1, OC2, OC3 and OC4) and ratio of OC fraction to TC are shown in Figures 2.22 (a) and (b). Organic carbon is observed higher than elemental carbon. However, the ratio of OC3/TC is observed higher that indicating the formation of secondary organic carbon in the atmosphere at OBD. Statistical results of carbon contents in $\text{PM}_{2.5}$ at OBD are presented in Table 2.16.

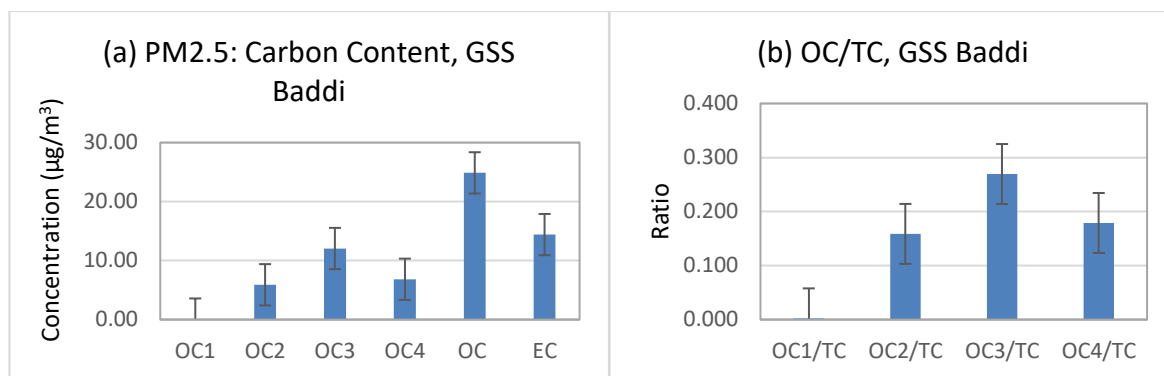


Figure 2.22: EC and OC Content in $\text{PM}_{2.5}$ at GSS

Table 2.16: Statistical Results of Carbon Contents ($\mu\text{g}/\text{m}^3$) in $\text{PM}_{2.5}$ at GSS

	OC1	OC2	OC3	OC4	OC	EC	TC	OC1/TC	OC2/TC	OC3/TC	OC4/TC
Mean	0.08	5.90	12.05	6.84	24.87	14.41	39.28	0.002	0.159	0.269	0.179
SD	0.07	3.15	13.12	4.56	20.71	7.01	26.76	0.002	0.015	0.072	0.020
CV	0.78	0.53	1.09	0.67	0.83	0.49	0.68	0.70	0.10	0.27	0.11
Max	0.19	12.58	43.85	17.59	74.18	25.47	99.66	0.005	0.175	0.440	0.215
Min	0.01	3.08	4.06	3.68	10.85	7.47	18.81	0.001	0.126	0.216	0.156

VMT

Average concentrations of EC, OC (OC1, OC2, OC3 and OC4) and ratio of OC fraction to TC are shown in Figures 2.23 (a) and (b). Organic carbon is observed higher than elemental carbon. However, the ratio of OC3/TC is observed higher that indicating the formation of secondary organic carbon in the atmosphere at OBD. Statistical Results of Carbon Contents ($\mu\text{g}/\text{m}^3$) in $\text{PM}_{2.5}$ at OBD are presented in Table 2.17.

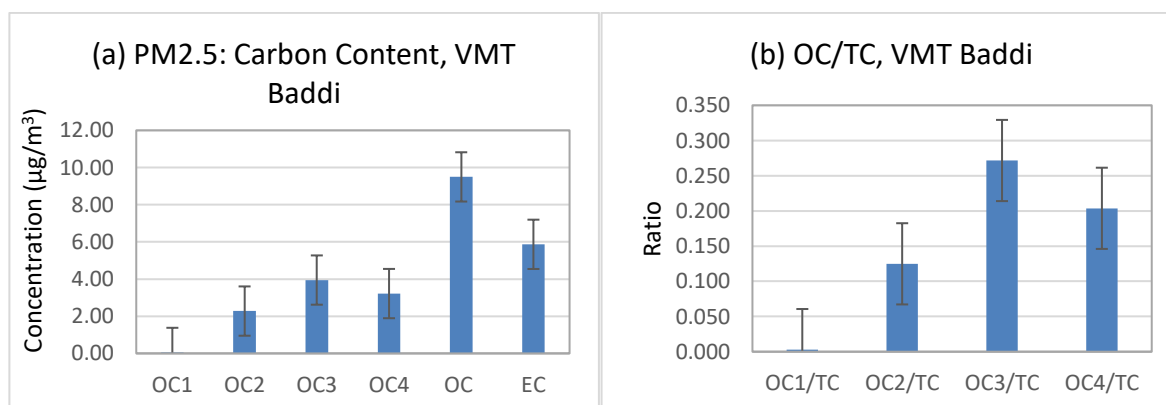


Figure 2.23: EC and OC Content in $\text{PM}_{2.5}$ at VMT

Table 2.17: Statistical Results of Carbon Contents ($\mu\text{g}/\text{m}^3$) in $\text{PM}_{2.5}$ at VMT

	OC1	OC2	OC3	OC4	OC	EC	TC	OC1/TC	OC2/TC	OC3/TC	OC4/TC
Mean	0.05	2.28	3.95	3.22	9.50	5.87	15.37	0.003	0.12	0.27	0.20
SD	0.06	1.97	2.55	2.37	6.85	3.96	10.77	0.003	0.12	0.27	0.20
CV	1.06	0.87	0.65	0.74	0.72	0.68	0.70	0.003	0.12	0.28	0.20
Max	0.16	4.97	7.59	6.01	18.56	12.16	30.72	0.003	0.10	0.29	0.19
Min	0.00	0.22	0.88	0.70	1.80	1.34	3.14	0.003	0.09	0.30	0.19

Overall

The comparison for OC and EC is presented in Figure 2.24 for $\text{PM}_{2.5}$. The overall summary of carbon content (TC, EC, OC; OC1, OC2, OC3 and OC4 with fractions OC1/TC, OC2/TC, OC3/TC and OC4/TC) is presented in Table 2.18.

The $\text{PM}_{2.5}$ contained a high fraction of TC (OC+EC), 25% in winter. The OC is observed higher than the EC at each site; this is generally true that in the atmosphere volatile and semi-volatile organic compounds continuously undergo nucleation, oxidation, condensation and conversion into organic particles, whereas EC remains unchanged, as a result, the ratio of OC to EC further increases. However, the ratio of OC3/TC is observed higher than other OC fractions; this indicates the formation of secondary organic carbon particles in the atmosphere is an important process. It is also observed that the OC and EC are high probably because of poor dispersion in winter and more combustion sources, including biomass and municipal solid waste (MSW) burning. It is observed that the average TC to $\text{PM}_{2.5}$ ratio was maximum (29%) at ARF followed by GSS and minimum (18%) at VMT in winter (Table 2.18).

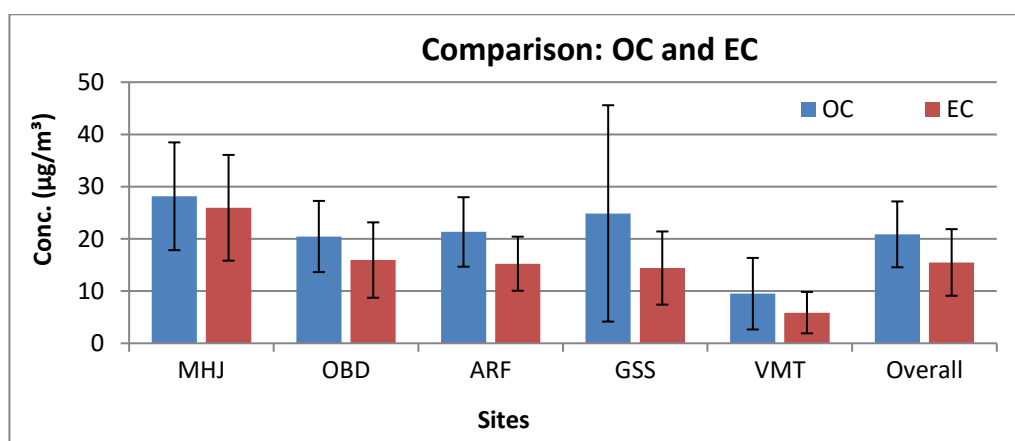
**Figure 2.24: Comparison of EC and OC in $\text{PM}_{2.5}$ for all Sites**

Table 2.18: Overall summary of Carbon Contents ($\mu\text{g}/\text{m}^3$) in $\text{PM}_{2.5}$

	PM_{2.5}	OC1	OC2	OC3	OC4	OC	EC	TC	OC1/TC	OC2/TC	OC3/TC	OC4/TC
MHJ	210	0.74	7.80	12.92	6.69	28.16	25.95	54.10	0.01	0.15	0.24	0.13
OBD	137	0.18	5.66	8.71	5.89	20.45	15.94	36.39	0.01	0.16	0.24	0.17
ARF	127	0.13	5.80	9.40	6.00	21.32	15.24	36.56	0.00	0.16	0.26	0.17
GSS	146	0.08	5.90	12.05	6.84	24.87	14.41	39.28	0.00	0.16	0.27	0.18
VMT	87	0.05	2.28	3.95	3.22	9.50	5.87	15.37	0.00	0.12	0.27	0.20
Overall	141	0.24	5.49	9.41	5.73	20.86	15.48	36.34	0.01	0.15	0.25	0.17
SD	40	0.26	1.79	3.15	1.31	6.31	6.38	12.36	0.00	0.01	0.01	0.02

2.3.5 PAHs in $\text{PM}_{2.5}$

The concentrations of PAHs (from solid phase only) with some specific markers were analyzed. Figure 2.25 shows the average measured concentration of PAHs in Baddi for winter. A statistical summary of PAHs is presented in Table 2.19 for winter season at all sites. The PAHs compounds analyzed were: (i) Di methyl Phthalate (DmP), (ii) Acenaphthylene (AcP), (iii) Di ethyl Phthalate (DEP), (iv) Fluorene (Flu), (v) Phenanthrene (Phe), (vi) Anthracene (Ant), (vii) Pyrene (Pyr), (viii) Butyl benzyl phthalate (BbP), (ix) Bis(2-ethylhexyl) adipate (BeA), (x) Benzo(a)anthracene (B(a)A), (xi) Chrysene (Chr), (xii) Benzo(b)fluoranthene (B(b)F), (xiii) Benzo(k)fluoranthene (B(k)F), (xiv) Benzo(a)pyrene (B(a)P), (xv) Indeno(1,2,3-cd)pyrene (InP), (xviii) Dibenzo(a,h)anthracene (D(a,h)A) and (xix) Benzo(ghi)perylene (B(ghi)P). Major PAHs (mostly higher molecular weight compounds) are B(b)F ($4.5 \text{ ng}/\text{m}^3$), B(ghi)P ($2.6 \text{ ng}/\text{m}^3$), DmP ($2.3 \text{ ng}/\text{m}^3$), Phe ($2.0 \text{ ng}/\text{m}^3$), InP ($2.0 \text{ ng}/\text{m}^3$), Chr ($1.9 \text{ ng}/\text{m}^3$) and B(a)P ($1.9 \text{ ng}/\text{m}^3$) in winter.

The overall average total PAHs were $24 \pm 15 \text{ ng}/\text{m}^3$. B(a)P, although has the annual standard of $1 \text{ ng}/\text{m}^3$ and we cannot compare it with levels of 7 days sampling at each site, however levels of B(a)P (mean: $1.9 \text{ ng}/\text{m}^3$) were high and annual standard may likely to exceed by a fair margin at most sites and meet at OBD.

Literature reported values for $\text{InP}/(\text{InP} + \text{B(ghi)P})$ ratio are 0.18, 0.37 and 0.56 for gasoline, diesel and coal respectively (Rajput and Lakhani, 2010). The ratio obtained in this study (0.44) is comparable to the reported values for coal combustion and diesel. It is inferred that the major source of PAHs is coal combustion and diesel vehicles.

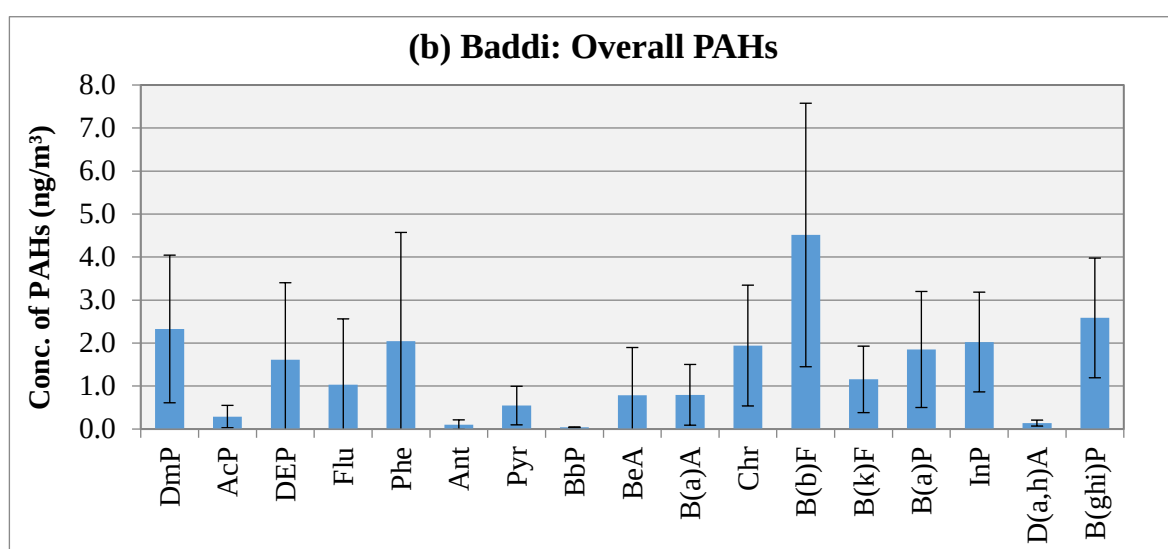
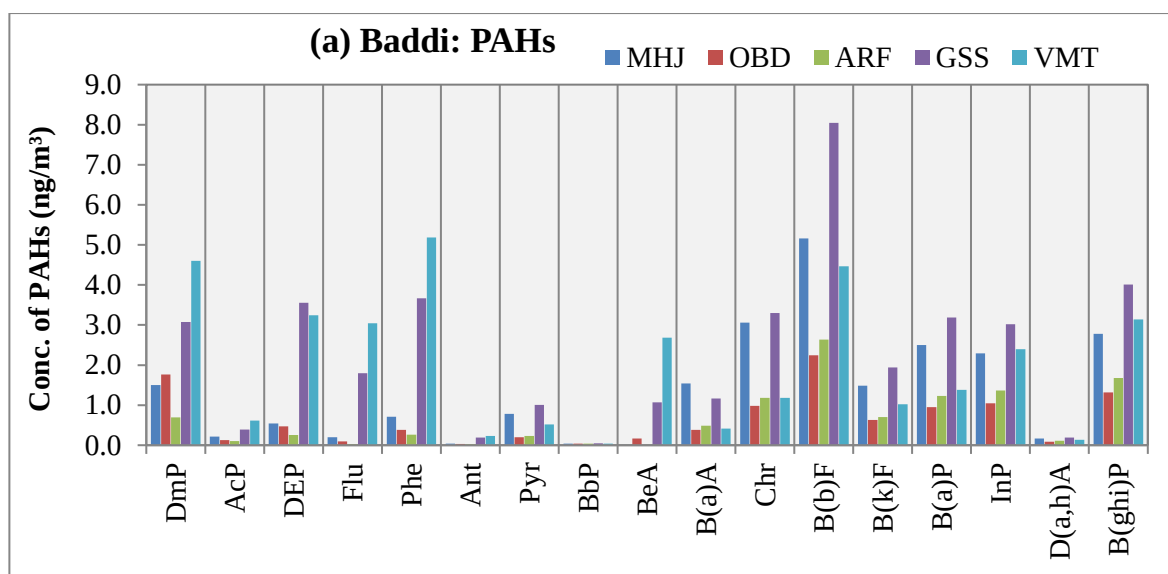


Figure 2.25: PAHs Concentrations in PM_{2.5}

2.3.6 Molecular Markers in PM_{2.5}

Total six molecular markers analyzed were: Tritriacontane, Hentriacontane, Pentriacontane, 17 β (H) 21 β (H)_hopane, 17 α (H) 21 α (H)_hopane, 17 α (H) - 22,29,30 - Trisnorhopane. The n-alkanes are generally emitted from all types of combustion sources and hopanes from combustion of coal (C), gasoline (G) and diesel (D) (Zhang et al., 2009).

Figure 2.26 and Table 2.20 show the levels of six molecular markers. Total concentration of markers was 62 ± 19 ng/m³ in winter. The presence of significant quantities of molecular markers, especially hopanes conclusively establishes contribution of CGD.

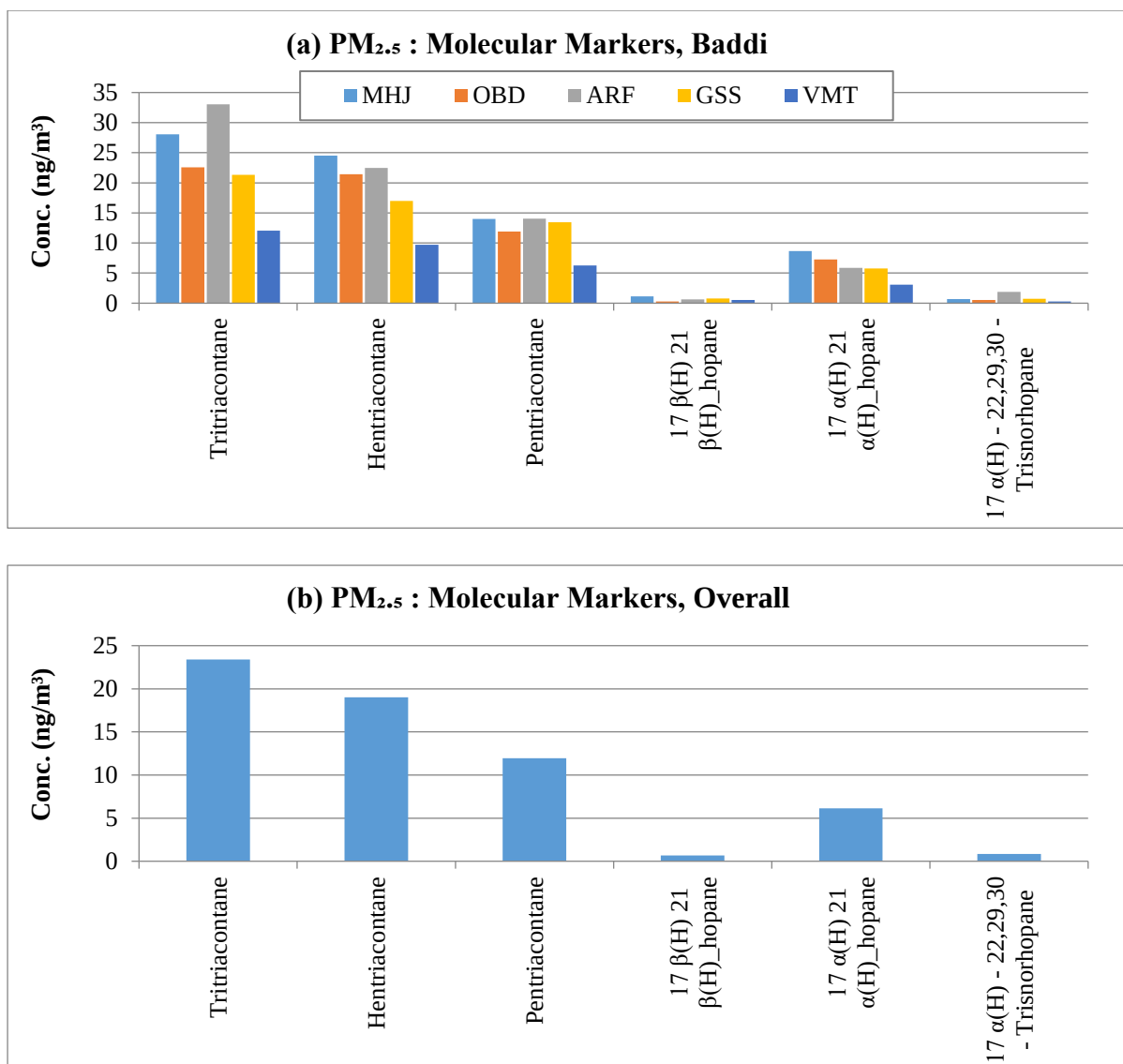


Figure 2.26: Molecular Markers in PM_{2.5}

2.3.7 Chemical Composition of PM₁₀ and PM_{2.5} and their correlation matrix

Graphical presentations of chemical species for PM₁₀ and PM_{2.5} for all the sites of Baddi are shown in Figure 2.27. Statistical summary for particulate matter (PM₁₀ and PM_{2.5}), its chemical composition [carbon content, ionic species and elements] along with mass percentage (% R) recovered from PM are presented in Tables 2.21 – 2.24.

The correlation between different parameters (i.e., PM, OC, EC, F⁻, Cl⁻, NO₃⁻, SO₄⁻², Na⁺, NH₄⁺, K⁺, Ca⁺², Mg⁺² and metals (elements) with major species (PM, OC, EC, NO₃⁻, SO₄⁻², NH₄⁺, Metals) for PM₁₀ and PM_{2.5} composition is presented in Table 2.25. It is seen that most of the parameters showed a good correlation (>0.30) with PM₁₀ and PM_{2.5}. The percentage constituent of the PM₁₀ and PM_{2.5} are presented in Figures 2.28 and 2.29 respectively.

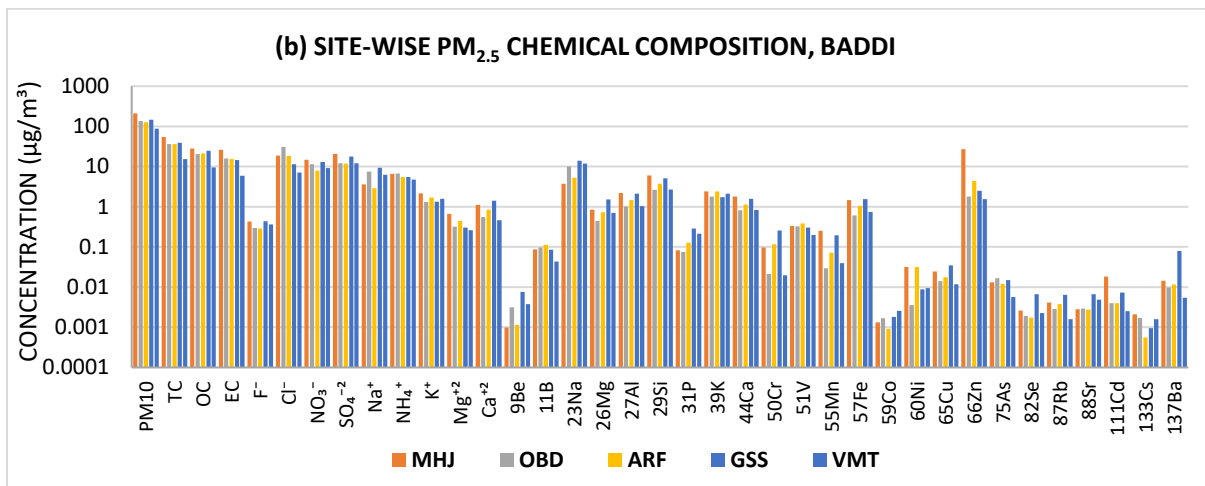
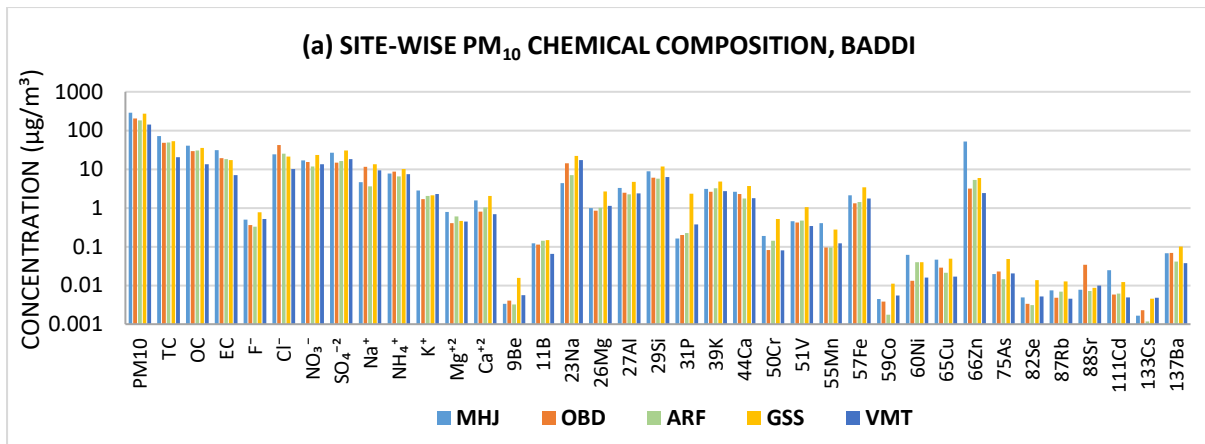
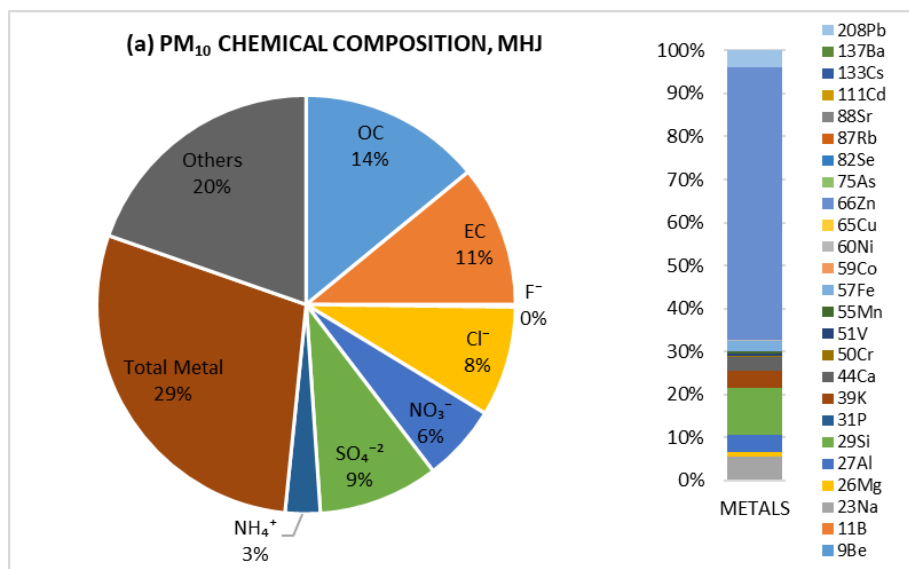
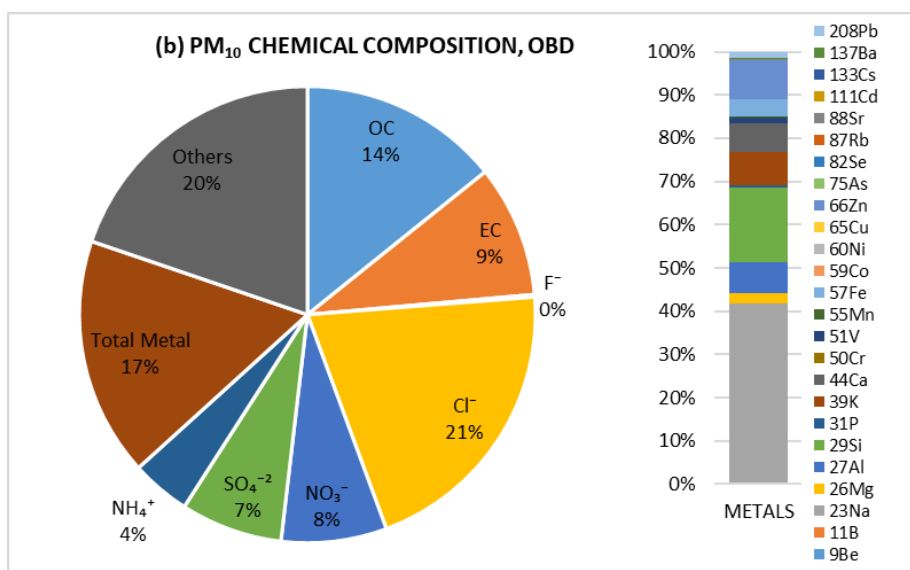
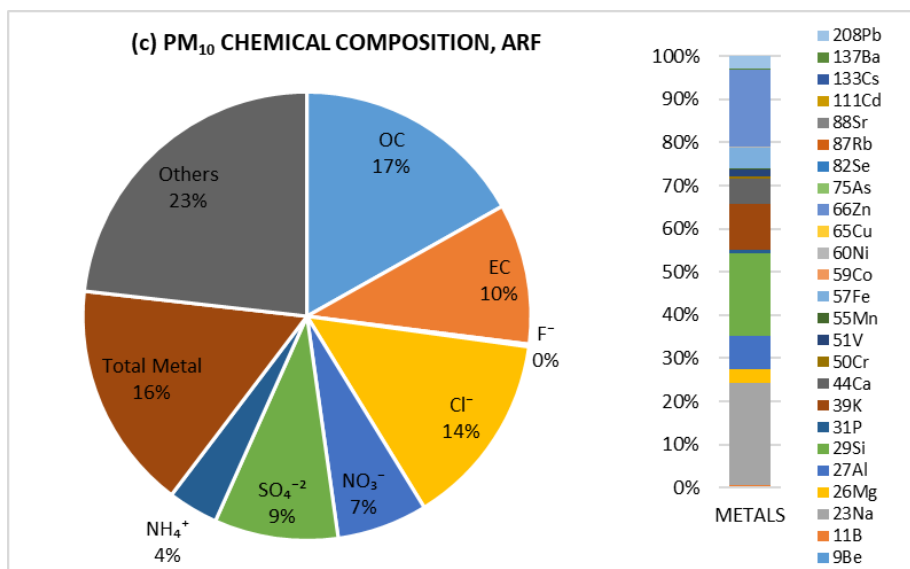
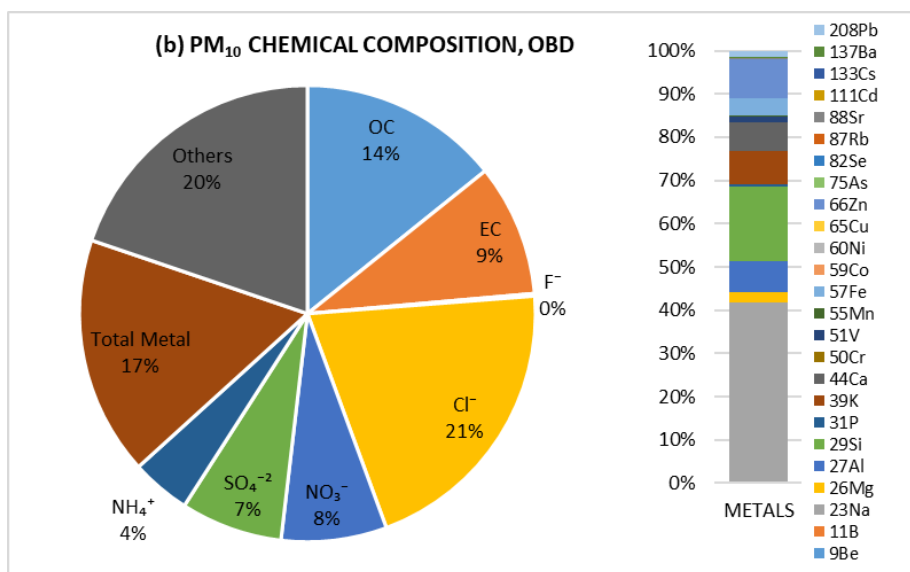


Figure 2.27: Concentrations of species in (a) PM₁₀ and (b) PM_{2.5} at Baddi





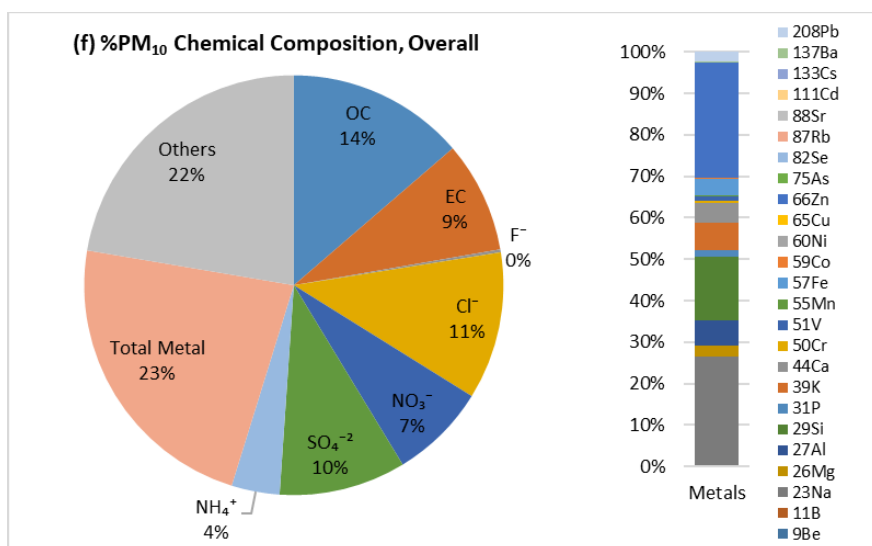
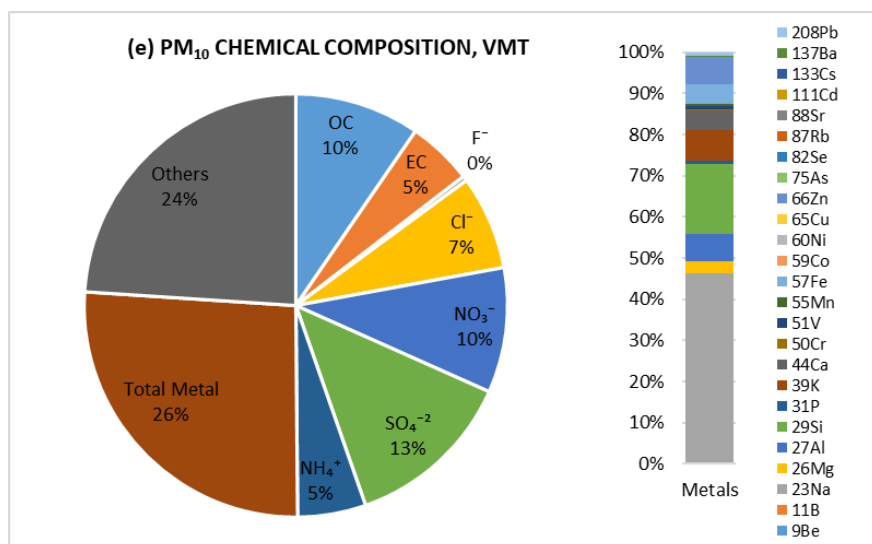
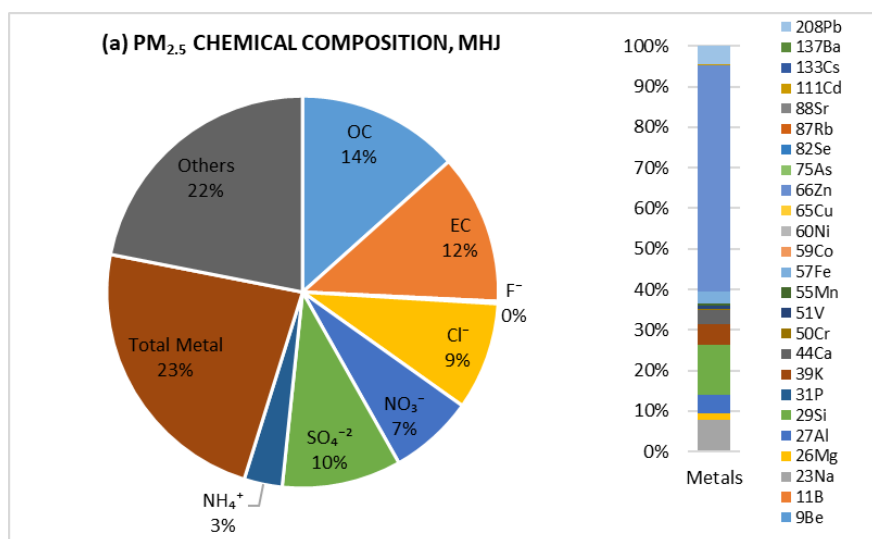
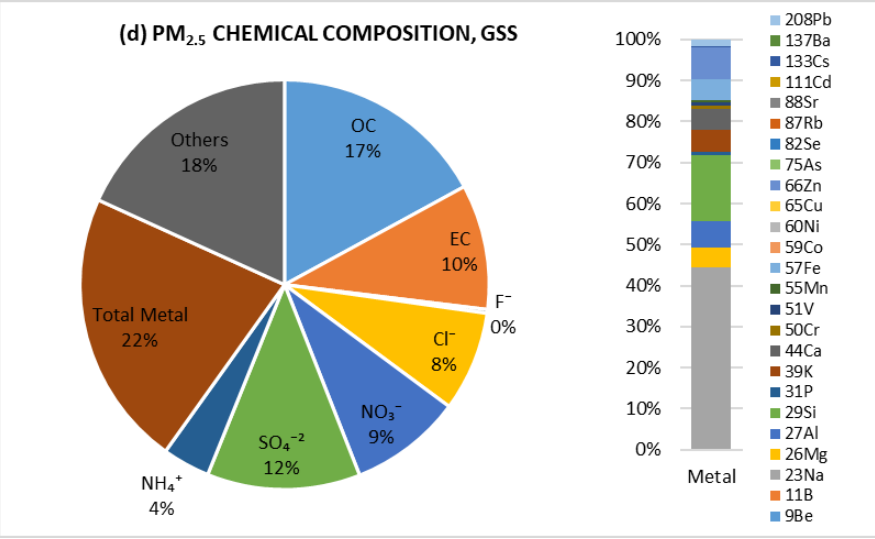
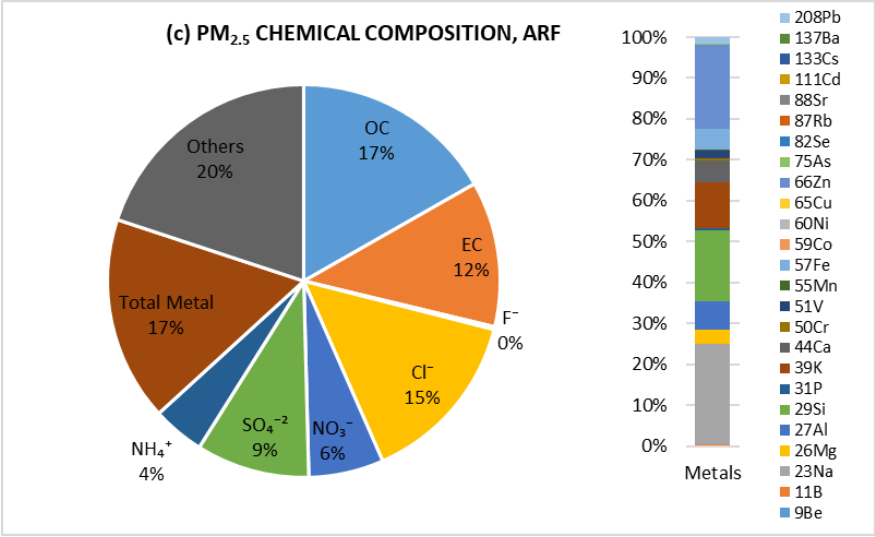
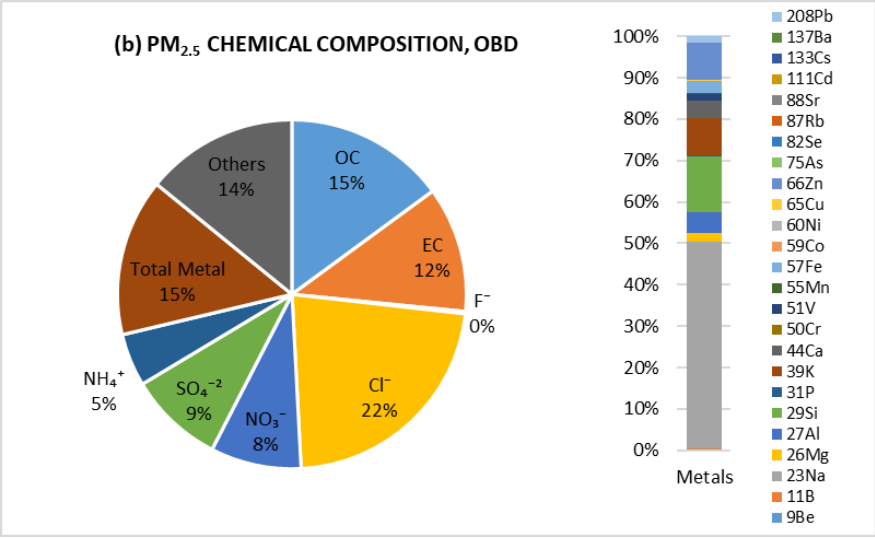


Figure 2.28: Percentage distribution of species in PM₁₀ at Baddi





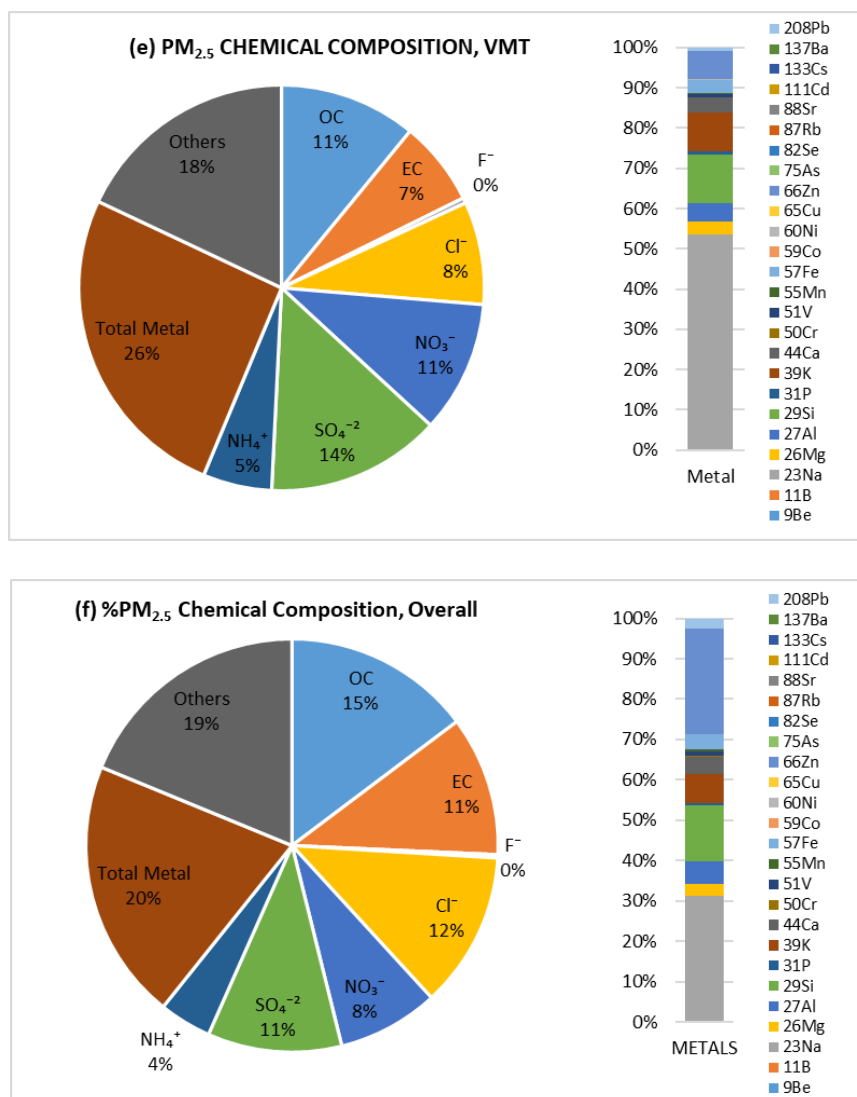


Figure 2.29: Percentage distribution of species in PM_{2.5} at Baddi

Table 2.19: Overall summary of average concentration (ng/m³) of PAHs in PM_{2.5} all sites

	DmP	AcP	DEP	Flu	Phe	Ant	Pyr	BbP	BeA	B(a)A	Chr	B(b)F	B(k)F	B(a)P	InP	D(a,h)A	B(ghi)P	Total PAHs
MHJ	1.50	0.21	0.54	0.20	0.71	0.04	0.78	0.04	0.01	1.54	3.06	5.16	1.48	2.50	2.29	0.17	2.78	23.02
OBD	1.77	0.13	0.47	0.10	0.38	0.03	0.20	0.04	0.16	0.38	0.98	2.25	0.63	0.95	1.04	0.09	1.32	10.92
ARF	0.69	0.11	0.25	0.03	0.27	0.02	0.23	0.04	0.00	0.48	1.19	2.64	0.70	1.23	1.36	0.11	1.67	11.02
GSS	3.08	0.39	3.55	1.80	3.67	0.19	1.00	0.04	1.07	1.16	3.30	8.05	1.94	3.19	3.02	0.19	4.01	39.67
VMT	4.60	0.62	3.24	3.04	5.19	0.23	0.52	0.04	2.68	0.41	1.18	4.47	1.02	1.38	2.40	0.14	3.14	34.31
Mean	2.33	0.29	1.61	1.03	2.04	0.10	0.55	0.04	0.79	0.80	1.94	4.51	1.16	1.85	2.02	0.14	2.58	23.78
SD	1.72	0.26	1.79	1.53	2.53	0.11	0.45	0.01	1.11	0.71	1.40	3.06	0.77	1.35	1.16	0.07	1.39	14.97
Max	6.16	0.91	5.31	4.55	7.53	0.30	1.53	0.05	3.03	2.36	4.54	11.45	2.70	4.78	4.21	0.29	5.17	55.04
Min	0.54	0.08	0.25	0.01	0.20	0.02	0.18	0.03	0.00	0.26	0.59	1.93	0.28	0.50	0.93	0.08	1.18	8.52
CV	0.74	0.89	1.11	1.48	1.24	1.06	0.82	0.18	1.42	0.89	0.72	0.68	0.67	0.73	0.57	0.49	0.54	0.63

Table 2.20: Overall summary of average concentration (ng/m³) of molecular markers in PM_{2.5} all sites

	Tritriacontane	Hentriacontane	Pentriacontane	17 β (H) 21 β (H) hopane	17 α (H) 21 α (H) hopane	17 α (H) - 22,29,30 - Trisnorhopane	Total
MHJ	28.04	24.52	14.01	1.13	8.68	0.70	77.08
OBD	22.59	21.44	11.90	0.29	7.25	0.52	63.99
ARF	33.02	22.46	14.06	0.63	5.86	1.90	77.93
GSS	21.33	16.97	13.45	0.76	5.78	0.75	59.04
VMT	12.03	9.69	6.28	0.53	3.08	0.27	31.88
Mean	23.40	19.02	11.94	0.67	6.13	0.83	61.98
SD	7.88	5.90	3.28	0.31	2.08	0.63	18.72
CV	0.34	0.31	0.27	0.47	0.34	0.76	0.30

Table 2.21: Statistical results of chemical characterization ($\mu\text{g}/\text{m}^3$) of PM₁₀ at sites

		PM ₁₀	OC	EC	F ⁻	Cl ⁻	NO ₃ ⁻	SO ₄ ⁻²	Na ⁺	NH ₄ ⁺	K ⁺	Mg ⁺²	Ca ⁺²	Be	B	Na	Mg	Al	Si	P
MHJ	MEAN	285.76	40.22	31.26	0.50	24.31	16.94	26.55	4.67	7.73	2.82	0.79	1.58	0.00	0.12	4.40	0.99	3.30	8.79	0.16
	SD	106.82	14.74	12.20	0.17	5.86	7.17	16.59	1.65	6.18	0.63	0.22	0.36	0.00	0.05	1.10	0.25	0.93	2.77	0.05
OBD	MEAN	205.25	29.21	19.20	0.36	42.29	15.36	14.83	11.50	8.63	1.70	0.40	0.80	0.00	0.11	14.36	0.86	2.46	6.03	0.20
	SD	62.70	9.74	8.70	0.09	17.83	4.83	6.25	1.91	2.91	0.44	0.08	0.16	0.00	0.05	2.18	0.22	0.55	1.41	0.06
ARF	MEAN	180.87	30.46	18.36	0.33	25.42	11.81	16.16	3.60	6.58	2.03	0.60	1.03	0.00	0.14	7.04	1.02	2.24	5.71	0.23
	SD	42.74	9.51	6.24	0.02	9.25	3.88	3.91	1.67	2.38	0.58	0.25	0.15	0.00	0.05	3.95	0.21	0.52	1.21	0.04
GSS	MEAN	274.41	35.53	17.36	0.77	21.45	23.32	30.48	13.40	10.07	2.12	0.47	2.04	0.02	0.15	22.28	2.67	4.70	11.76	2.36
	SD	103.63	29.59	8.44	0.38	9.06	7.16	7.59	5.81	4.56	0.79	0.38	1.48	0.01	0.11	5.22	0.71	1.70	3.92	1.34
VMT	MEAN	141.80	13.57	7.07	0.52	10.20	13.55	18.40	9.33	7.39	2.30	0.44	0.70	0.01	0.07	17.11	1.13	2.38	6.31	0.38
	SD	28.15	9.79	4.78	0.22	3.67	5.96	9.01	2.98	4.31	0.45	0.31	0.42	0.00	0.03	3.74	0.35	0.92	2.52	0.18
		K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	%R
MHJ	MEAN	3.13	2.63	0.19	0.46	0.40	2.12	0.00	0.06	0.05	52.05	0.02	0.00	0.01	0.01	0.02	0.00	0.07	3.11	79.46
	SD	0.63	0.99	0.09	0.12	0.30	0.54	0.00	0.03	0.03	59.40	0.01	0.00	0.00	0.00	0.03	0.00	0.02	3.31	7.08
OBD	MEAN	2.64	2.27	0.08	0.42	0.10	1.33	0.00	0.01	0.03	3.14	0.02	0.00	0.00	0.03	0.01	0.00	0.07	0.53	80.45
	SD	0.76	0.60	0.08	0.07	0.07	0.26	0.00	0.01	0.02	1.93	0.01	0.00	0.00	0.01	0.00	0.00	0.05	0.31	2.77
ARF	MEAN	3.22	1.75	0.14	0.47	0.10	1.43	0.00	0.04	0.02	5.28	0.01	0.00	0.01	0.01	0.01	0.00	0.04	0.87	76.83
	SD	2.25	0.44	0.06	0.08	0.05	0.27	0.00	0.05	0.01	2.86	0.00	0.00	0.00	0.01	0.00	0.00	0.02	0.84	2.89
GSS	MEAN	4.81	3.70	0.52	1.04	0.28	3.39	0.01	0.04	0.05	5.92	0.05	0.01	0.01	0.01	0.01	0.00	0.10	1.14	74.90
	SD	1.47	1.92	0.29	0.34	0.16	1.38	0.01	0.04	0.02	2.29	0.02	0.01	0.01	0.01	0.01	0.01	0.05	0.93	2.97
VMT	MEAN	2.72	1.78	0.08	0.34	0.12	1.76	0.01	0.02	0.02	2.44	0.02	0.01	0.00	0.01	0.00	0.00	0.04	0.37	76.05
	SD	0.41	0.65	0.04	0.07	0.15	0.62	0.00	0.01	0.00	1.28	0.03	0.00	0.00	0.00	0.00	0.00	0.02	0.22	2.34

Table 2.22: Statistical results of chemical characterization ($\mu\text{g}/\text{m}^3$) of PM_{2.5} at all sites

		PM _{2.5}	OC	EC	F ⁻	Cl ⁻	NO ₃ ⁻	SO ₄ ⁻²	Na ⁺	NH ₄ ⁺	K ⁺	Mg ⁺²	Ca ⁺²	Be	B	Na	Mg	Al	Si	P
MHJ	MEAN	210.09	28.16	25.95	0.42	18.65	14.69	20.70	3.61	6.63	2.16	0.67	1.11	0.00	0.09	3.72	0.85	2.18	6.01	0.08
	SD	84.63	10.32	10.13	0.14	7.65	6.91	10.28	1.25	5.67	0.48	0.23	0.42	0.00	0.05	0.86	0.30	0.87	2.26	0.04
OBD	MEAN	136.94	20.45	15.94	0.30	30.64	11.52	12.08	7.47	6.69	1.30	0.32	0.56	0.00	0.10	9.96	0.44	1.01	2.65	0.08
	SD	49.97	6.82	7.22	0.03	13.88	5.35	5.58	1.50	2.34	0.43	0.05	0.19	0.00	0.04	1.26	0.10	0.27	0.78	0.03
ARF	MEAN	127.17	21.32	15.24	0.29	18.37	7.85	11.89	2.87	5.46	1.69	0.45	0.84	0.00	0.11	5.25	0.74	1.47	3.71	0.13
	SD	32.62	6.65	5.18	0.05	6.40	2.57	3.11	1.13	2.23	0.47	0.21	0.16	0.00	0.03	2.54	0.21	0.21	0.53	0.04
GSS	MEAN	145.80	24.87	14.41	0.44	11.51	12.96	17.66	9.35	5.48	1.34	0.30	1.42	0.01	0.09	14.08	1.52	2.11	5.09	0.29
	SD	63.29	20.71	7.01	0.33	4.34	4.67	4.75	4.32	2.57	0.42	0.20	0.82	0.01	0.07	6.18	0.43	1.38	3.31	0.17
VMT	MEAN	86.84	9.50	5.87	0.37	7.12	9.15	12.10	6.20	4.78	1.58	0.26	0.46	0.00	0.04	11.93	0.71	1.04	2.67	0.21
	SD	25.82	6.85	3.96	0.11	2.95	4.51	6.29	2.91	2.80	0.36	0.17	0.26	0.00	0.02	4.27	0.33	0.39	1.19	0.08
		K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	%R
MHJ	MEAN	2.40	1.78	0.10	0.33	0.25	1.46	0.00	0.03	0.02	27.26	0.01	0.00	0.00	0.00	0.02	0.00	0.01	2.23	78.37
	SD	0.44	0.62	0.06	0.08	0.21	0.59	0.00	0.03	0.02	24.23	0.01	0.00	0.00	0.00	0.02	0.00	0.01	2.77	2.12
OBD	MEAN	1.80	0.81	0.02	0.32	0.03	0.61	0.00	0.00	0.01	1.81	0.02	0.00	0.00	0.00	0.00	0.00	0.01	0.28	86.59
	SD	0.44	0.21	0.01	0.04	0.02	0.18	0.00	0.00	0.00	1.87	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.23	4.46
ARF	MEAN	2.41	1.14	0.12	0.38	0.07	1.05	0.00	0.03	0.02	4.39	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.35	80.21
	SD	1.25	0.17	0.06	0.09	0.05	0.16	0.00	0.04	0.01	2.67	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.20	1.41
GSS	MEAN	1.73	1.58	0.26	0.30	0.20	1.55	0.00	0.01	0.03	2.48	0.01	0.01	0.01	0.01	0.01	0.00	0.08	0.49	82.04
	SD	0.76	0.93	0.13	0.20	0.11	0.95	0.00	0.01	0.02	1.34	0.00	0.01	0.00	0.01	0.01	0.00	0.04	0.43	4.63
VMT	MEAN	2.12	0.83	0.02	0.20	0.04	0.74	0.00	0.01	0.01	1.55	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.18	82.51
	SD	0.48	0.29	0.01	0.04	0.02	0.33	0.00	0.00	0.00	0.97	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.13	3.75

Table 2.23 : Overall statistical results of chemical characterization ($\mu\text{g}/\text{m}^3$) of PM₁₀ in Baddi

	PM ₁₀	OC	EC	F ⁻	Cl ⁻	NO ₃ ⁻	SO ₄ ⁻²	Na ⁺	NH ₄ ⁺	K ⁺	Mg ⁺²	Ca ⁺²	Be	B	Na	Mg	Al	Si	P
MEAN	216.15	29.54	18.30	0.50	24.29	16.20	21.32	8.52	8.07	2.19	0.54	1.23	0.01	0.12	13.23	1.36	3.02	7.74	0.69
SD	90.29	18.34	11.00	0.26	14.06	6.95	10.91	4.96	4.20	0.67	0.29	0.86	0.01	0.07	7.48	0.79	1.36	3.40	1.06
MAX	482.33	105.98	43.46	1.56	61.63	36.45	57.46	25.15	18.98	3.93	1.34	5.48	0.05	0.33	29.00	3.34	7.01	17.43	4.39
MIN	105.13	2.57	1.61	0.27	5.80	3.06	6.97	1.84	1.93	1.04	0.08	0.33	0.00	0.02	3.06	0.53	1.21	2.69	0.08
CV	0.42	0.62	0.60	0.52	0.58	0.43	0.51	0.58	0.52	0.30	0.54	0.70	1.21	0.57	0.57	0.58	0.45	0.44	1.53
	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	%R
MEAN	3.33	2.42	0.21	0.55	0.20	2.02	0.01	0.03	0.03	13.04	0.03	0.01	0.01	0.01	0.01	0.00	0.06	1.17	77.41
SD	1.49	1.26	0.22	0.31	0.20	1.05	0.01	0.03	0.02	30.50	0.02	0.01	0.01	0.01	0.01	0.00	0.04	1.75	4.25
MAX	8.72	7.79	1.09	1.44	0.89	5.68	0.03	0.15	0.10	161.59	0.10	0.05	0.03	0.06	0.07	0.02	0.18	8.36	94.51
MIN	1.82	0.82	0.02	0.24	0.03	0.87	0.00	0.00	0.01	0.78	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.12	71.28
CV	0.45	0.52	1.06	0.56	1.01	0.52	1.06	1.01	0.70	2.34	0.81	1.26	0.73	0.90	1.34	1.10	0.66	1.49	0.05

Table 2.24: Overall statistical results of chemical characterization ($\mu\text{g}/\text{m}^3$) of PM_{2.5} in Baddi

	PM _{2.5}	OC	EC	F ⁻	Cl ⁻	NO ₃ ⁻	SO ₄ ⁻²	Na ⁺	NH ₄ ⁺	K ⁺	Mg ⁺²	Ca ⁺²	Be	B	Na	Mg	Al	Si	P
MEAN	139.68	20.68	15.19	0.36	16.87	11.13	14.80	5.92	5.76	1.61	0.39	0.88	0.00	0.08	9.10	0.86	1.56	4.01	0.16
SD	65.09	12.84	9.13	0.18	10.83	5.28	7.00	3.47	3.21	0.51	0.23	0.56	0.00	0.05	5.31	0.47	0.89	2.25	0.12
MAX	316.13	74.18	36.07	1.25	50.90	24.20	34.17	19.68	17.92	3.00	0.99	3.15	0.02	0.24	23.90	2.38	5.35	12.97	0.70
MIN	90.29	2.57	1.61	0.27	1.93	0.67	0.08	0.33	0.00	0.02	0.08	0.33	0.00	0.02	0.08	0.53	1.21	2.69	0.08
CV	0.47	0.62	0.60	0.48	0.64	0.47	0.47	0.59	0.56	0.32	0.58	0.63	1.01	0.58	0.58	0.54	0.57	0.56	0.74
	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	%R
MEAN	2.09	1.23	0.10	0.31	0.12	1.08	0.00	0.02	0.02	7.13	0.01	0.00	0.00	0.00	0.01	0.00	0.02	0.68	81.92
SD	0.77	0.64	0.11	0.12	0.13	0.63	0.00	0.03	0.01	13.88	0.01	0.00	0.00	0.00	0.01	0.00	0.04	1.37	4.27
MAX	5.41	3.65	0.51	0.79	0.56	3.81	0.01	0.13	0.06	64.95	0.03	0.02	0.02	0.02	0.07	0.00	0.13	7.31	93.45
MIN	0.82	0.79	0.02	0.24	0.03	0.57	0.00	-0.01	0.01	0.37	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.12	71.28
CV	0.37	0.52	1.07	0.40	1.15	0.58	0.82	1.49	0.72	1.95	0.54	1.20	0.75	0.91	1.58	0.68	1.42	2.02	0.05

Table 2.25: Correlation matrix for PM and its composition at Baddi

	PM _{2.5}	PM ₁₀	OC	EC	F ⁻	Cl ⁻	NO ₃ ⁻	SO ₄ ⁻²	Na ⁺	NH ₄ ⁺	K ⁺	Mg ⁺²	Ca ⁺²	Metals PM _{2.5}	Metals PM ₁₀
PM _{2.5}	1.00	0.92	0.82	0.90	0.53	0.58	0.77	0.73	0.25	0.58	0.54	0.55	0.68	0.82	0.65
PM ₁₀	0.92	1.00	0.83	0.82	0.59	0.48	0.78	0.67	0.45	0.44	0.38	0.44	0.80	0.79	0.72
OC	0.83	0.83	1.00	0.79	0.68	0.43	0.57	0.49	0.37	0.38	0.37	0.50	0.79	0.57	0.39
EC	0.90	0.82	0.79	1.00	0.33	0.57	0.57	0.56	-0.01	0.41	0.56	0.58	0.55	0.70	0.58
NO ₃ ⁻	0.77	0.78	0.57	0.57	0.46	0.43	1.00	0.71	0.49	0.63	0.23	0.27	0.58	0.60	0.52
SO ₄ ⁻²	0.73	0.67	0.49	0.56	0.34	0.24	0.71	1.00	0.29	0.75	0.42	0.45	0.56	0.54	0.34
NH ₄ ⁺	0.58	0.44	0.38	0.41	0.11	0.44	0.63	0.75	0.22	1.00	0.38	0.36	0.29	0.19	-0.01
Metals_PM _{2.5}	0.82	0.79	0.57	0.70	0.57	0.25	0.60	0.54	0.19	0.19	0.39	0.34	0.57	1.00	0.91
Metals_PM ₁₀	0.65	0.72	0.39	0.58	0.40	0.19	0.52	0.34	0.17	-0.01	0.20	0.14	0.46	0.91	1.00

2.3.8 Comparison of PM₁₀ and PM_{2.5} Composition

The graphical compositional comparison of PM_{2.5} Vs PM₁₀ for all species is shown (Figure 2.30). The chemical species considered for the comparisons are carbon content (TC, OC and EC), ionic species (F⁻, Cl⁻, NO₃⁻, SO₄⁻², Na⁺, NH₄⁺, K⁺, Ca⁺², Mg⁺²) and elements (Be, B, Na, Mg, Al, Si, P, K, Ca, Cr, V, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Rb, Sr, Cd, Cs, Ba, Pb).

It is observed that a significant portion of PM is having more fine-mode particles during winter (65%). The major species contributing to fine mode are TC, OC, EC, NO₃⁻, SO₄⁻², Na⁺, V and As; whereas major species contributing to coarse mode are Ca, Mg, Al, Si, P, Ca, Cr, Fe and Cu.

The average ratio (PM_{2.5}/PM₁₀) was taken from the previous studies (Puxbaum et al., 2004; Samara et al., 2014; Wang et al., 2014) for EC (0.70) and OC (0.83) to estimate the carbon content in PM₁₀. Therefore, the percentage of EC (70%) and OC (83%) are constant for all sites by converting from levels known in PM_{2.5} and translating these into EC and OC levels of PM₁₀.

The average ratio (PM_{2.5}/PM₁₀) was taken from the previous studies (Puxbaum et al., 2004; Samara et al., 2014; Wang et al., 2014) for EC (0.70) and OC (0.83) to estimate the carbon content in PM₁₀. Therefore, the percentage of EC (70%) and OC (83%) are constant for all sites by converting from levels known in PM_{2.5} and translating these into EC and OC levels of PM₁₀.

The statistical summary of the major components (i.e., crustal elements – Si, Al, Fe, Ca; Secondary ions - NO₃⁻, SO₄⁻², NH₄⁺; TC) in PM₁₀ and PM_{2.5} are presented in Tables 2.26 – 2.27.

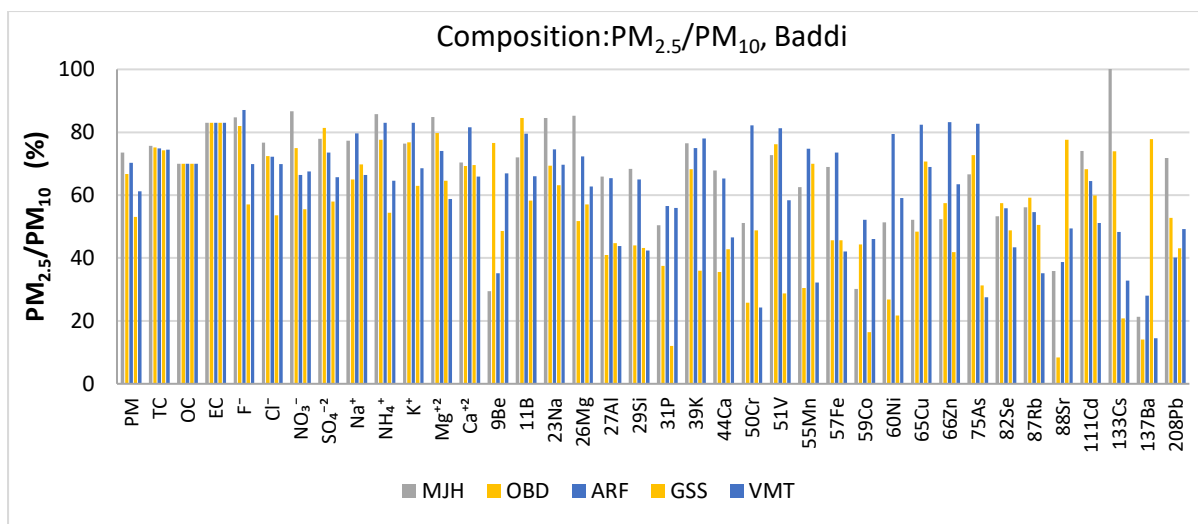


Figure 2.30: Compositional comparison of species in PM_{2.5} vs PM₁₀

Table 2.26: Mean of major components: PM₁₀, winter (µg/m³)

Sites	PM ₁₀	Crustal (Si + Al + Fe + Ca)	Ratio Crustal/PM ₁₀	Sec Ions (NO ₃ ⁻ + SO ₄ ⁻² + NH ₄ ⁺)	Ratio Sec Ions/PM ₁₀	TC	Ratio TC/PM ₁₀
MHJ	286	16.8	0.059	51.2	0.179	71.5	0.250
OBD	205	12.1	0.059	38.8	0.189	48.4	0.236
ARF	181	11.1	0.062	34.6	0.191	48.8	0.270
GSS	274	23.6	0.086	63.9	0.233	52.9	0.193
VMT	142	12.2	0.086	39.3	0.277	20.6	0.146
Overall	218	15.2	0.070	45.6	0.214	48.4	0.219
SD	61	5.2	0.014	12.0	0.041	18.2	0.050
CV	0.283	0.342	0.205	0.263	0.192	0.375	0.228

Table 2.27: Statistical summary of major components: PM_{2.5}, winter (µg/m³)

Sites	PM _{2.5}	Crustal (Si + Al + Fe + Ca)	Ratio Crustal/PM _{2.5}	Sec Ions (NO ₃ ⁻ + SO ₄ ⁻² + NH ₄ ⁺)	Ratio Sec Ions/PM _{2.5}	TC	Ratio TC/PM _{2.5}
MHJ	210	11.4	0.054	42.0	0.200	54.1	0.258
OBD	137	5.1	0.037	30.3	0.221	36.4	0.266
ARF	127	7.4	0.058	25.2	0.198	36.6	0.288
GSS	146	10.3	0.071	36.1	0.248	39.3	0.269
VMT	87	5.3	0.061	26.0	0.300	15.4	0.177
Overall	141	7.9	0.056	31.9	0.233	36.3	0.251
SD	45	2.9	0.012	7.1	0.042	13.8	0.043
CV	0.315	0.366	0.219	0.223	0.181	0.380	0.171

2.3.9 Carbon monoxide (CO)

CO levels were measured at four sites. 8 Hourly Statistical Results of CO ($\mu\text{g}/\text{m}^3$) at all four sites are presented in Table 2.28.

MHJ

The hourly average concentration of CO was observed at MHJ. From Figure 2.31, it can be seen that the maximum concentration is observed during the peak hours of traffic during the day (both in the morning as well as evening). It was observed that maximum concentration occurs at the time peak traffic higher in evening hours than in morning hours.

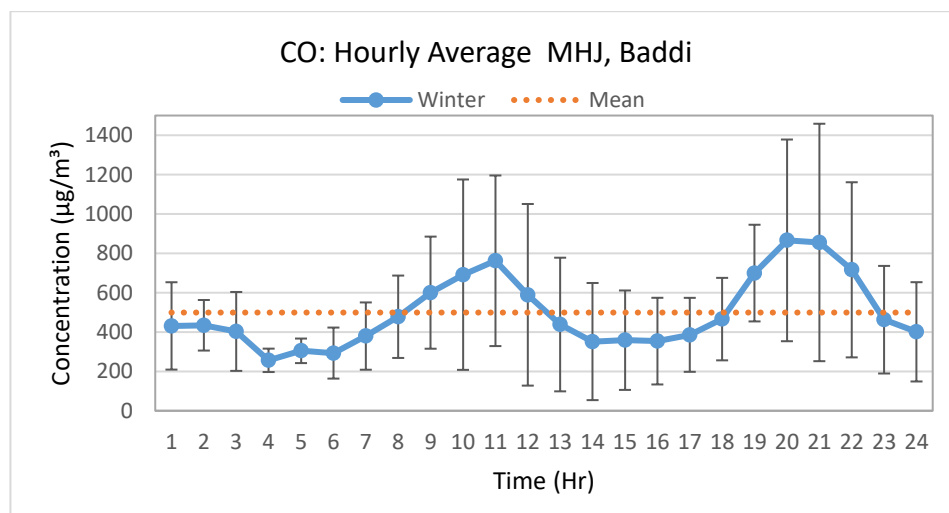


Figure 2.31: Hourly average concentration ($\mu\text{g}/\text{m}^3$) of CO at MHJ

OBD

The hourly average concentration of CO was observed at OBD. From Figure 2.32, it can be seen that the maximum concentration is observed during the peak hours of traffic during the day (both in the morning as well as evening). It was observed that maximum concentration occurs at the time peak traffic higher in evening hours than in morning hours.

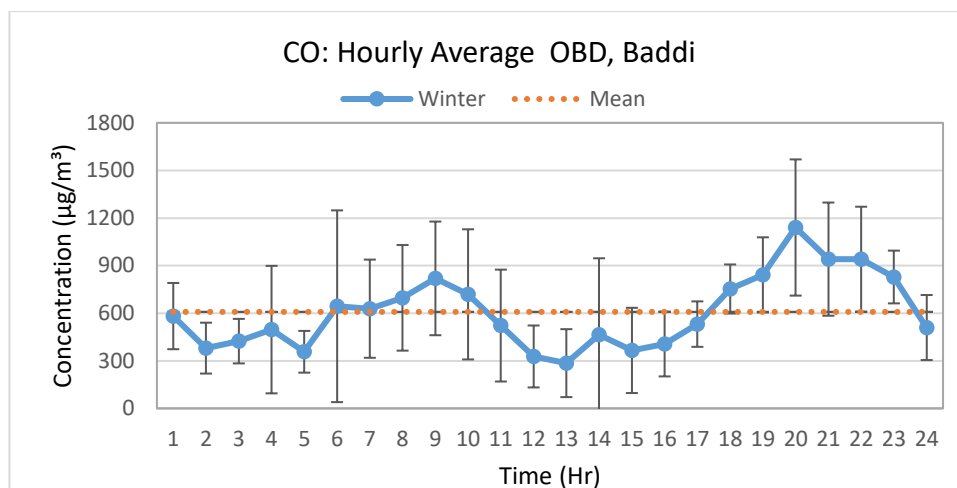


Figure 2.32: Hourly average concentration ($\mu\text{g}/\text{m}^3$) of CO at OBD

GSS

The hourly average concentration of CO was observed at GSS. From Figure 2.33, it can be seen that the maximum concentration is observed during the peak hours of traffic during the day (both in the morning as well as evening). It was observed that maximum concentration occurs at the time peak traffic higher in evening hours than in morning hours.

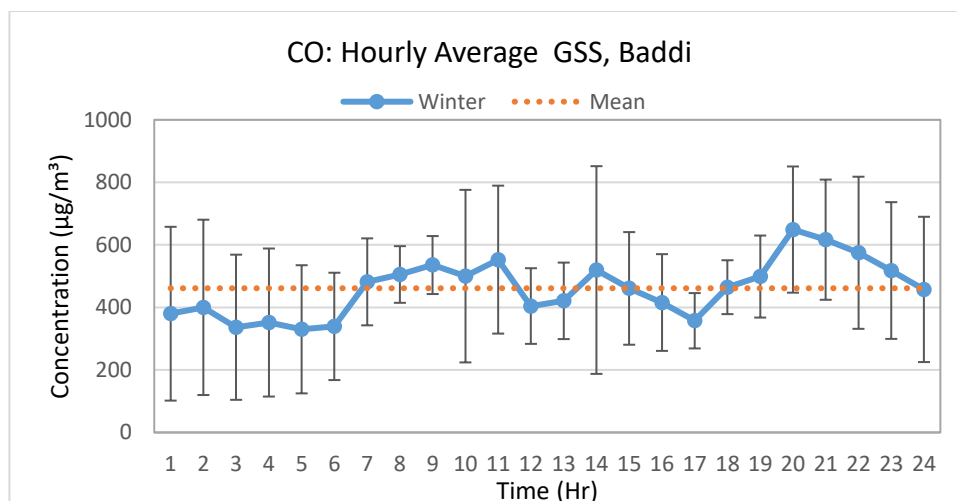


Figure 2.33: Hourly average concentration ($\mu\text{g}/\text{m}^3$) of CO at GSS

VMT

The hourly average concentration of CO was observed at VMT. From Figure 2.34, it can be seen that the maximum concentration is observed during the peak hours of traffic during the

day (both in the morning as well as evening). It was observed that maximum concentration occurs at the time peak traffic higher in evening hours than in morning hours.

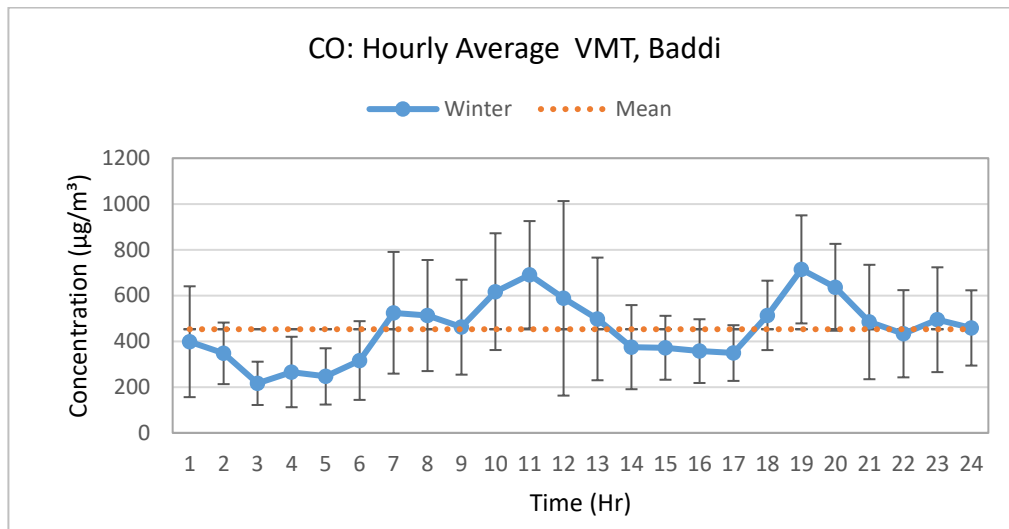


Figure 2.34: Hourly average concentration (µg/m³) of CO at VMT

Table 2.28: 8 Hourly Statistical Results of CO (µg/m³) at BADDI

CO												
SITE	MHJ			OBD			GSS			VMT		
Time	0-8 Hr	8-16 Hr	16-24 Hr	0-8 Hr	8-16 Hr	16-24 Hr	0-8 Hr	8-16 Hr	16-24 Hr	0-8 Hr	8-16 Hr	16-24 Hr
Mean	372.51	518.20	606.54	526.13	488.61	810.75	390.62	476.25	517.11	390.62	476.25	517.11
SD	79.06	163.83	200.42	129.81	190.30	212.39	68.05	58.50	94.71	68.05	58.50	94.71
CV	0.21	0.32	0.33	0.25	0.39	0.26	0.17	0.12	0.18	0.17	0.12	0.18
Max	477.75	762.18	865.83	696.96	819.54	1140.37	505.34	552.87	649.04	505.34	552.87	649.04
Min	256.25	351.73	385.83	356.98	285.34	509.70	330.03	404.38	357.34	330.03	404.38	357.34

2.3.10 Ozone (O₃)

O₃ levels were measured at four sites. 8 Hourly Statistical Results of O₃ levels (µg/m³) at all four sites are presented in Table 2.29.

MHJ

The hourly average concentration of O₃ was observed at MHJ. From Figure 2.35, it can be seen that the maximum concentration is observed during the peak hours of traffic during the day (both in the morning as well as evening). It was observed that maximum concentration

occurs at the time peak traffic higher in evening hours than in morning hours. The lower levels of ozone in noon period appears due to rapid increase in convective mixing height and concurrent increase in wind speed in day time. The increase in ozone levels during evening hours could be due to decrease in mixing height and lowered wind speed (Varshney and Aggarwal, 1992).

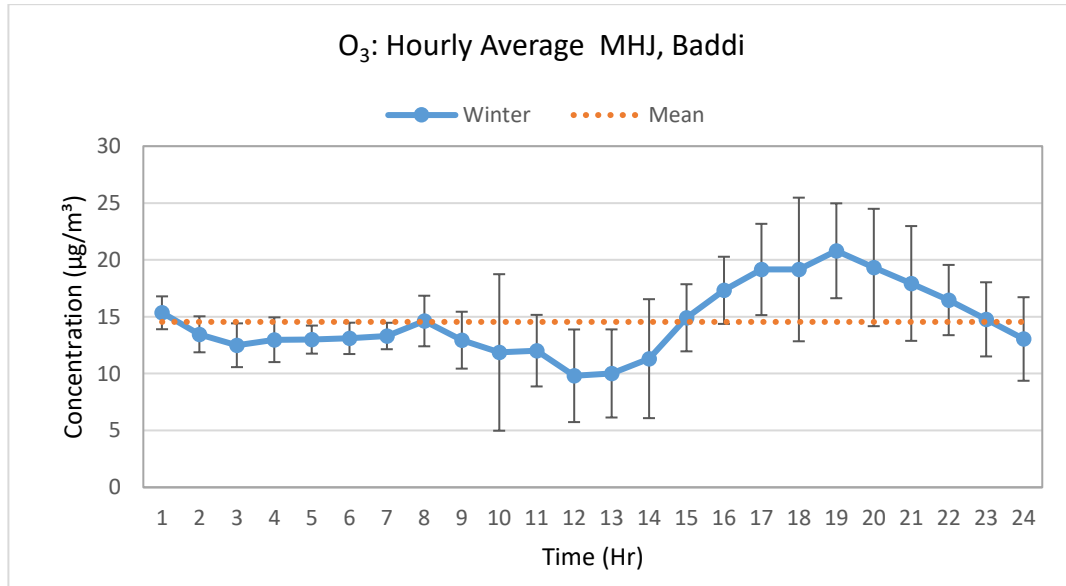


Figure 2.35: Hourly average concentration (µg/m³) of O₃ at MHJ

OBD

Hourly average concentration of O₃ was observed at OBD. From Figure 2.36, it can be seen that the maximum concentration is observed during the peak hours of traffic during the day (both in morning as well as evening). It was observed that maximum concentration occurs at the time peak traffic higher in evening hours than in morning hours.

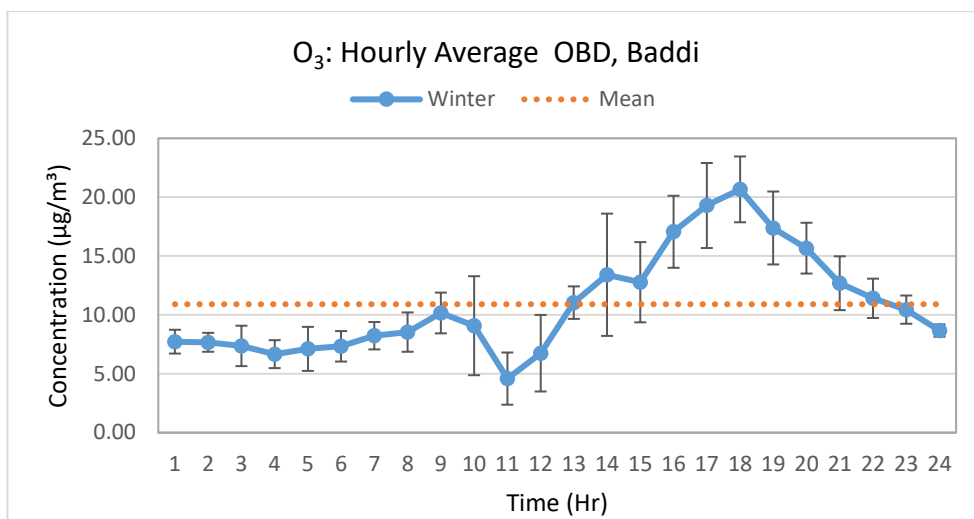


Figure 2.36: Hourly average concentration (µg/m³) of O₃ at OBD

GSS

The hourly average concentration of O₃ was observed at GSS. From Figure 2.37, it can be seen that the maximum concentration is observed during the peak hours of traffic during the day (both in the morning as well as evening). It was observed that maximum concentration occurs at the time peak traffic higher in evening hours than in morning hours. The lower levels of ozone in noon period appears due to rapid increase in convective mixing height and concurrent increase in wind speed in day time. The increase in ozone levels during evening hours could be due to decrease in mixing height and lowered wind speed (Varshney and Aggarwal, 1992).

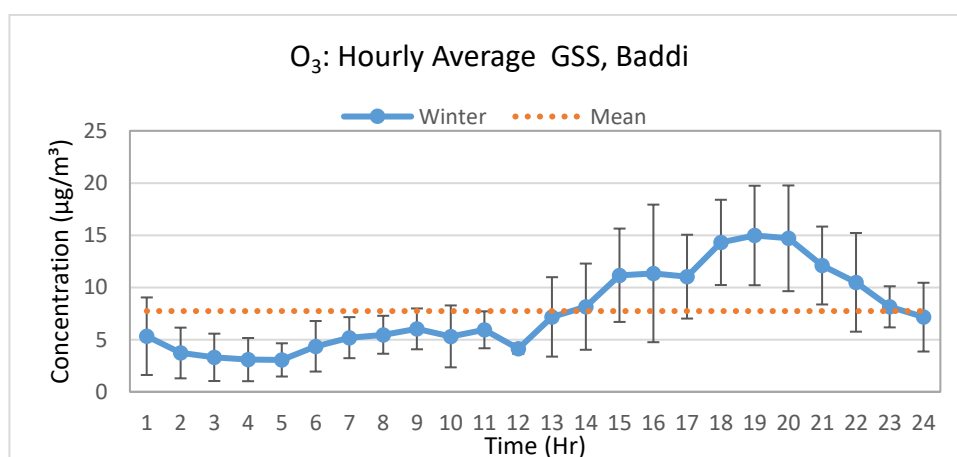


Figure 2.37: Hourly average concentration (µg/m³) of O₃ at GSS

VMT

The hourly average concentration of O₃ was observed at VMT. From Figure 2.38, it can be seen that the maximum concentration is observed during the peak hours of traffic during the day (both in the morning as well as evening). It was observed that maximum concentration occurs at the time peak traffic higher in evening hours than in morning hours.

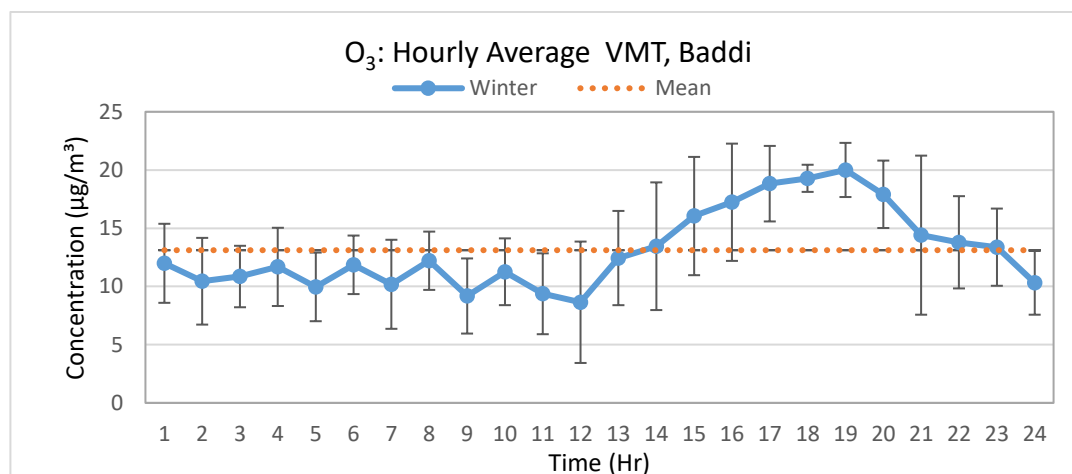


Figure 2.38: Hourly average concentration (µg/m³) of O₃ at VMT

Table 2.29: 8 Hourly Statistical Results of O₃ (µg/m³) at BADDI

O ₃												
SITE	MHJ			OBD			GSS			VMT		
Time	0-8 Hr	8-16 Hr	16-24 Hr	0-8 Hr	8-16 Hr	16-24 Hr	0-8 Hr	8-16 Hr	16-24 Hr	0-8 Hr	8-16 Hr	16-24 Hr
Mean	13.54	12.52	17.58	7.58	10.61	14.53	4.19	7.41	11.61	4.19	7.41	11.61
SD	0.96	2.53	2.62	0.60	3.93	4.37	1.03	2.66	2.98	1.03	2.66	2.98
CV	0.07	0.20	0.15	0.08	0.37	0.30	0.25	0.36	0.26	0.25	0.36	0.26
Max	15.35	17.32	20.80	8.54	17.06	20.66	5.46	11.34	14.98	5.46	11.34	14.98
Min	12.49	9.81	13.04	6.67	4.59	8.67	3.06	4.13	7.15	3.06	4.13	7.15

2.4 Interpretations and Inferences

Based on the extensive air quality measurements in the winter months and critical analyses of air quality data, the following inferences and insights are drawn for developing a causal relationship between emission and impact through receptor modeling (Chapters 5). The site-specific average air concentration of PM₁₀, PM_{2.5} and their compositions (Tables 2.10, 2.18-2.27) have been referred to bring the important inferences to the fore.

- The mean PM₁₀ levels were 142 – 286 µg/m³ (Baddi) and the mean PM_{2.5} levels were 87 – 210 µg/m³.
- Particulate pollution is the main concern in the city, where PM₁₀ levels are 1.4 – 2.9 times higher than the national air quality standards and PM_{2.5} levels are 1.4 – 3.5 times higher than the national standard in the winter months. It is observed that the air quality in terms of PM₁₀ and PM_{2.5} falls in the poor to severe category of air quality index (AQI).
- The chemical composition of PM₁₀ and PM_{2.5} carries the signature of sources and their harmful contents. The chemical composition is variable depending on the size fraction of particles.

PM₁₀

The overall average concentration of PM₁₀ is 218±55 µg/m³ against the acceptable level of 100 µg/m³. The highest levels were observed at MHJ and the lowest at VMT.

The important components are the secondary particles (NO₃⁻ + SO₄⁻² + NH₄⁺), which account for about 21% of total PM₁₀, and combustion-related total carbon (TC = EC + OC) accounts for about 22%; both fractions of secondary particles and combustion-related carbons account for 44% of PM₁₀ in winter months.

The crustal component (Si + Al + Fe + Ca) accounts for about seven percent in PM₁₀. This suggests soil and road dust have significant contributions. The coefficient of variation (CV) is about 0.21 (of the fraction of crustal component), which suggests the crustal source contributes consistently in the winter months.

The Cl⁻ content in PM₁₀ is not consistent and varies between 7 – 21%, which is an indicator of the burning of municipal and plastic solid waste (MSW); recall polyvinyl chloride (PVC) is a major part of MSW. The highest Cl⁻ content is observed at OBD at 42 µg/m³ compared to the overall city level of 25 µg/m³. The high level at OBD signifies some local burning of waste either in industrial processes or as a means of disposal of solid waste.

PM_{2.5}

The overall average concentration of PM_{2.5} in winter is 141±40 µg/m³ against the acceptable level of 60 µg/m³. The highest levels are observed at MHJ and the lowest at VMT.

The important components are the secondary particles (NO₃⁻ + SO₄⁻² + NH₄⁺), which account for about 23% of total PM_{2.5} and combustion-related total carbon (TC = EC + OC) accounts for about 25%; both fractions of secondary particles and combustion-related carbons account for 48% of PM_{2.5} in winter months. The highest levels of secondary particles were observed at VMT (30%) and TC at ARF (29%).

The Cl⁻ content in PM_{2.5} is not consistent and varies between 8 – 22%, which is an indicator of the burning of MSW and plastic waste.

Gaseous pollutant levels

NO₂ and SO₂ levels meet the national air quality standard of 80 µg/m³. The highest NO₂ and SO₂ levels were at MHJ with some high peaks, an industrial site having high coal combustion in nearby areas. In addition, high levels of NO₂ and SO₂ are expected to undergo chemical transformation to form fine secondary particles in the form of nitrates and sulfates, adding to high levels of existing PM₁₀ and PM_{2.5}. NH₃ levels in the city were well within the air quality standard.

The VOCs (benzene, toluene, and xylene) are generally quite low at all sites and maximum at ARF. The annual benzene levels are expected to be well below the NAQS of 5µg/m³ and in the safe limit in the city.

The mean 8-hourly ozone and CO levels are within the acceptable limits of NAQS (8-hourly O₃:100 µg/m³; CO: 2 mg/m³). The diurnal pattern of CO and ozone are consistent as expected.

General inferences

It is to be noted that OC3/TC ratio is above 0.23 and the highest ratio of the fraction of OC to TC. It suggests a significant component of secondary organic aerosol is formed in the atmosphere due to condensation and nucleation of volatile to semi-volatile organic compounds, which suggests emissions within and outside of Baddi.

Total PAH levels (17 compounds; particulate phase) had high variability in the range of 11 to 40 and B(a)P at 1.9 ng/m³ (annual standard is one ng/m³); the comparison with the annual standard is not advisable due to different averaging times. The highest PAH levels were observed at GSS.

The concentrations of molecular markers in PM_{2.5} (a total of 6 compounds) vary in the range of 32 to 78 ng/m³, indicating the presence of common sources of emissions from coal, gasoline and domestic fuel.

In a broad sense, the air is toxic in the winter months as it contains a much larger contribution of fine particulates emitted from combustion sources. Fractions of secondary particles of both PM₁₀ and PM_{2.5} were consistent and needed to be controlled for better air quality. Combustion sources (vehicles, coal, and MSW burning) are consistent and require a strategy to control these sources. A possible effective mixture of control options is discussed in Chapter 6.

3 Time Series Analysis and Trend

3.1 Introduction

The regulatory agencies at federal and urban levels have taken actions in nearly all sectors to control air pollution over the past decade. Despite taking several initiatives and data generated over the years to reveal the air pollution trend pattern.

Several techniques provide trends, including simple plotting of data to more complex autoregressive integrated moving average (ARIMA) models. This analysis is done for PM₁₀ and NO_x the results provide information in terms of trends such as:

(i) Significant downward, (ii) Significant upward, (iii) Firstly decreasing and then increasing, (iv) Firstly increasing then decreasing and (iv) No trend. The long-term (2008-2019) temporal PM₁₀ and NO_x levels at three locations are analyzed for (i) annual and seasonal variations and (ii) understanding of the rate at which the concentrations are varying over the years (trend analysis). Since SO₂ levels were very low (generally less than 5 µg/m³) and insignificant compared to NAQS levels, trend and time-series analyses were not carried out for SO₂ levels.

3.2 Methodology

The long-term (2008–2019) air quality data for three sites were considered for Baddi. The sites were Station-I DIC (industrial area), Station-II Housing Board (residential area) and Station-III A.H.C. Barotiwala (industrial area). The air quality data for these sites were provided by HPSPCB, Shimla.

A summary of the methodology and major tasks is presented in Figure 3.1. The collected data were organized, classified, analyzed, compared, and interpreted with statistical techniques and visual presentations in the form of graphs and tables. Mean monthly PM₁₀ and NO_x concentrations over the years were calculated and plotted against the corresponding monthly slot for each site. A fifth-degree polynomial was fitted by regression analysis to each plot to obtain a minimum R² value of 0.50 (lower degree polynomial did not fill well). These plots help in understanding the pattern of concentrations with the changing time and seasons.

To detect the long-term trends in air quality parameters (PM₁₀ and NO_x), the Mann-Kendall Test (<https://www.real-statistics.com/time-series-analysis/time-series-miscellaneous/mann->

kendall-test/) has been used to determine whether a time-series has a monotonic upward or downward trend. The null hypothesis for this test is that there is no trend, and the alternative hypothesis is that there is a trend (upward or downward). The idea behind the test is that it looks for all possible differences between the relative magnitude of one sample to another successive sample and if differences keep on increasing or keep on decreasing then it signifies the presence of a trend. Based on a 5% significance level, if p-value is less than and equal to 0.05, then the alternative hypothesis is accepted which signifies the presence of a trend and if the p-value is greater than 0.05, then the null hypothesis is accepted which signifies the absence of a trend in the data.

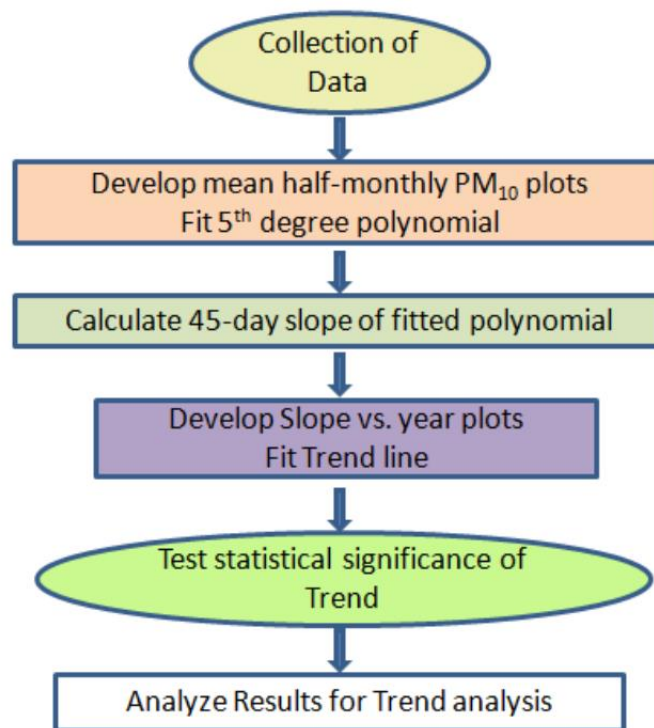


Figure 3.1: Stepwise methodology and major tasks (Nagar et al., 2019)

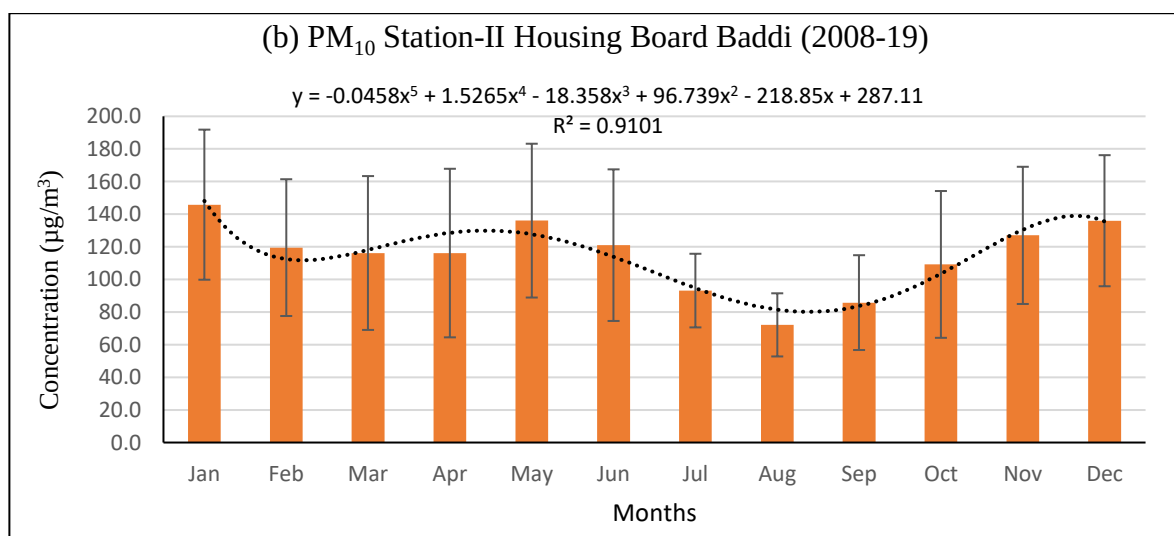
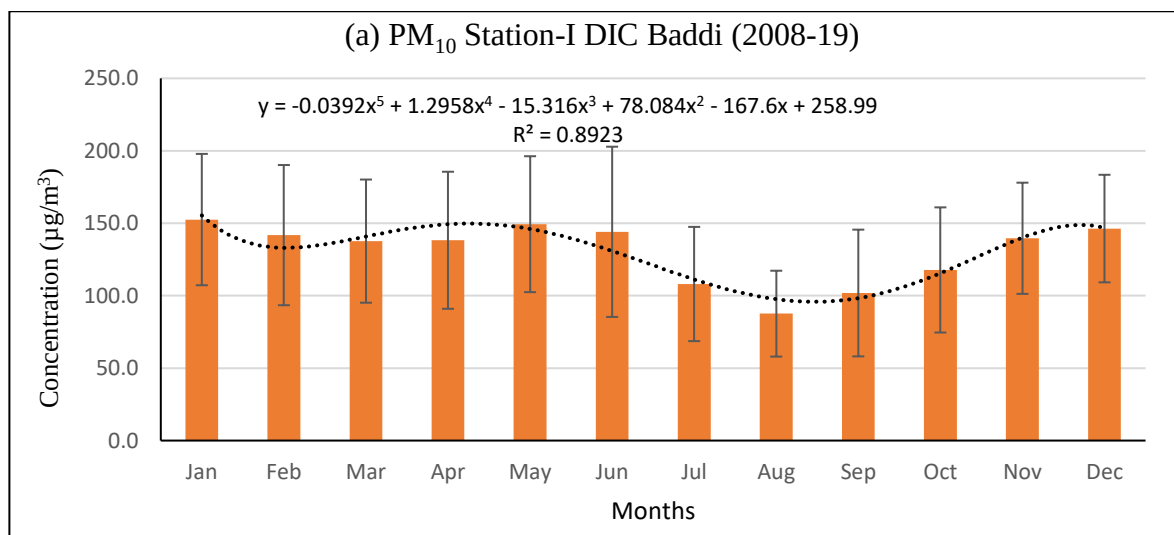
3.3 Results and Interpretations

3.3.1 Annual pattern in PM₁₀ and NO₂

The total number of monthly means of 24-hr PM₁₀ and NO_x measurements in Baddi was 400 (at three sites). The monthly mean levels of PM₁₀ and NO_x averaged over 2008 – 2019 for three sites in Figures 3.2 – 3.3. The annual time-series variations of PM₁₀ and NO_x mean concentrations over 2008-2019 for three sites are presented in Figures 3.4 – 3.5.

Two peaks were observed (Figure 3.2) in PM₁₀, one during pre-monsoon season and the other during post-monsoon to winter. A sharp increase in the levels during post-monsoon is observed. The PM₁₀ levels continue to gradually increase in winter or tend to stabilize. It is interesting to note that in May, levels increase and show significant variability. Baddi has dust storms in April and May. However, PM₁₀ levels except in monsoon months (July – September), exceed the 24-hr national air quality standard.

The NO_x levels are highest in the winter months (December and January) and observed lowest in monsoon months like August and September (Figure 3.3). There is no sharp increase is seen in months. The NO_x levels meet the 24-hr national standard. However, it is a concern in the winter months to take necessary measures to prevent high levels of NO_x.



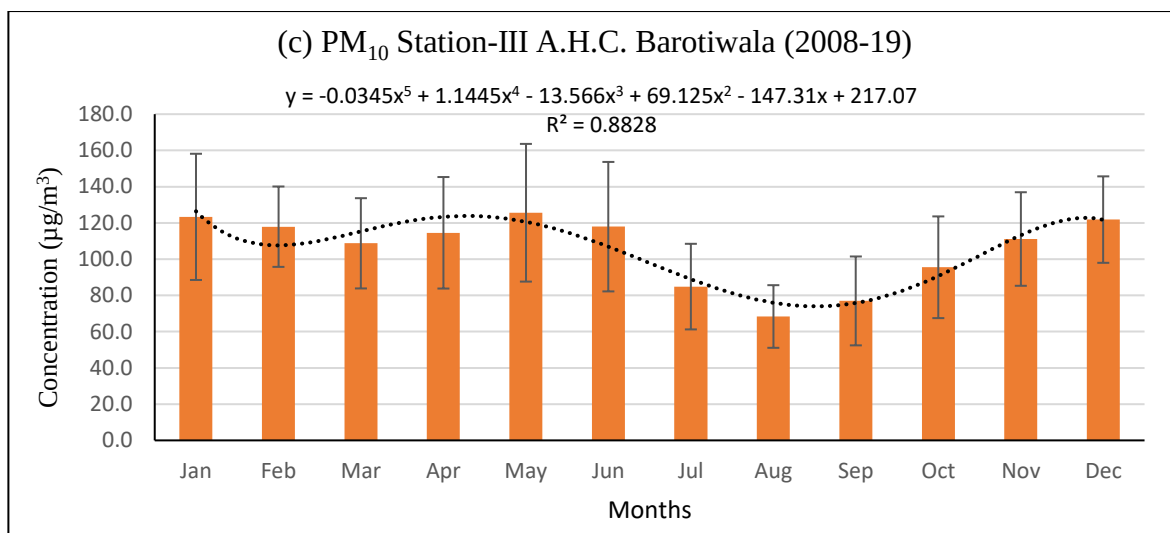
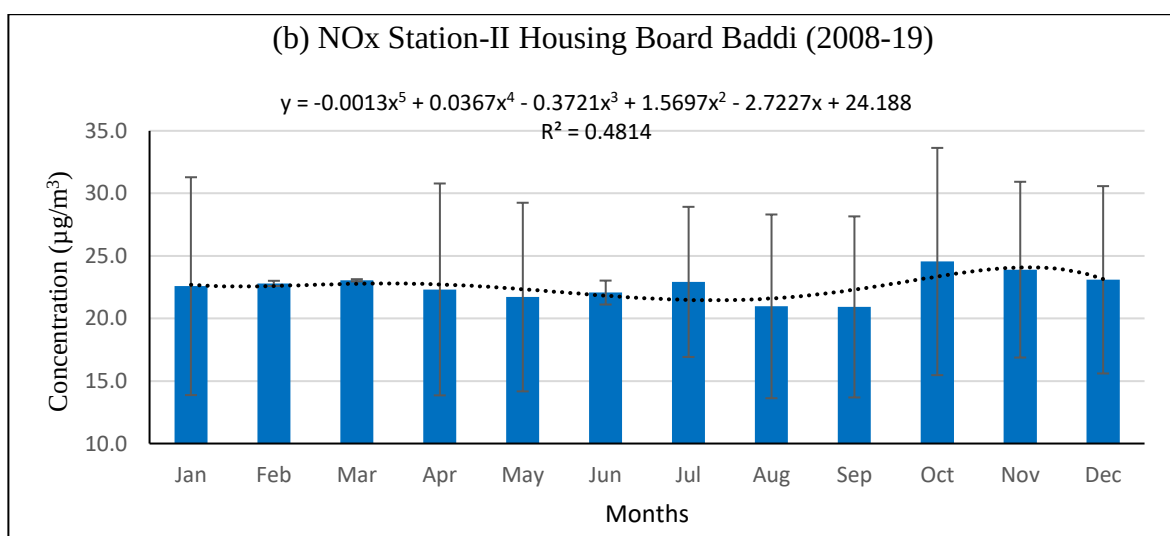
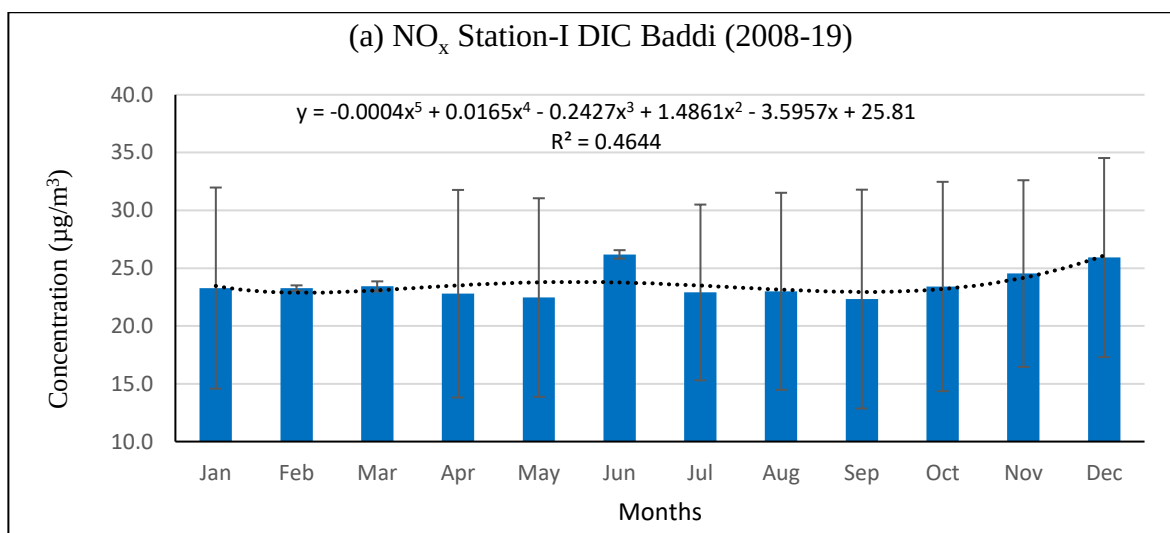


Figure 3.2: Variation in PM₁₀ at various sites in Baddi



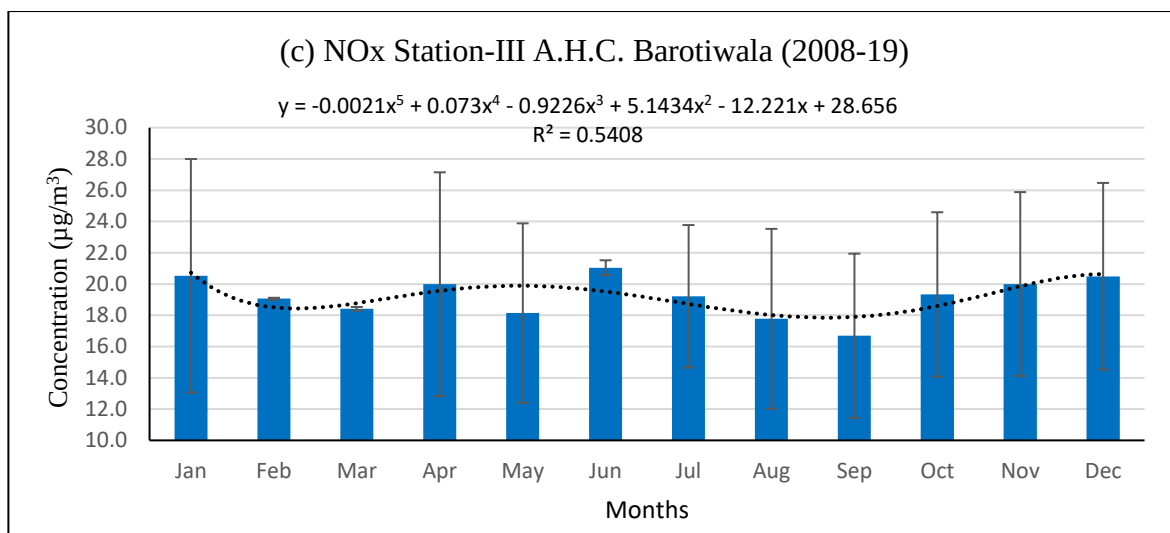
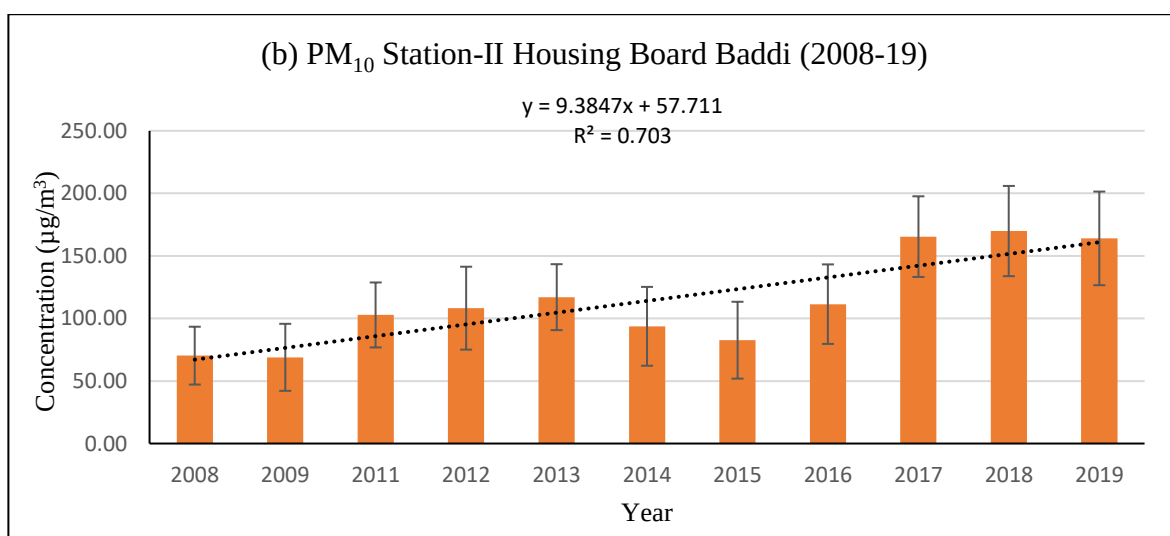
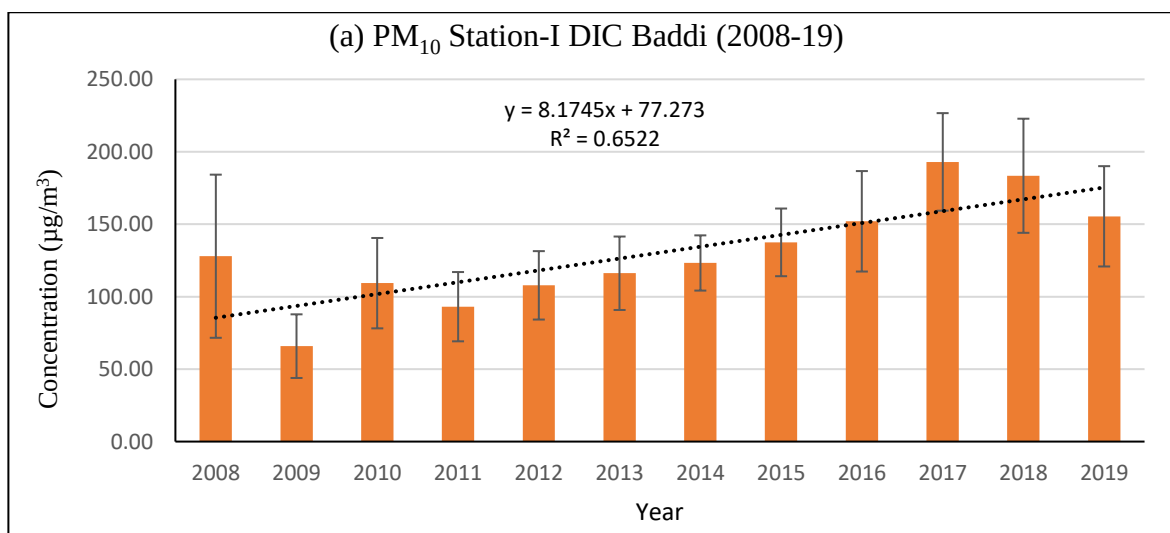


Figure 3.3: Time series variation in NO_x at various sites



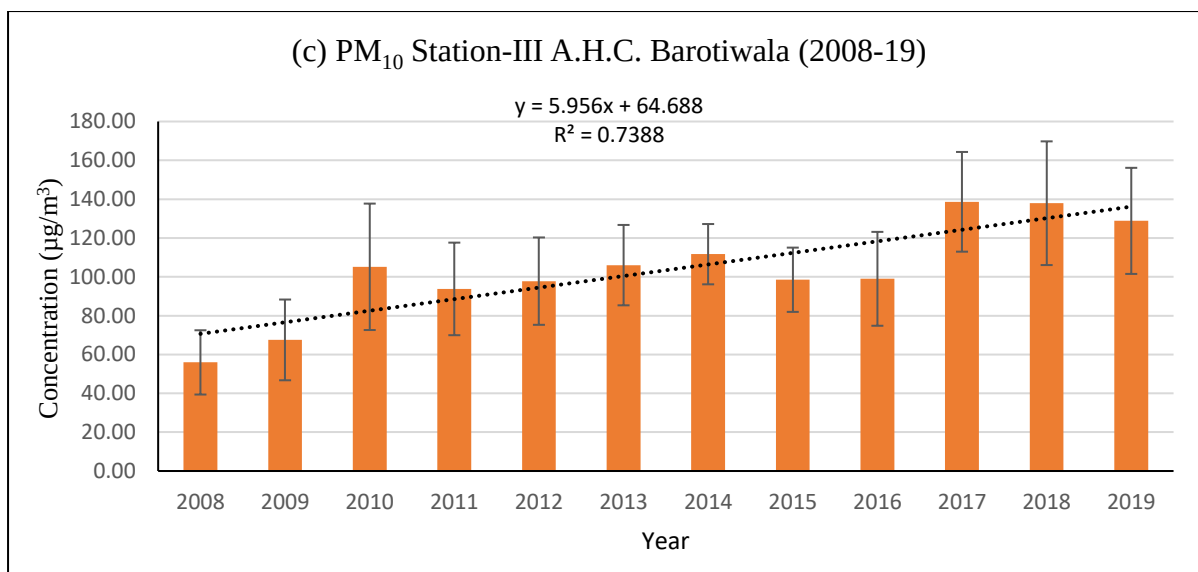
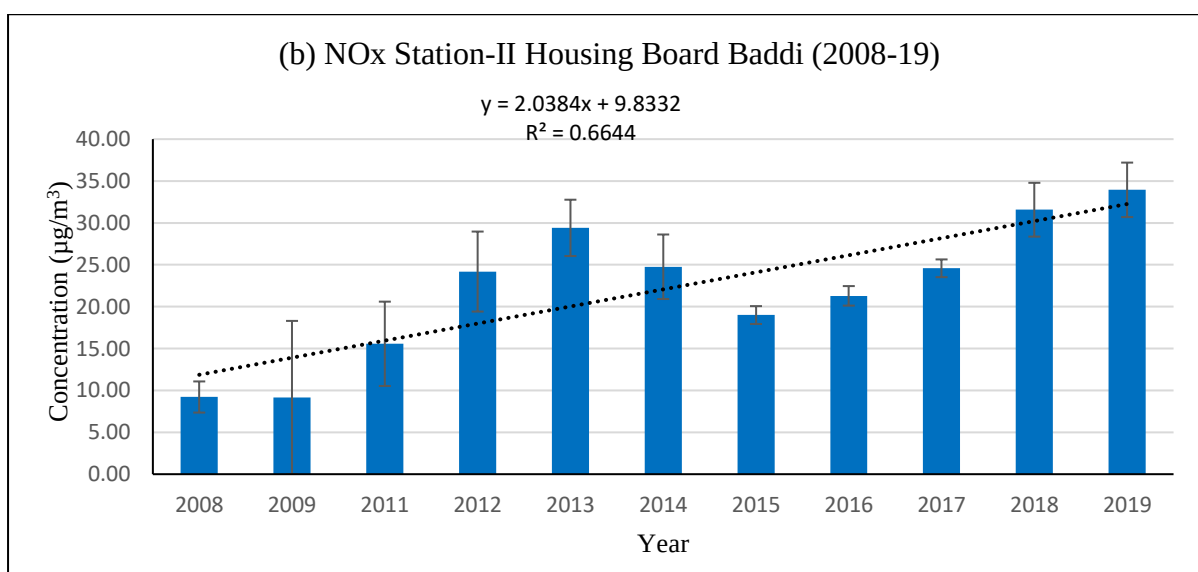
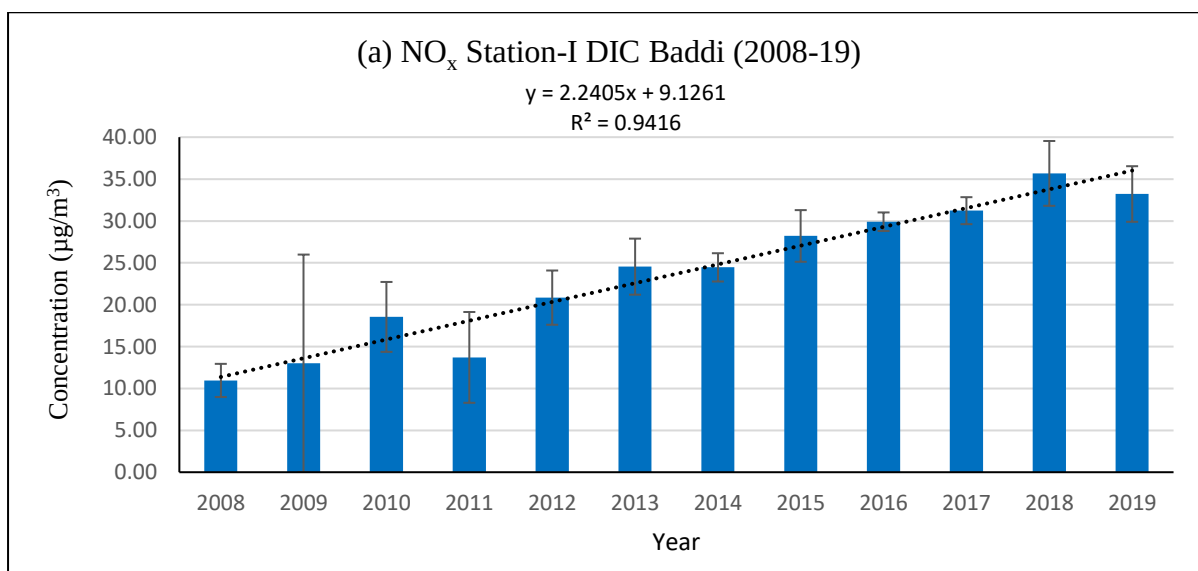


Figure 3.4: Timeseries of annual mean levels of PM₁₀ at various sites



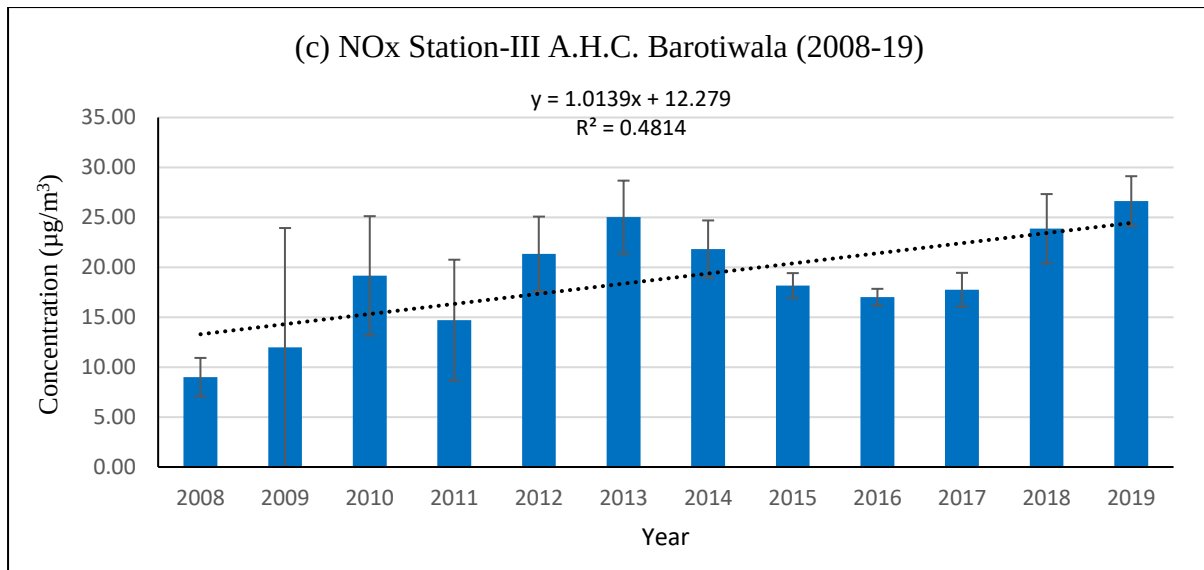


Figure 3.5: Timeseries of annual mean levels of NO_x at various sites

3.3.2 Variation in the slope: Trend analyses

As seen, levels may increase or decrease depending on the season (primarily due to changes in meteorology and emissions). Tables 3.1–3.2 present the obtained mean slopes in 12 slots of each month and annual levels along with trends using the Mann-Kendall test in PM₁₀ and NO_x at three sites in Baddi. The statistically significant trends are shown as an upward arrow (↑: increasing trend) and downward arrow (↓: decreasing trend) and a left-right arrow (↔: no trend). In other words, both slope and trend can acquire negative or positive numerical values.

There is no specific trend in PM₁₀ and NO_x at Housing Board and A.H.C. Barotiwala, however, some months show an increasing trend and some months indicate no trend. At the DIC site, PM₁₀ shows an increasing trend in all months and NO_x also shows an increasing trend in all months except March. The annual levels of PM₁₀ show an increasing trend at all sites and NO_x at DIC and housing board. There is no trend in NO_x at A.H.C. Barotiwala both in monthly mean and annual levels.

Table 3.1: Comparison of mean PM₁₀ slopes (in µg/m³/day) and trends at various sites in monthly slots during 2008-2019

Sites	PM ₁₀	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1. DIC	Slope	11.77	12.68	10.93	9.43	12.49	15.67	10.15	6.38	10.68	8.74	9.57	7.40	10.49
	Trend (MK)	Yes (↑)	Yes (↑)	Yes (↑)	Yes (↑)	Yes (↑)	Yes (↑)	Yes (↑)	Yes (↑)	Yes (↑)	Yes (↑)	Yes (↑)	Yes (↑)	Yes (↑)
2. Housing Board	Slope	12.36	9.25	7.66	10.91	5.15	10.95	5.67	3.23	9.45	7.48	11.51	8.87	9.10
	Trend (MK)	Yes (↑)	Yes (↑)	No (↔)	No (↔)	No (↔)	No (↔)	No (↔)	No (↔)	No (↔)	No (↔)	No (↔)	Yes (↑)	Yes (↑)
3. A.H.C. Barotiwalla	Slope	6.21	6.71	5.12	1.62	3.03	8.76	5.20	2.97	5.09	4.82	2.91	1.89	5.15
	Trend (MK)	No (↔)	Yes (↑)	Yes (↑)	No (↔)	No (↔)	Yes (↑)	Yes (↑)	No (↔)	Yes (↑)	No (↔)	No (↔)	No (↔)	Yes (↑)
MK: Mann Kendall Test		↑ Increasing Trend				↓ Decreasing Trend				↔ Statistically Insignificant Trend				

Table 3.2: Comparison of mean NO_x slopes (in µg/m³/day) and trends at various sites in monthly slots during 2008-2019

Sites	NO _x	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1. DIC	Slope	2.41	2.15	2.48	2.54	2.46	1.90	2.07	1.97	2.43	2.26	1.97	2.00	2.22
	Trend (MK)	Yes (↑)	Yes (↑)	No (↔)	Yes (↑)	Yes (↑)	Yes (↑)	Yes (↑)	Yes (↑)	Yes (↑)	Yes (↑)	Yes (↑)	Yes (↑)	Yes (↑)
2. Housing Board	Slope	1.54	1.04	1.28	1.67	1.61	1.25	0.76	1.15	1.45	1.97	0.51	1.37	1.82
	Trend (MK)	No (↔)	No (↔)	No (↔)	Yes (↑)	Yes (↑)	No (↔)	No (↔)	No (↔)	No (↔)	No (↔)	No (↔)	No (↔)	Yes (↑)
3. A.H.C. Barotiwalla	Slope	0.92	0.60	0.88	0.17	0.77	0.43	0.54	0.52	0.99	0.51	0.62	0.67	0.78
	Trend (MK)	No (↔)	No (↔)	No (↔)	No (↔)	No (↔)	No (↔)	No (↔)	No (↔)	No (↔)	No (↔)	No (↔)	No (↔)	No (↔)
MK: Mann Kendall Test		↑ Increasing Trend				↓ Decreasing Trend				↔ Statistically Insignificant Trend				

4 Emission Inventory

4.1 Introduction

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 Baddi city for the year 2020 is presented.

Baddi, an industrial belt of district Solan in Himachal Pradesh has carved out a name for itself as a pharmaceutical hub in North India. It is one of the important growth centres of the economy of Himachal Pradesh having one major urban settlement, Baddi Municipal Council.

4.2 Methodology

The stepwise methodology adopted for this study is presented in Figure 4.1.

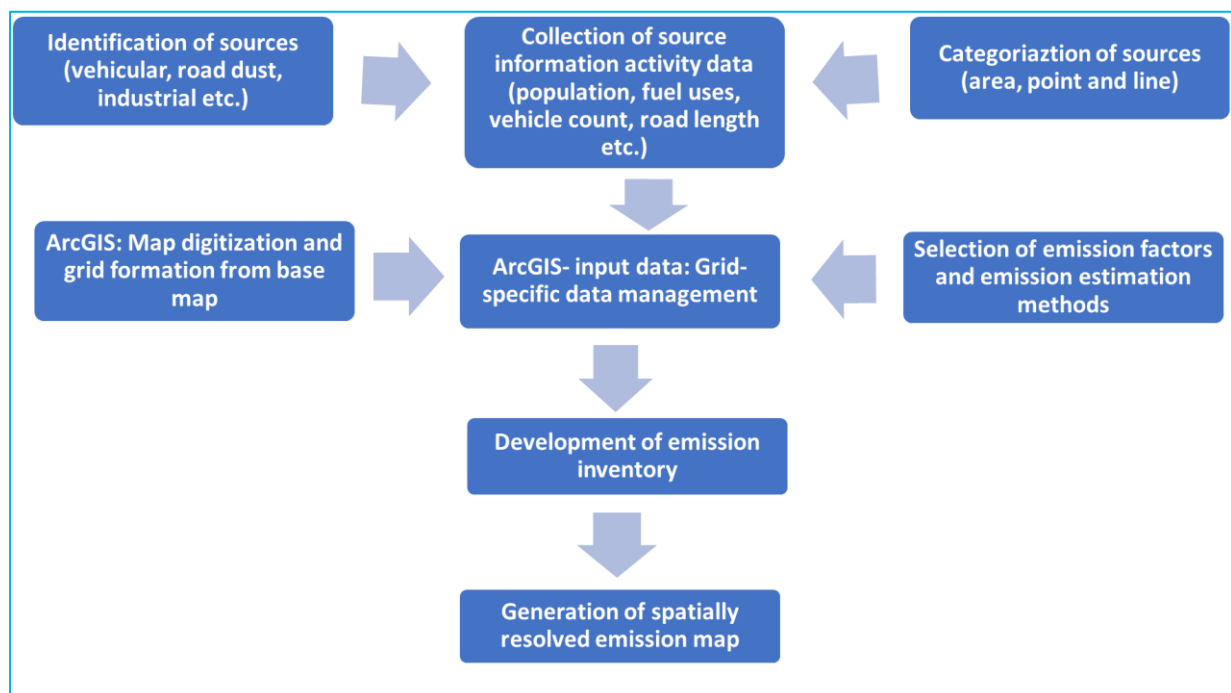


Figure 4.1: Stepwise Methodology adopted for the Study

4.2.1 Categorization of Sources

The air quality of a region is affected by emissions from different sources. Depending upon the emissions from sources, their contribution to air quality varies. It is important to identify and quantify these sources to control the emission and thereby improve the air quality. Air pollution sources are widely categorized as area (domestic and fugitive combustion type emission sources), industrial (point and area) sources, and vehicular (line) sources. The source category and type of sources are shown in Figure 4.2.

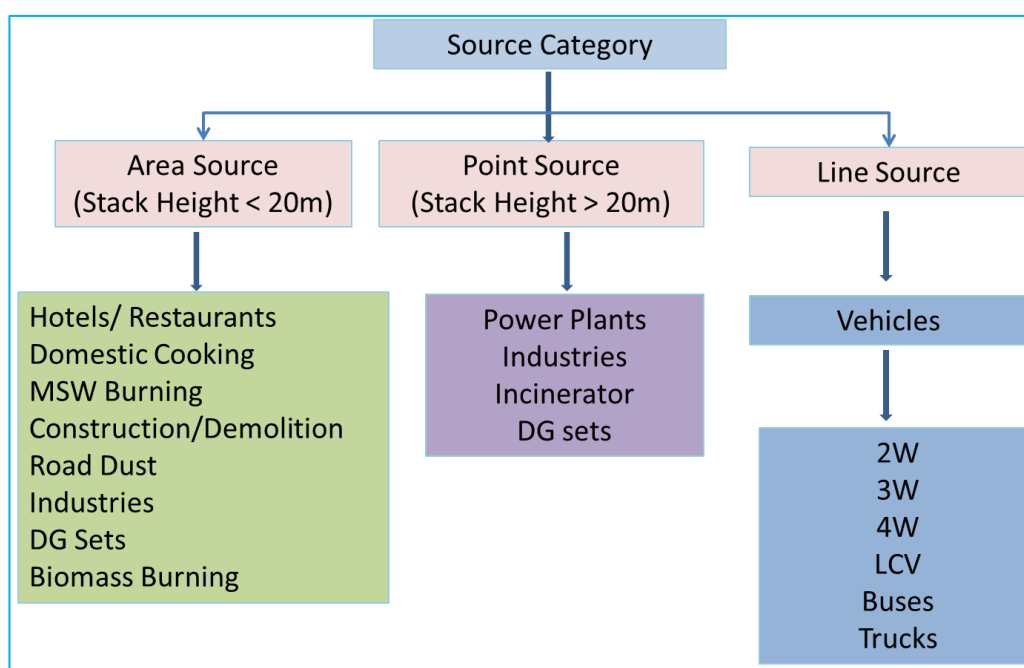


Figure 4.2: Source Category and type of sources

4.2.2 Data Collection

The primary and secondary data were collected by the IITK team. For example, construction and demolition data were collected by field survey and validated by satellite imagery. Road dust sampling at seven locations was conducted. A physical survey of industrial areas was also done. The main sources of secondary data collection are from HPSPCB, Census of India, CPCB website, Transport Department, and Toll Plazas. The information has also been collected through the Internet by visiting various websites. Although all possible efforts have been made to collect the data, some information/data could be missing.

4.2.3 Digital Data Generation

The land-use map of the study area is prepared in terms of settlements, agriculture, road network, water bodies, etc., (Figure 4.3 to Figure 4.13).

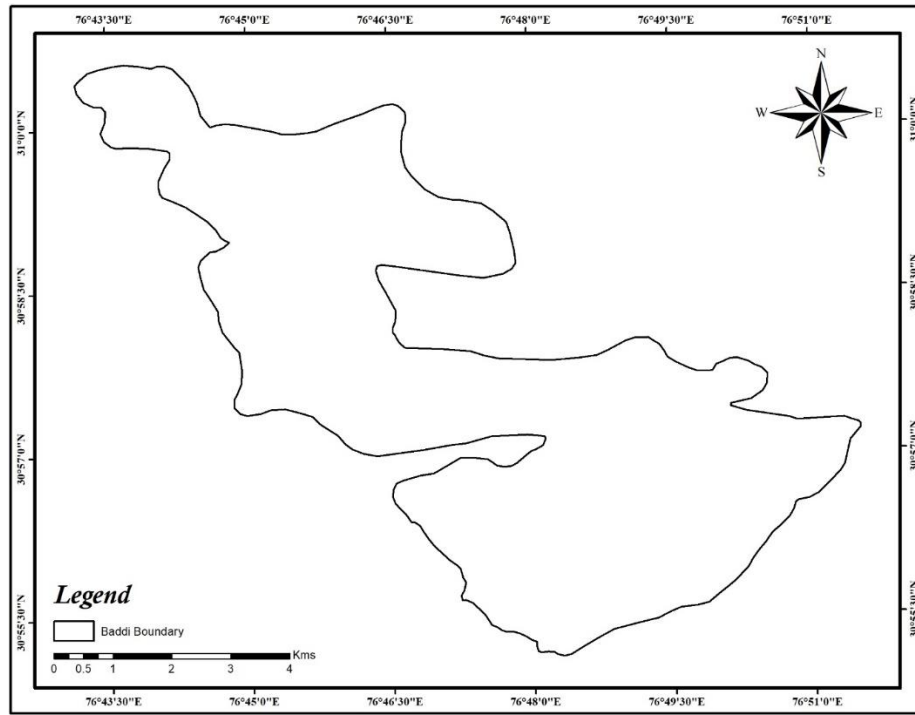


Figure 4.3: Baddi City Boundary

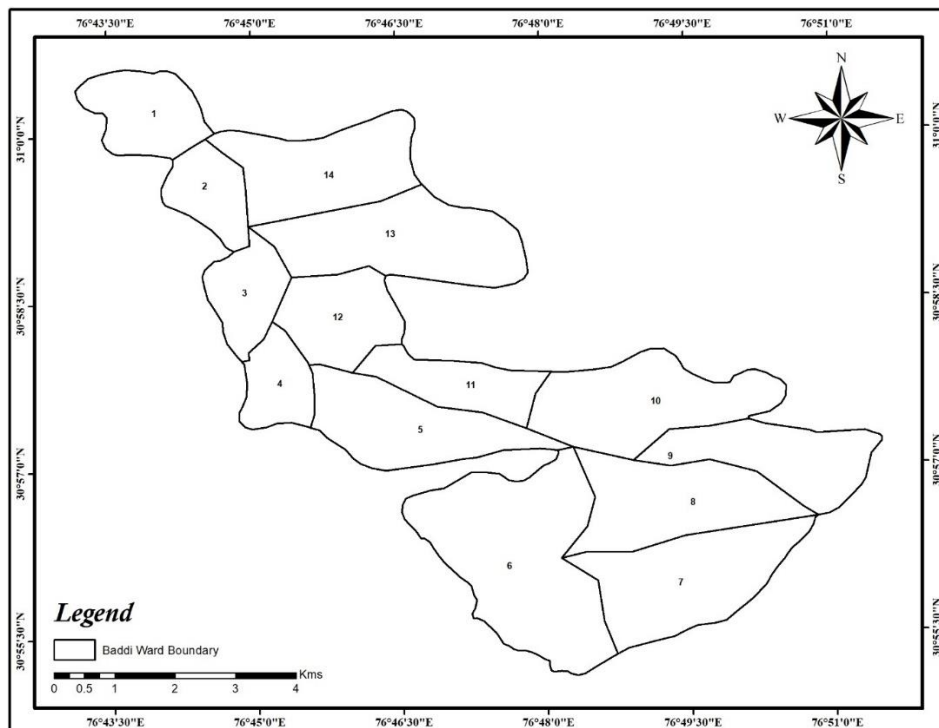


Figure 4.4: Ward Map

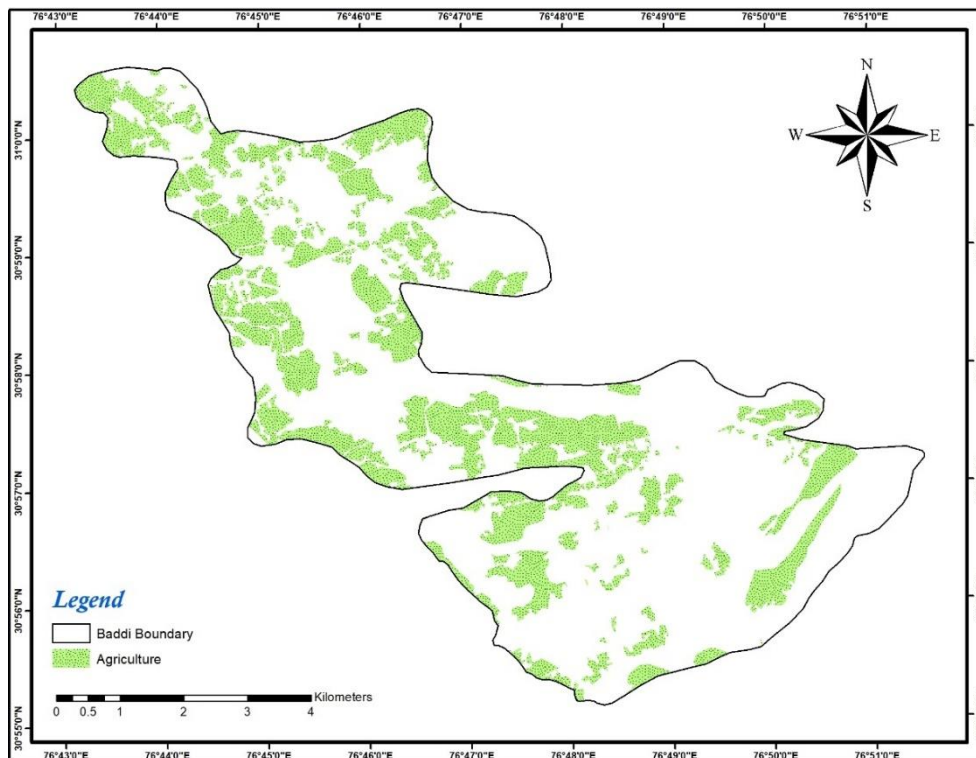


Figure 4.5: Agricultural Area Map

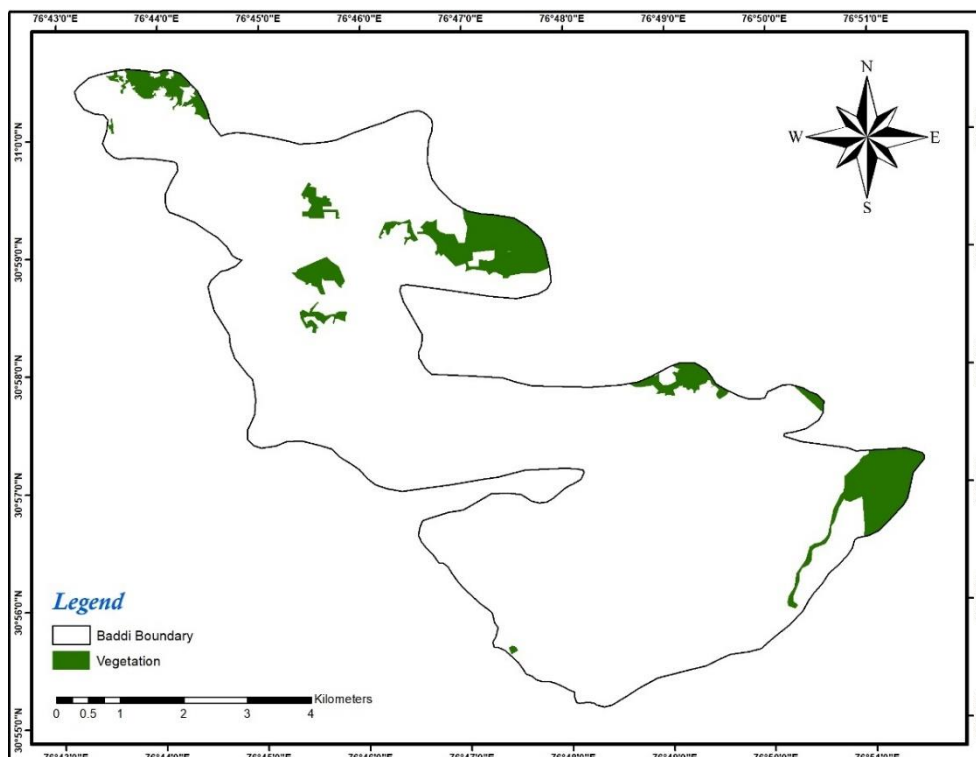


Figure 4.6: Green Area Map

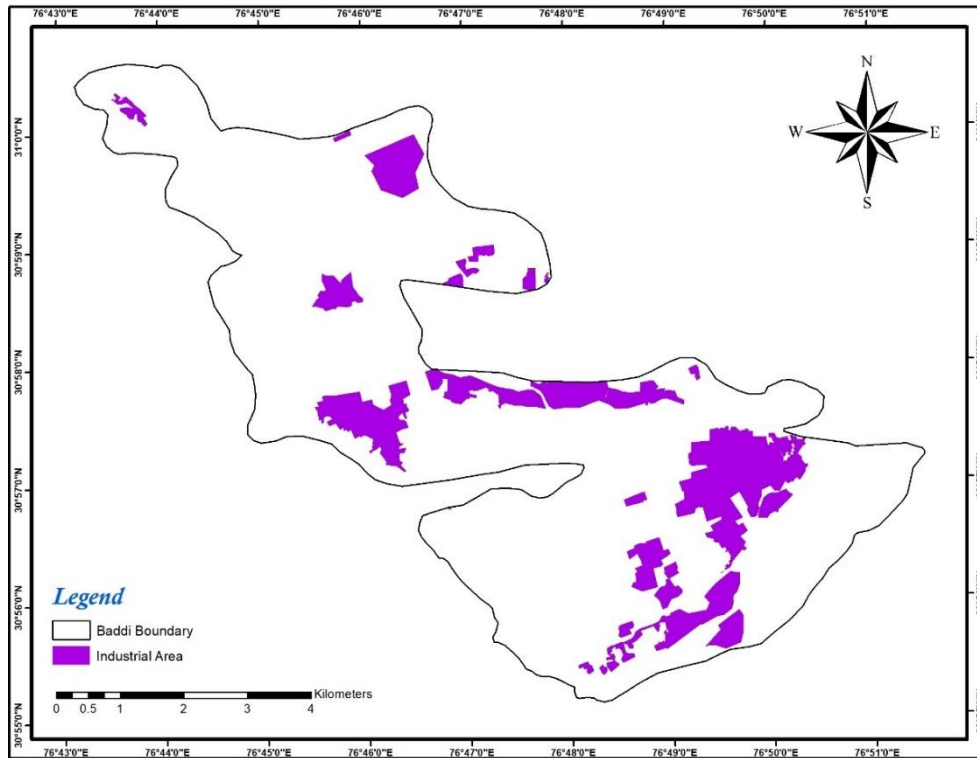


Figure 4.7: Industrial Area Map

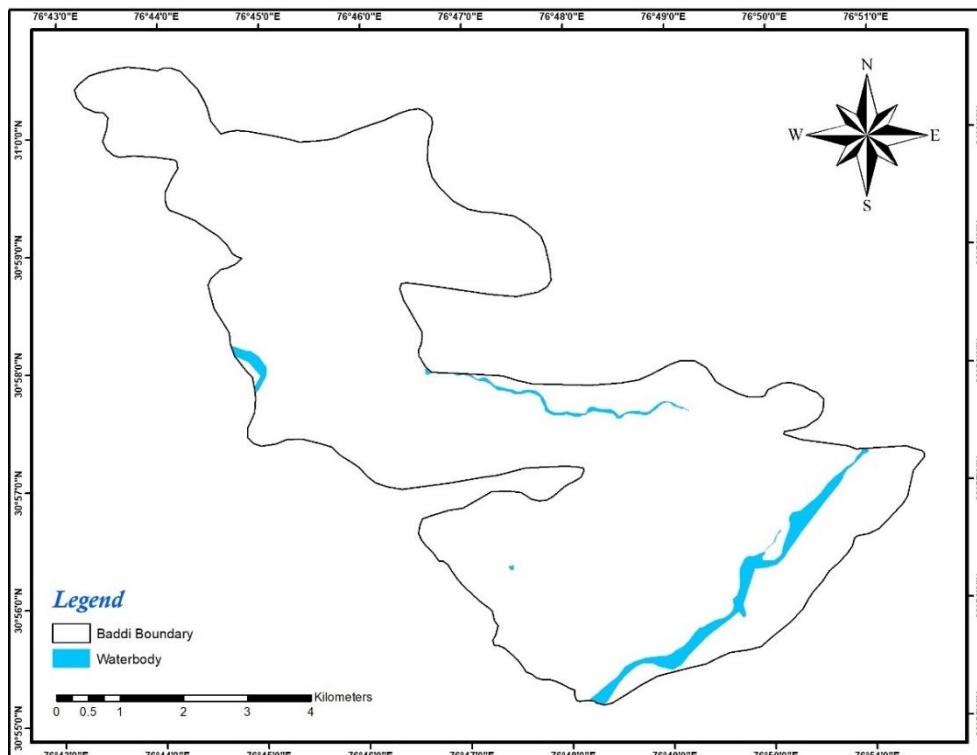


Figure 4.8: Waterbodies Area Map

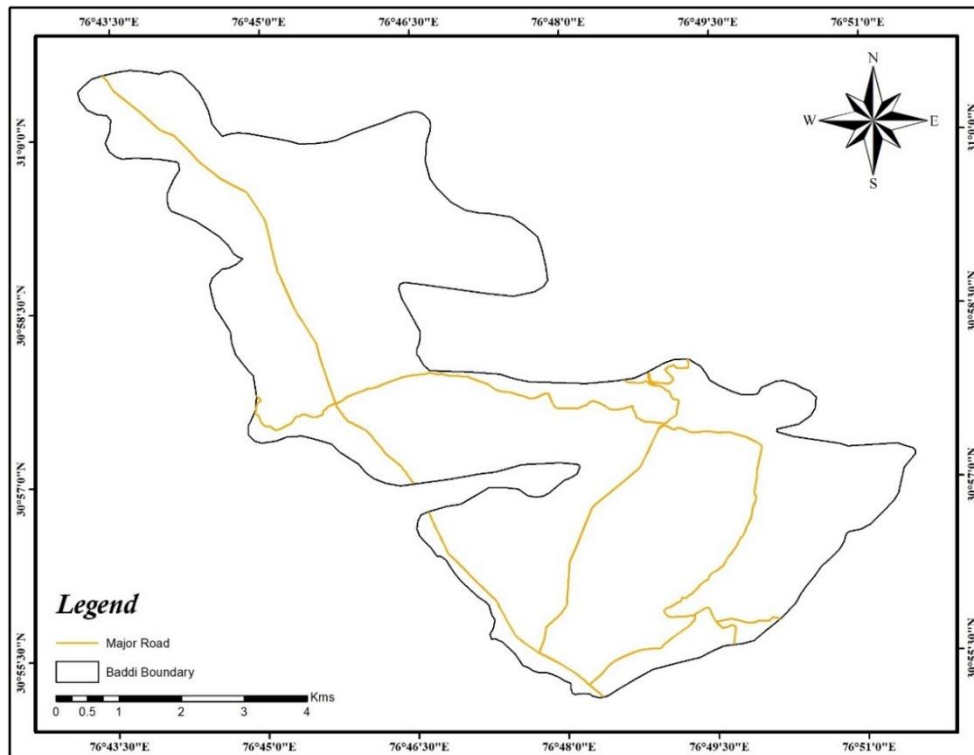


Figure 4.9: Major Road Network Map

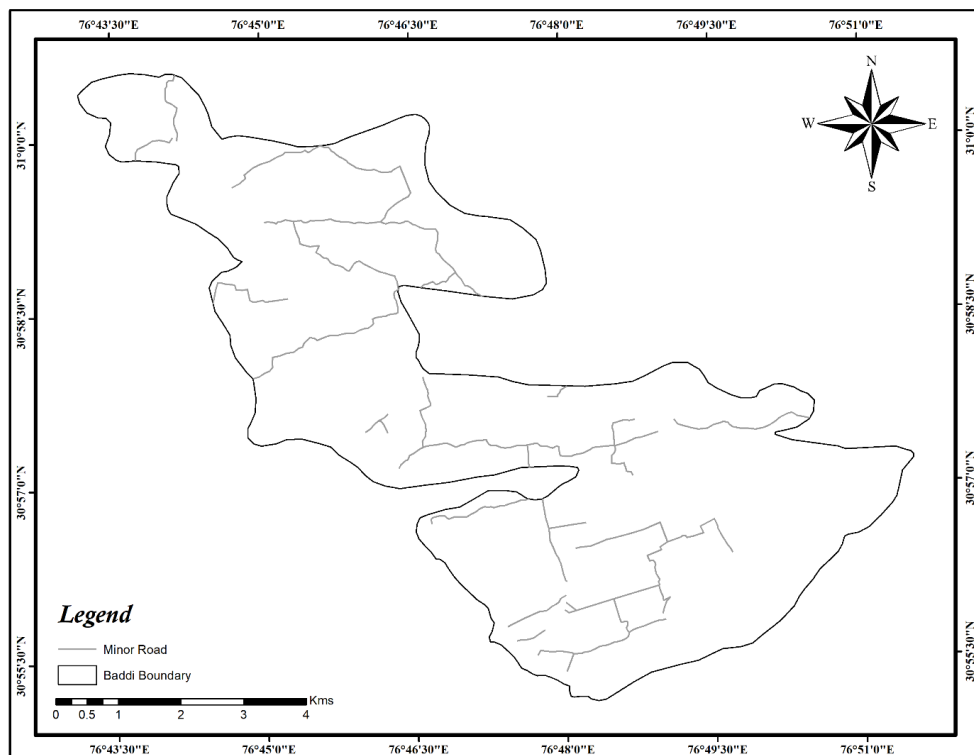


Figure 4.10: Minor Road Network Map

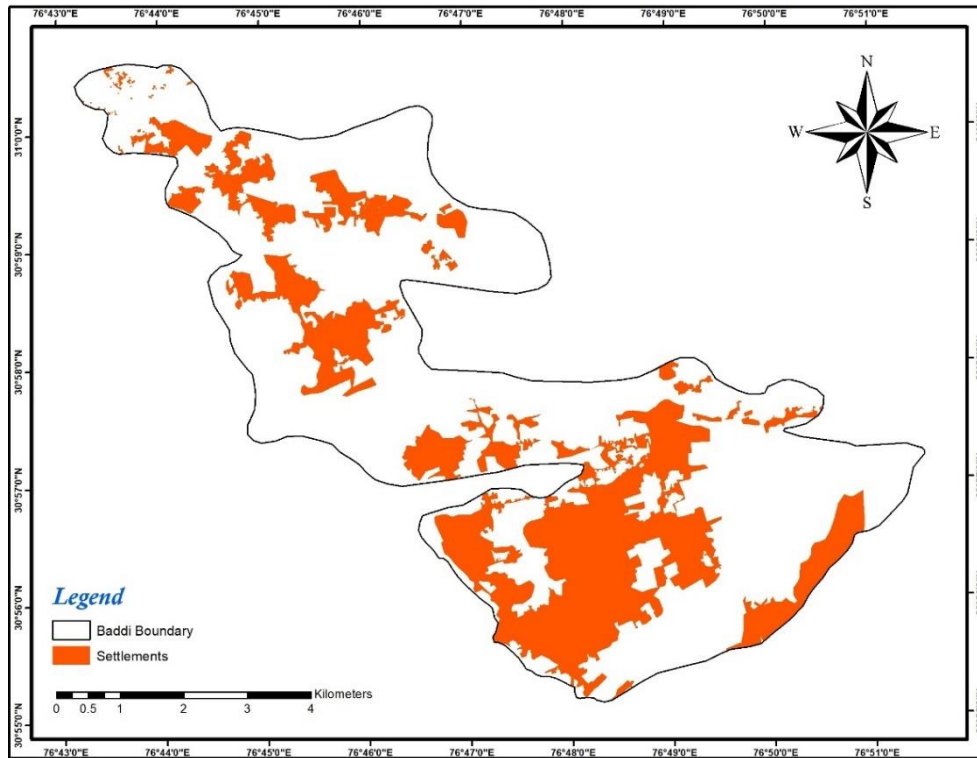


Figure 4.11: Settlement Area Map

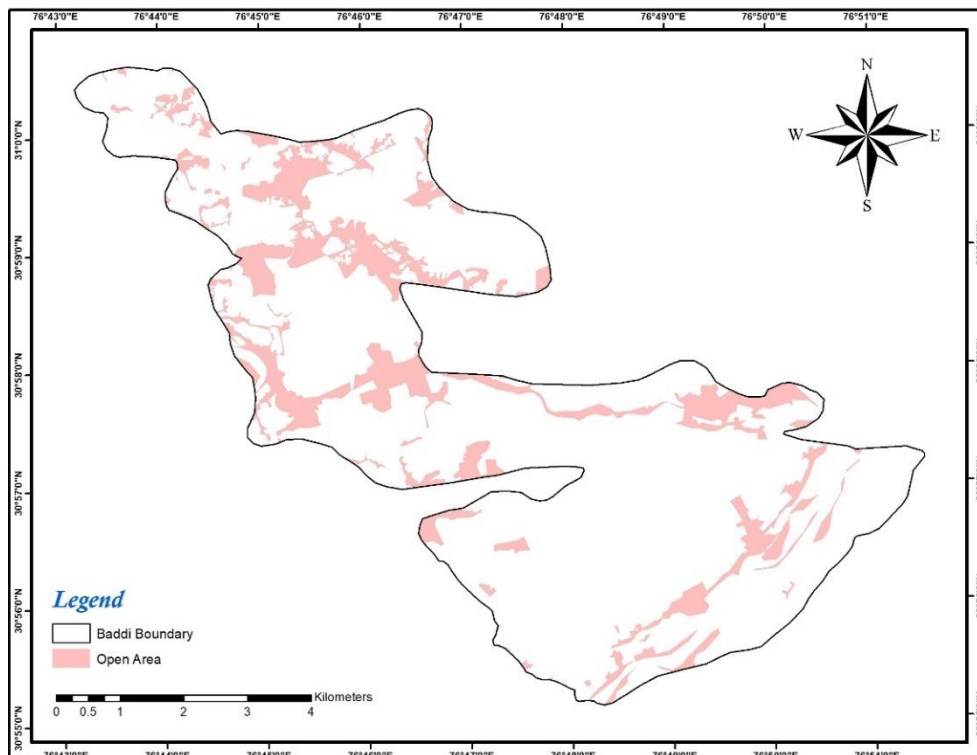


Figure 4.12: Open Area Map

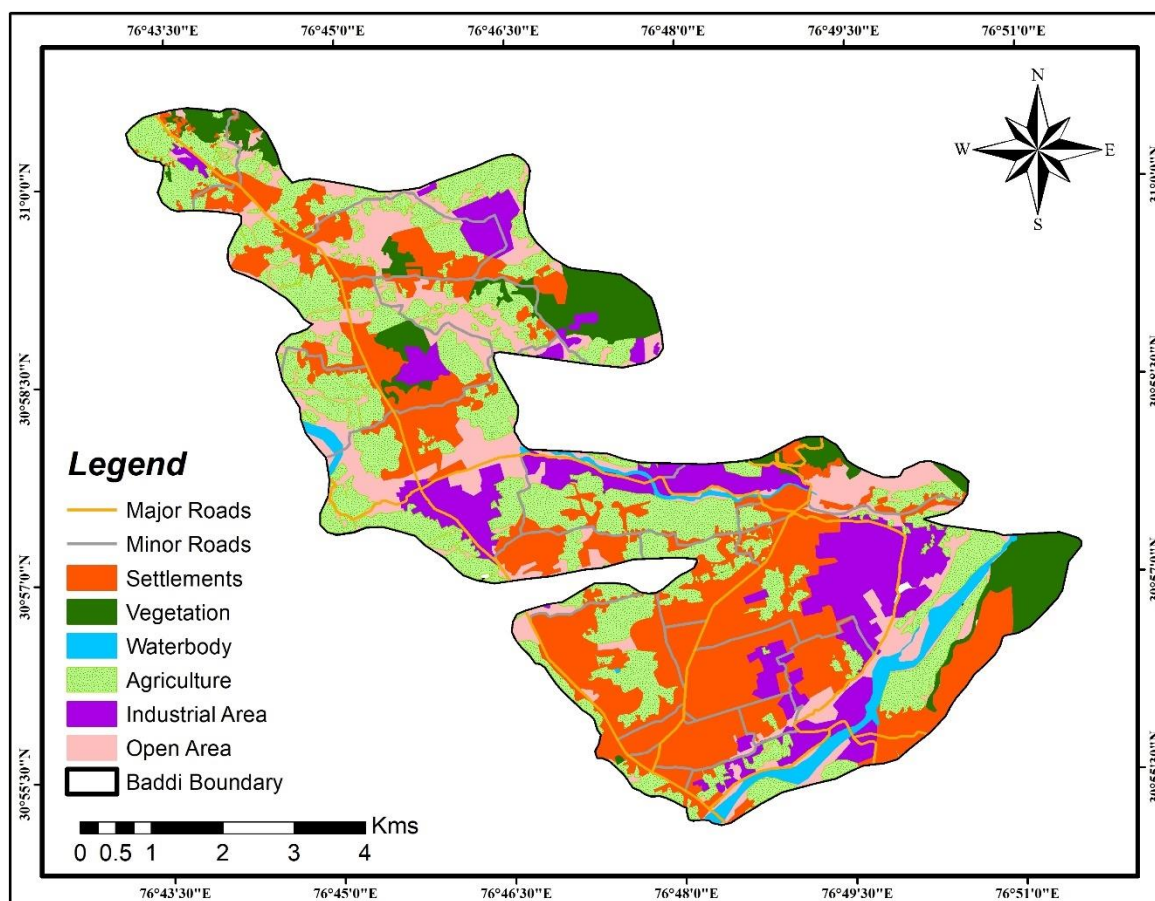


Figure 4.13: Land use Map of Baddi City

At the time of the development of the emission inventory, a suitable coding system was adopted to avoid the confusion and misrepresentation of results and interpretation. The emissions have been calculated for Baddi city. The Grid map of Baddi with grid identity numbers is shown in Figure 4.14. The entire study area was divided into grid cells of 1 km x 1 km.

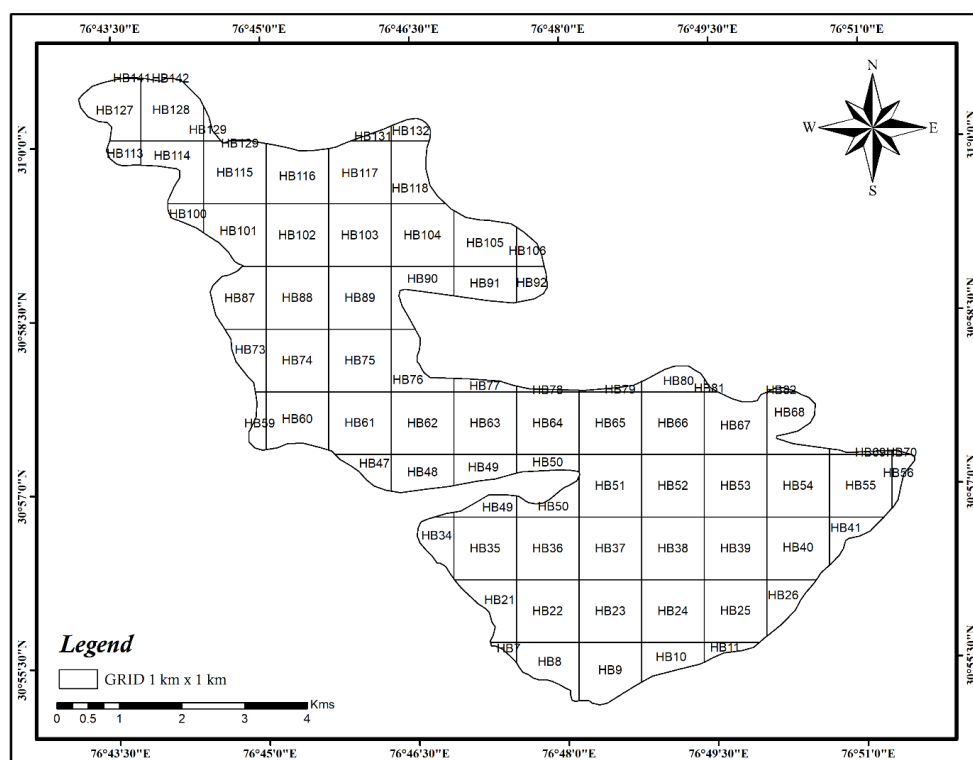


Figure 4.14: Grid Map of Baddi City showing Grid Identity Numbers

4.2.4 Emission Factor

An emissions 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 pollutant per unit mass of raw material, volume, distance travelled, 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 emission factors used in the report are mentioned in Annexure 1.

The general equation for emissions estimation is:

$$E = A \times EF \times (1 - ER/100) \quad \dots\dots\dots (Eq. 4.1)$$

Where:

E = Emissions;

A = Activity rate;

EF = Emission factor, and

ER = Overall emission reduction efficiency, %

4.2.5 Domestic Sector

The interior boundaries in the map with 14 wards (Figure 4.4) show the administrative boundaries of wards in Baddi City. The projected population of Baddi city for the year 2020 is approximately 40,000 and the emission from the domestic sector for the same is calculated. The fuel consumption pattern shows LPG (79%) consumption (PPAC, MoPNG, 2016), Wood (12%), Dung (2%), Coal (2%), Kerosene (4%) and Crop Residue (1%). During the field survey, it was observed that most of the economically weaker/ slum areas are using wood and dung as fuel for cooking. Although they have been given LPG cylinders, due to their economic condition, refilling of cylinders is irregular.

The area of wards was calculated using GIS, and the emission density for each ward is calculated for different pollutants (PM₁₀, PM_{2.5}, SO₂, NO_x, and CO). The emission factors given by CPCB (2011) and AP-42 (USEPA, 2000) were used for each fuel type.

The overall emission from domestic sources is presented in Figure 4.15 (a) & (b). The emission contribution from different fuel types to different pollutants is shown in Figure 4.16 to Figure 4.20. For spatial distribution of different pollutants (Figure 4.21 to Figure 4.25), emission per capita, in each ward was calculated, as activity data was available based on per capita.

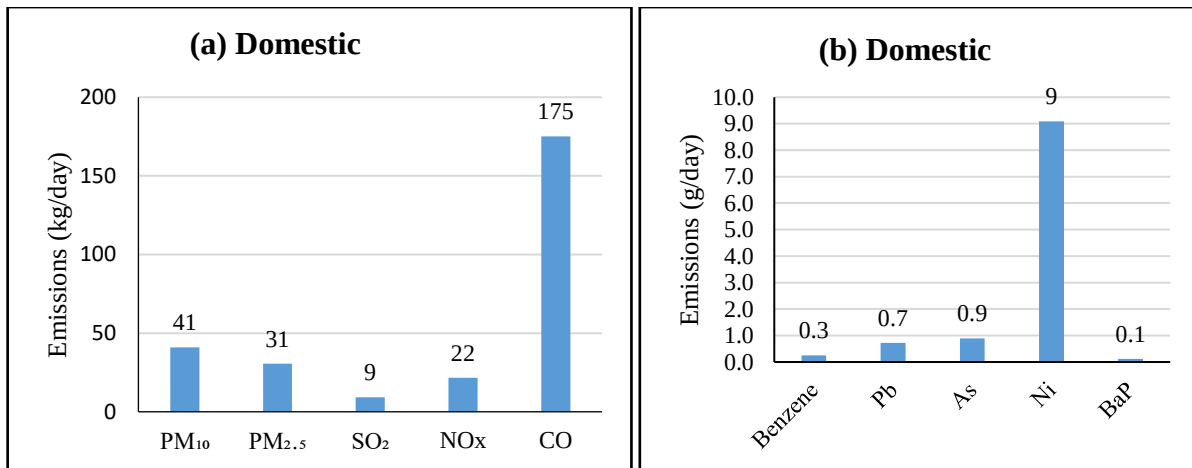
The emission density in terms of kg/day/m² in each ward was calculated based on the population and area of the ward for different pollutants (PM₁₀, PM_{2.5}, SO₂, NO_x, and CO); see below.

$$\text{Emission Density (kg/day/m}^2\text{)} = \text{Emission of Ward (kg/day)}/\text{Ward Area (m}^2\text{)} \dots \dots \text{(Eq. 4.2)}$$

For calculating emissions 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 the emission density of the ward, the emissions were calculated, see below.

$$\text{Grid Emissions} = \sum_{i=1}^N (\text{area of fraction ward } i \text{ in grid} \times \text{emission density of ward, } i) \dots \dots \dots \text{(Eq. 4.3)}$$

Where N= no. of wards in the grid.



a) PM Emission Load in kg/day

b) Other Pollutants Emission in g/day

Figure 4.15: Emission Load from Domestic Sector

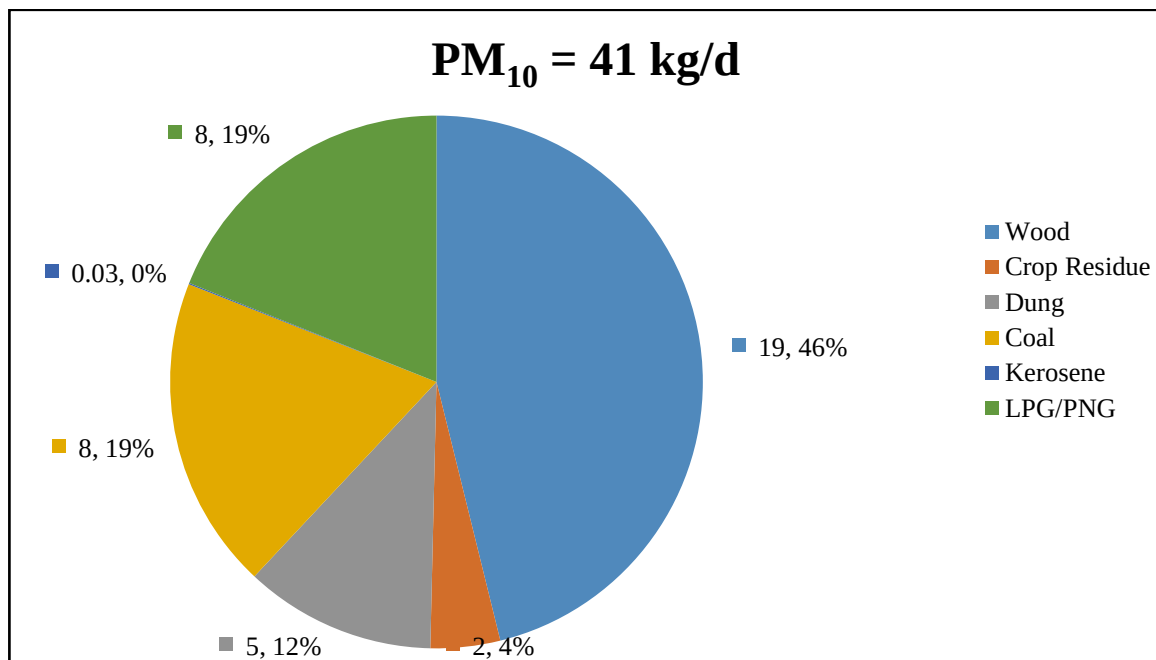


Figure 4.16: PM₁₀ Emission load from Domestic Sector (Kg/day, %)

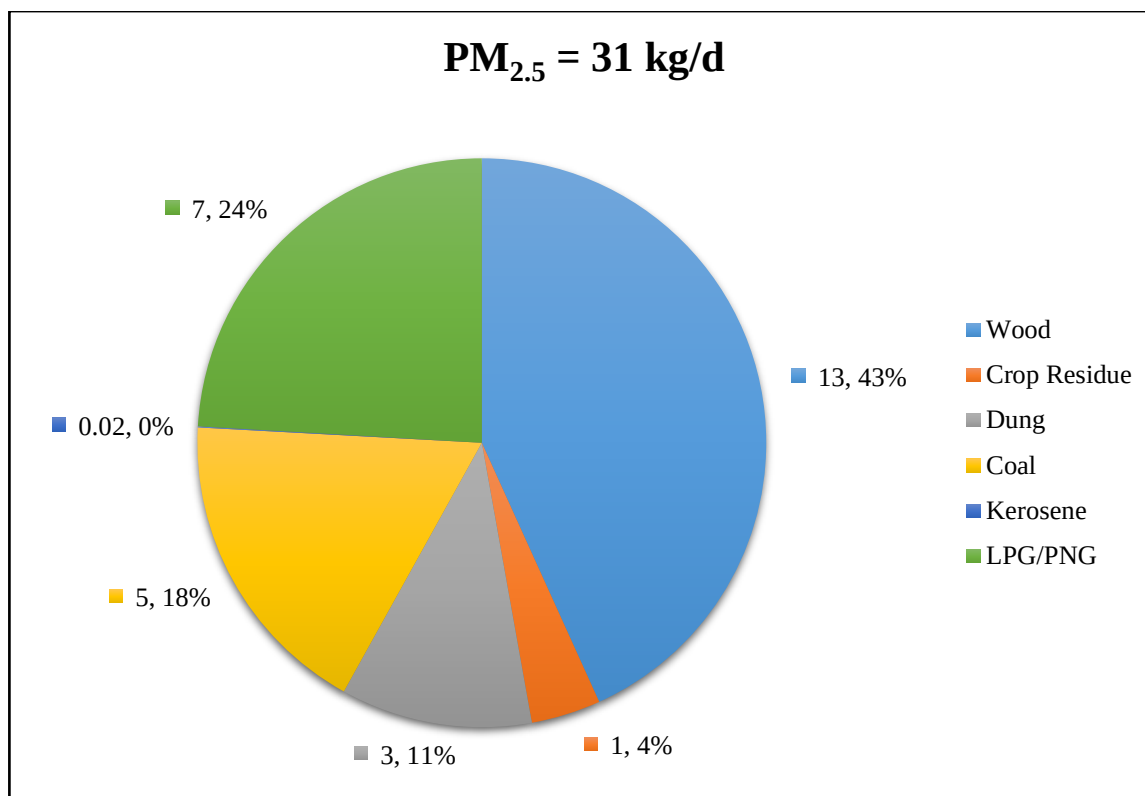


Figure 4.17: PM_{2.5} Emission load from Domestic Sector (Kg/day, %)

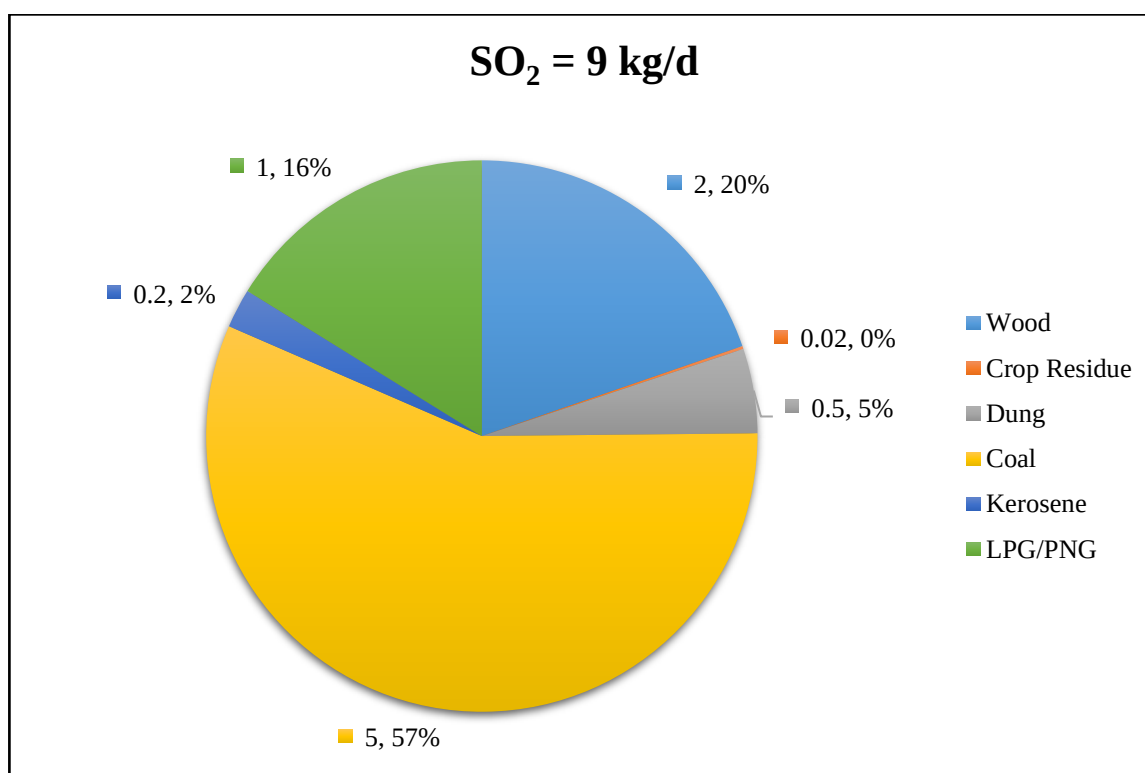


Figure 4.18: SO₂ Emission load from Domestic Sector (Kg/day, %)

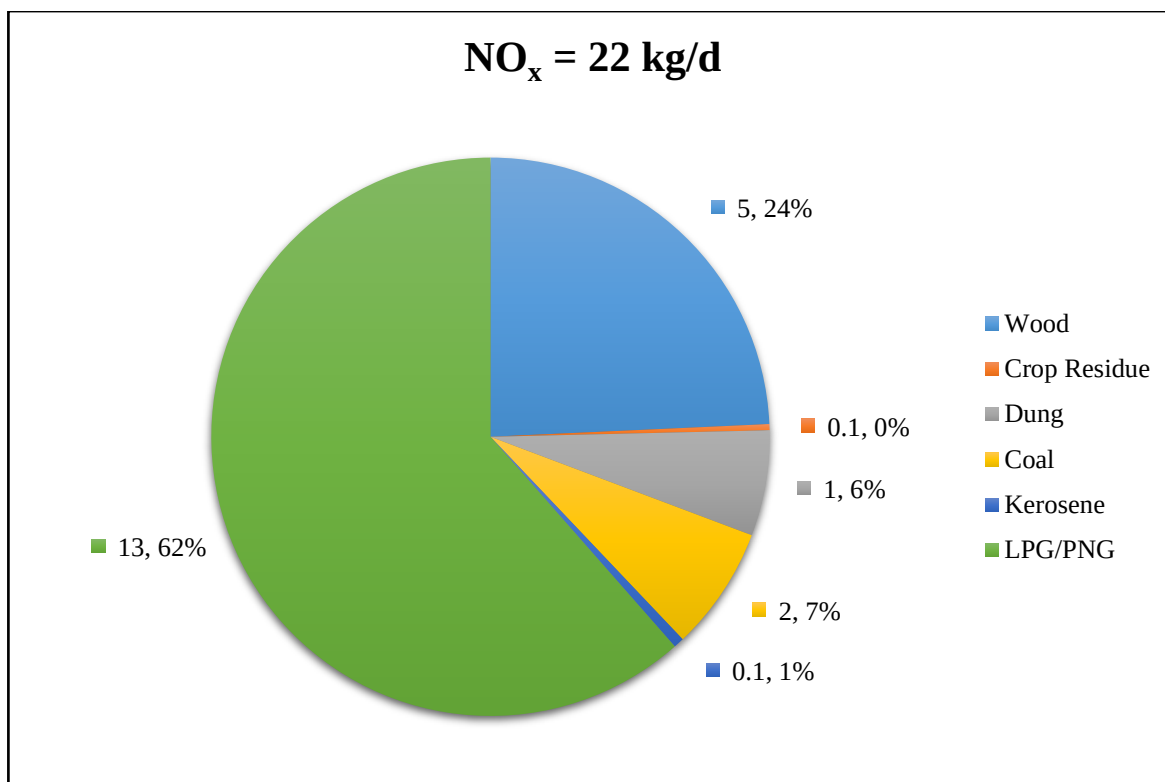


Figure 4.19: NO_x Emission load from Domestic Sector (Kg/day, %)

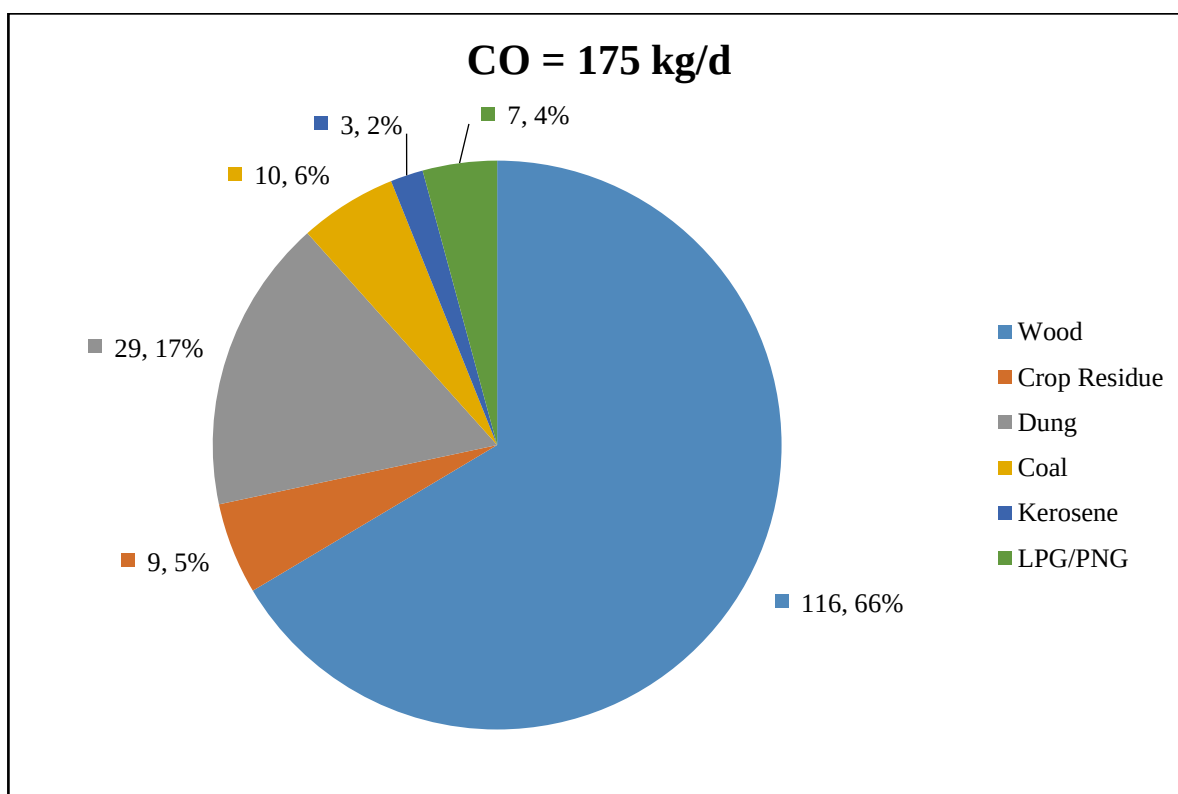


Figure 4.20: CO Emission load from Domestic Sector (Kg/day, %)

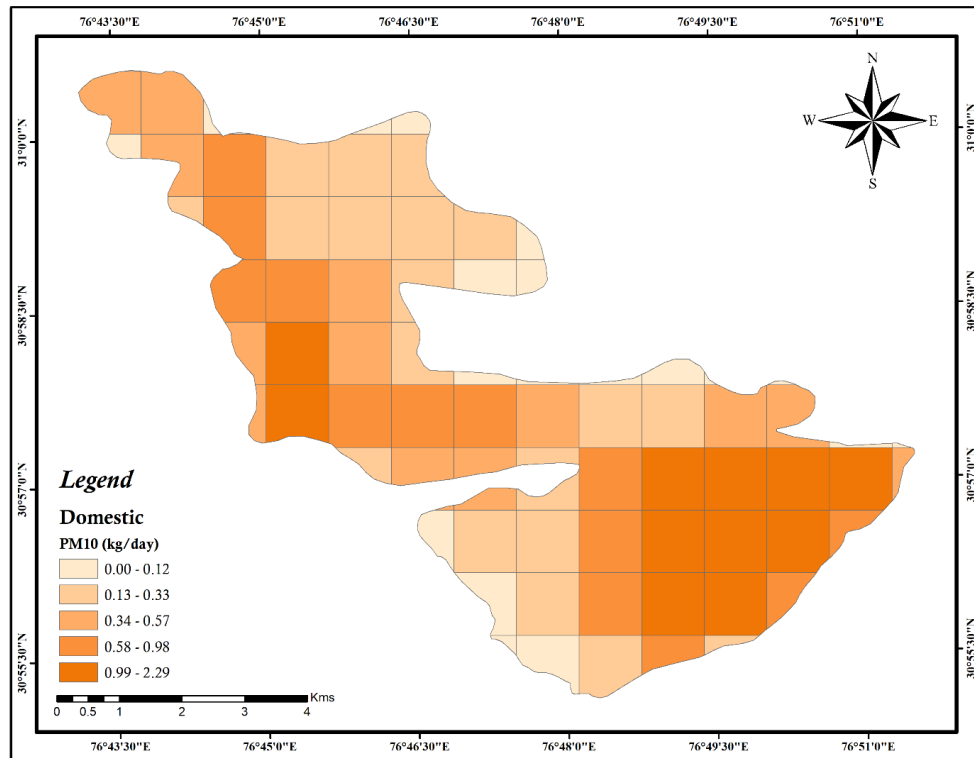


Figure 4.21: Spatial Distribution of PM₁₀ Emissions from Domestic Sector

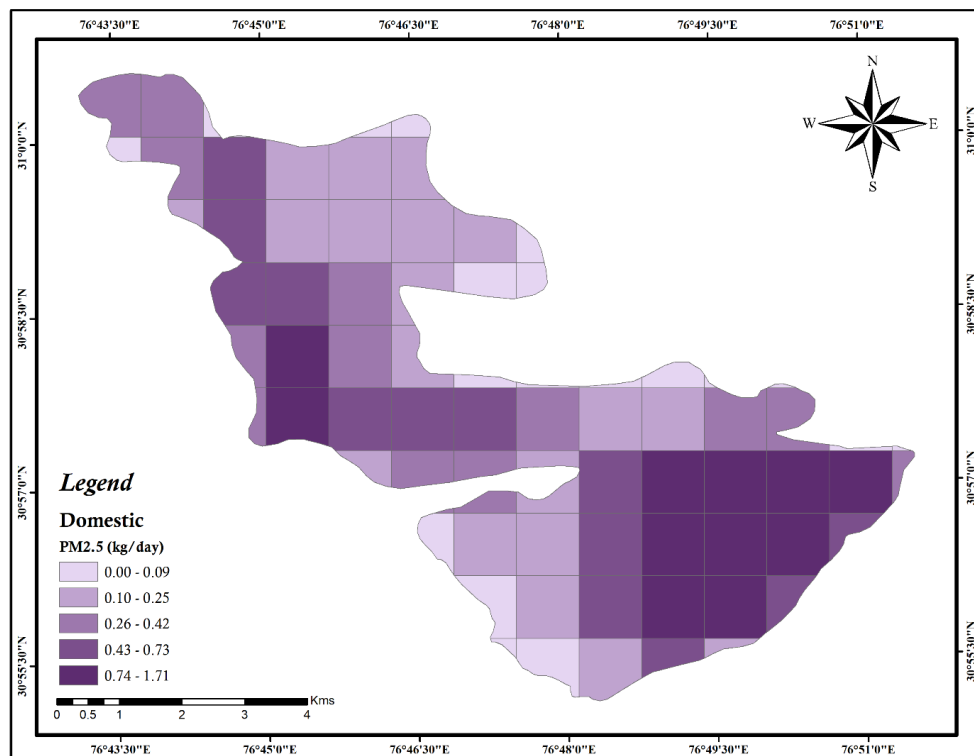


Figure 4.22: Spatial Distribution of PM_{2.5} Emissions from Domestic Sector

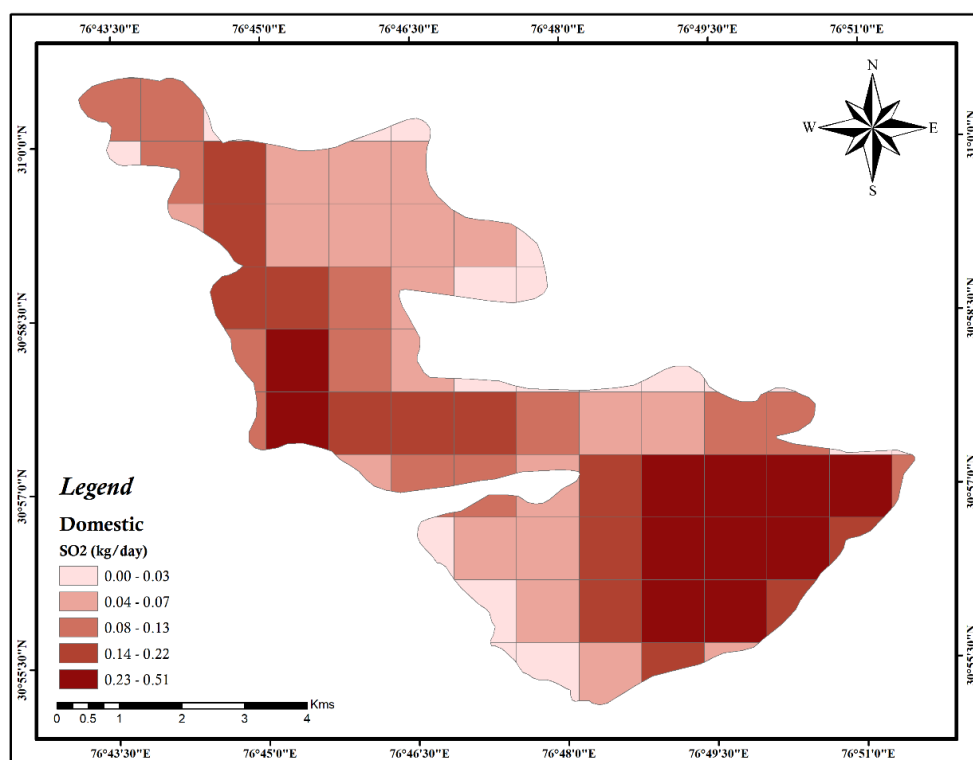


Figure 4.23: Spatial Distribution of SO₂ Emissions from Domestic Sector

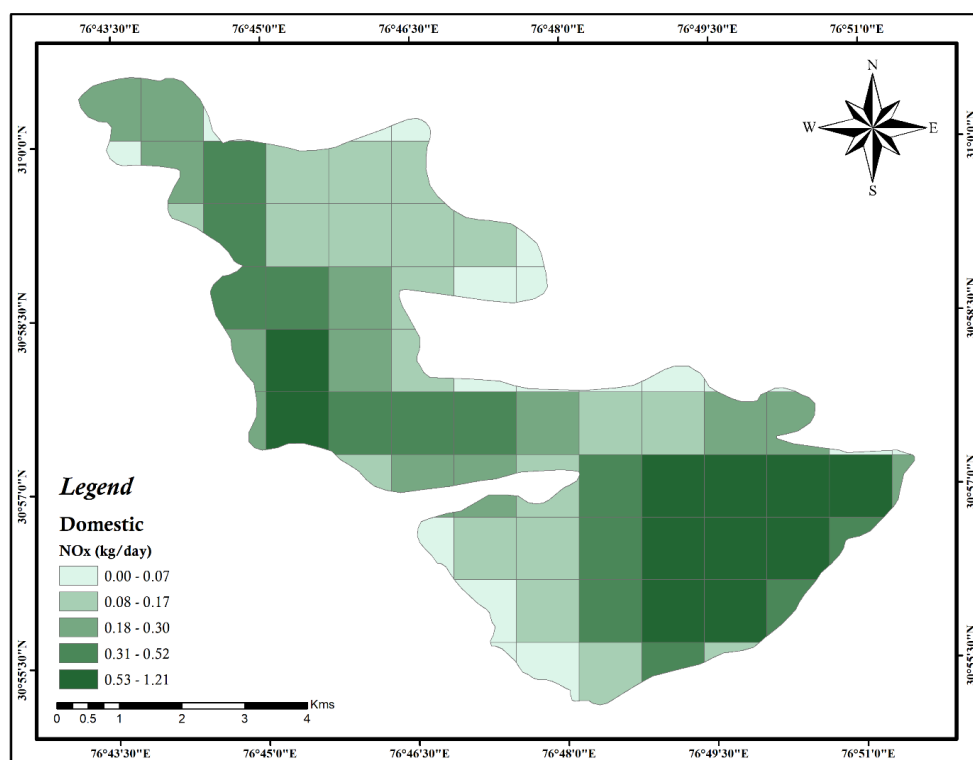


Figure 4.24: Spatial Distribution of NO_x Emissions from Domestic Sector

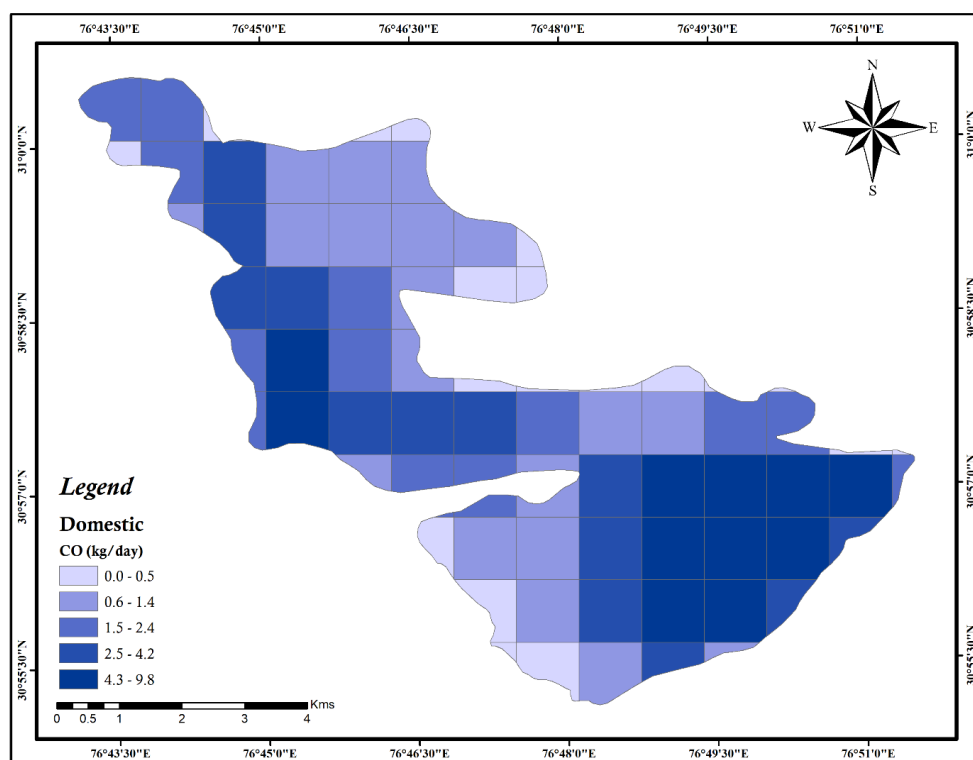


Figure 4.25: Spatial Distribution of CO Emissions from Domestic Sector

4.2.6 Construction and Demolition

A detailed survey was undertaken to assess construction and demolition activities. Satellite imagery (Google Earth, <https://earth.google.com/>) was also used to identify the construction activities. The major construction activities include buildings (including residential housing and apartments) information was obtained from Baddi Nagar Nigam, PWD, CPWD, and a detailed survey was done. Nearly at all the construction sites, the construction material and their debris (lying open, without cover) are being stored outside the construction premises, near the road (Figure 4.26). The areas under construction activities were calculated based on survey data and GIS. The location of construction and demolition sites at Baddi is given in Figure 4.27. The emissions were estimated using Eq (4.4) given by AP-42 (USEPA, 2000).

$$E = 1.2 \text{ tons/acre/month of activity} \quad \dots\dots\dots(\text{Eq 4.4})$$



Figure 4.26: Construction material and debris near construction sites

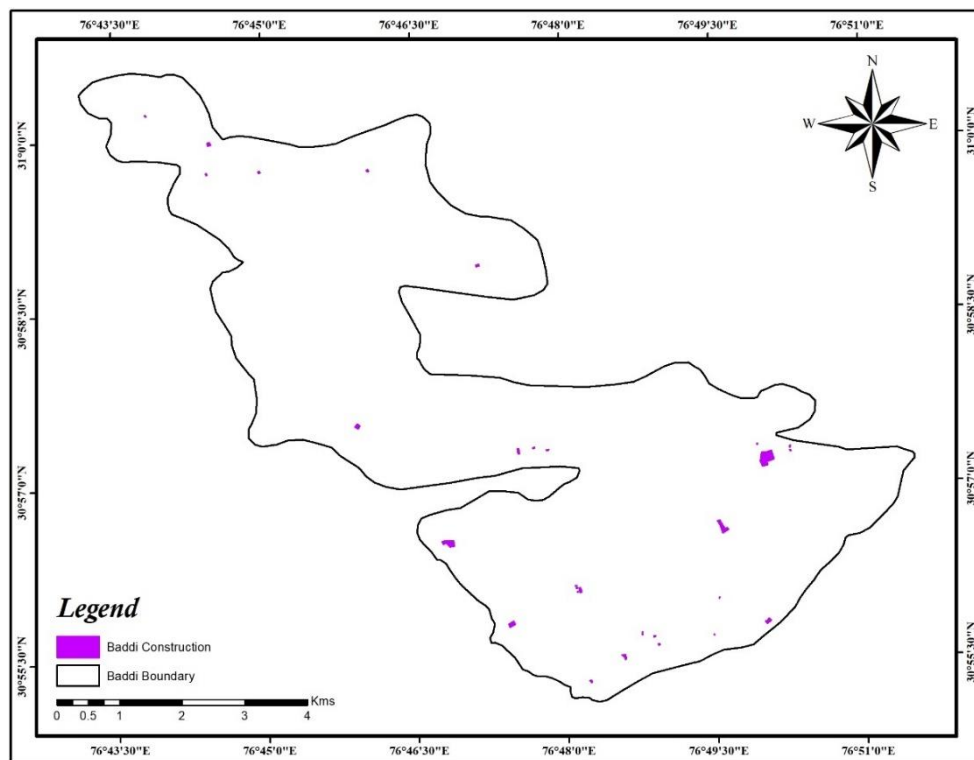
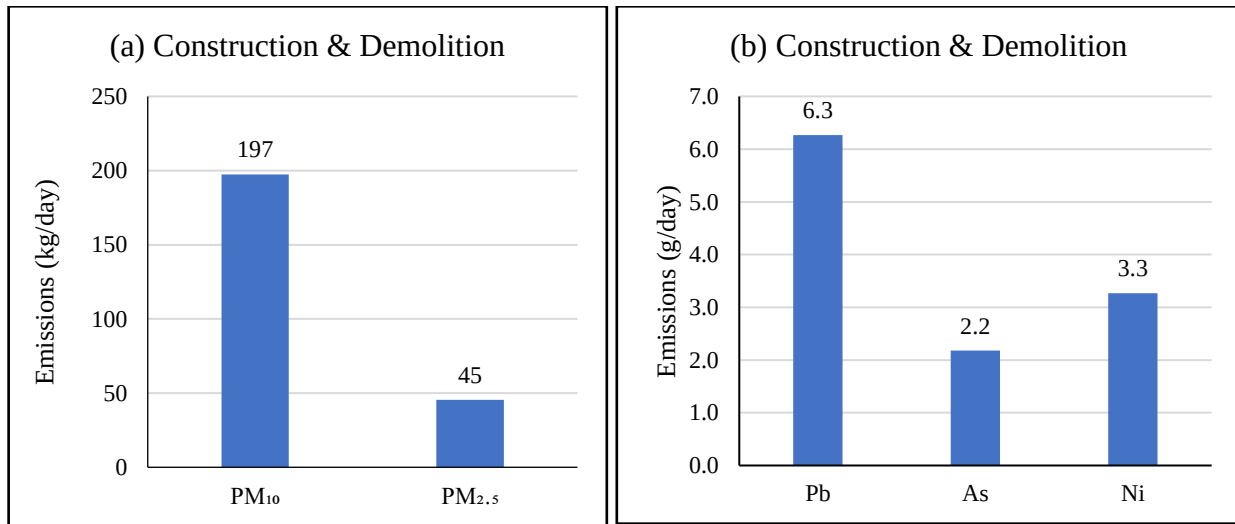


Figure 4.27: Location of Construction and Demolition sites at Baddi city

Total emissions from construction and demolition activities are presented in Figure 4.28 (a) & (b). The spatially resolved map of construction and demolition activities is shown in Figure 4.29 & Figure 4.30. The Emission load of PM₁₀ and PM_{2.5} from construction and demolition is 197 kg/day and 45 kg/day.



a) PM Emission Load in kg/day

b) Other Pollutants Emission in g/day

Figure 4.28: Emission Load from Construction and Demolition activities

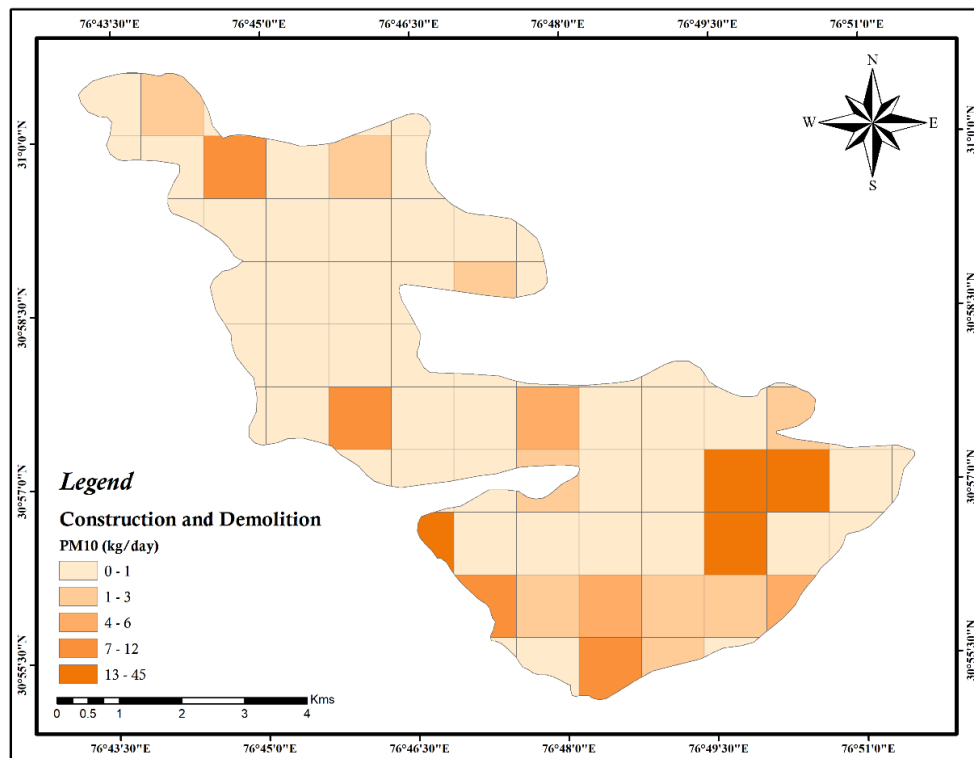


Figure 4.29: Spatial Distribution of PM₁₀ Emissions from Construction/Demolition

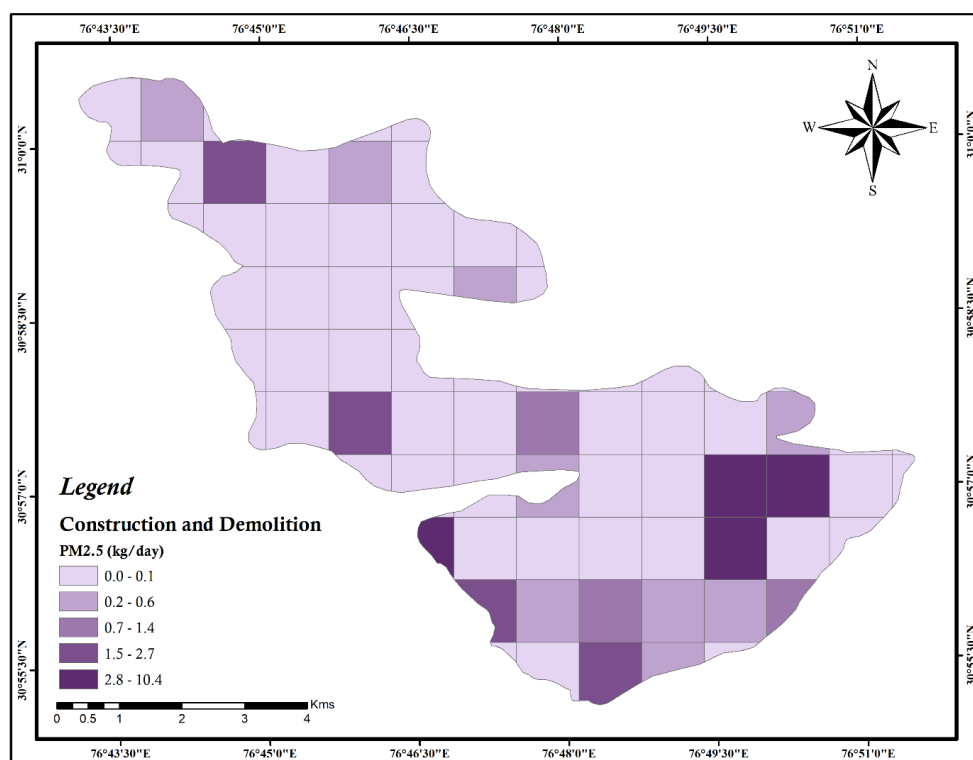


Figure 4.30: Spatial Distribution of PM_{2.5} Emissions from Construction/Demolition

4.2.7 Industrial Diesel Generator Sets (Industrial DG sets)

The industries use DG sets as a backup, approximately 505 DG sets are installed in industries (source: consent data; Figure 4.31). The capacities of DG sets are in the range of 40 KVA to 13500 KVA with an average capacity of 580 KVA. During the industrial survey, it was found that these DG sets operate for two hours per day. Most industries use diesel as fuel for generator sets. The calculation is based on Eq (4.1), where ER, overall efficiency reduction was taken as zero. The total emissions from DG sets are shown in Figure 4.32 (a) & (b), and the spatial distribution of emissions from DG Sets lying within the boundary is shown in Figure 4.33 to Figure 4.37. Some DG sets in industries are also shown for the adjacent Barotiwalla area that may influence the air quality in Baddi area (Figure 4.31), but not included for emission calculations.

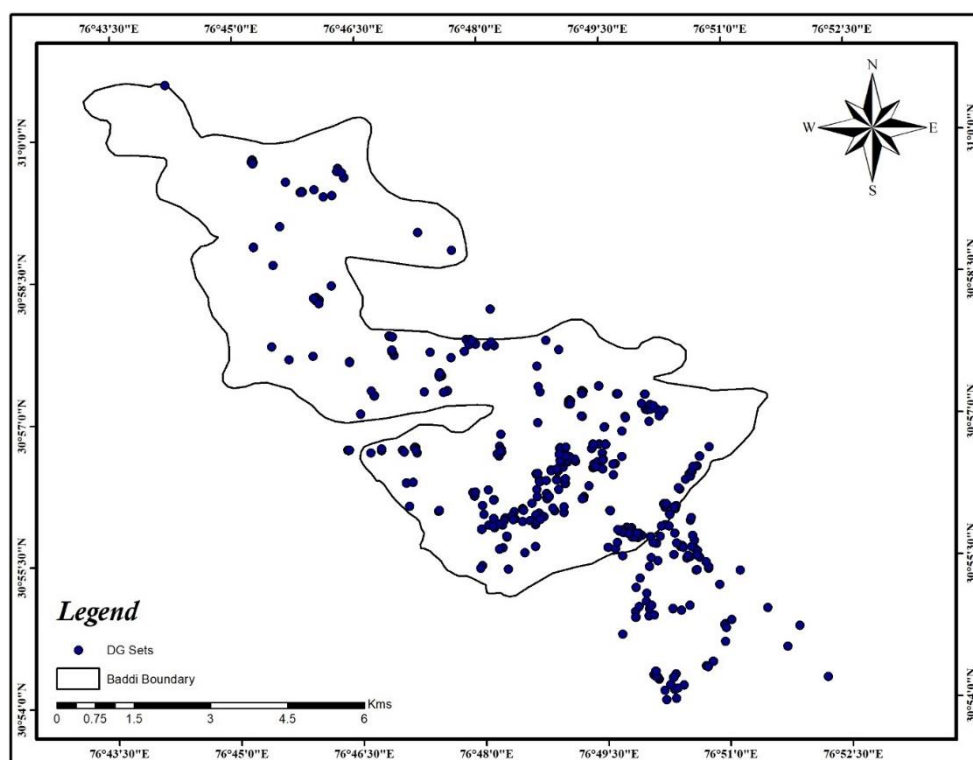
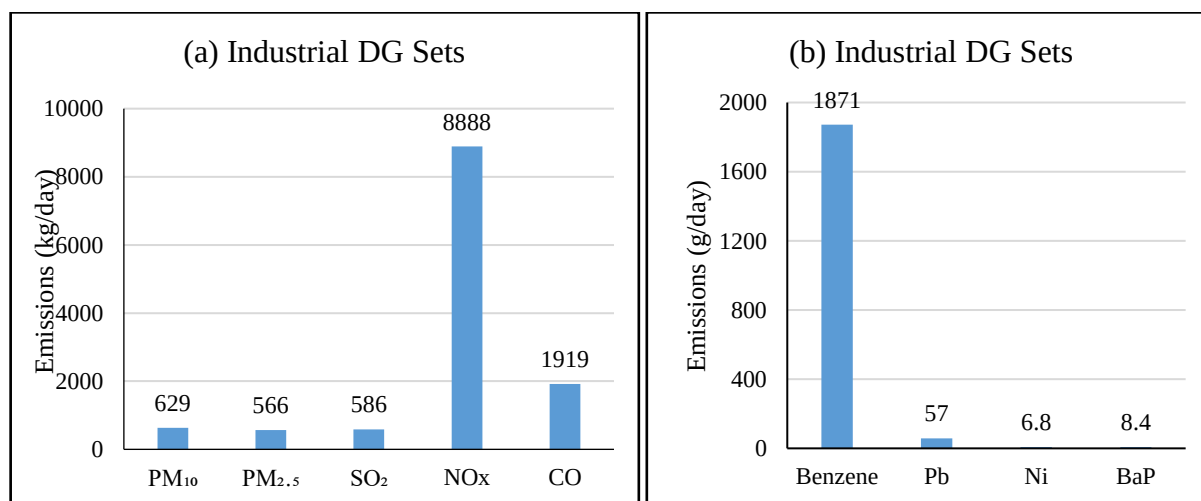


Figure 4.31: Location of Industrial DG Sets



a) PM and Gaseous Emission in kg/day

b) Pollutant Emission Load in g/day

Figure 4.32: Emission Load from Industrial DG sets

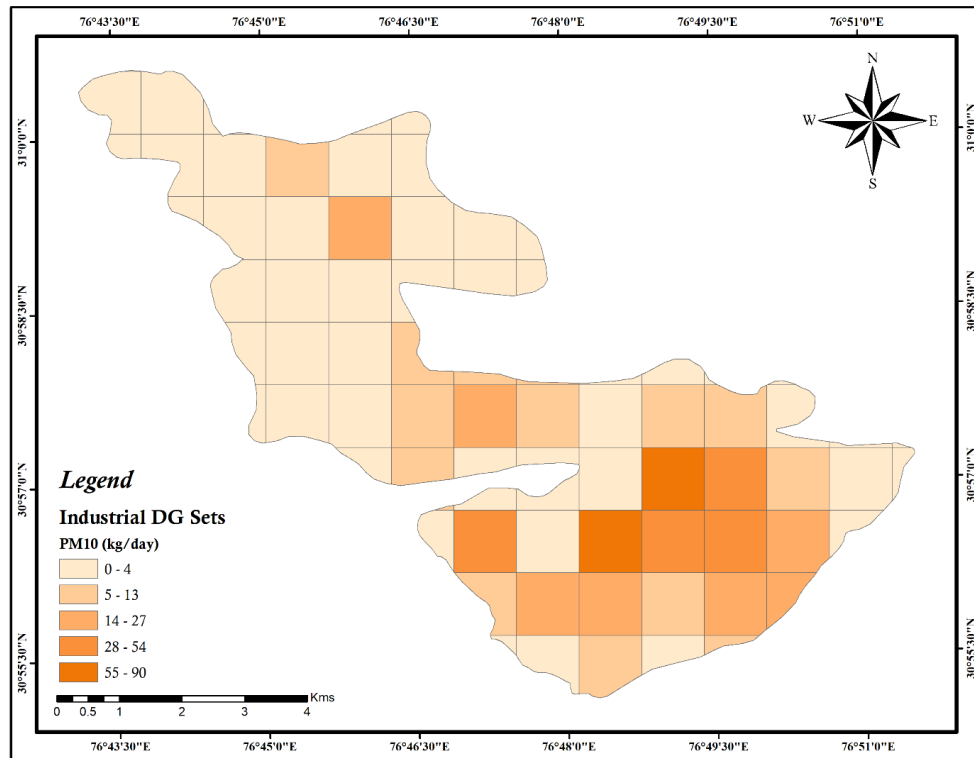


Figure 4.33: Spatial Distribution of PM₁₀ Emissions from Industrial DG sets

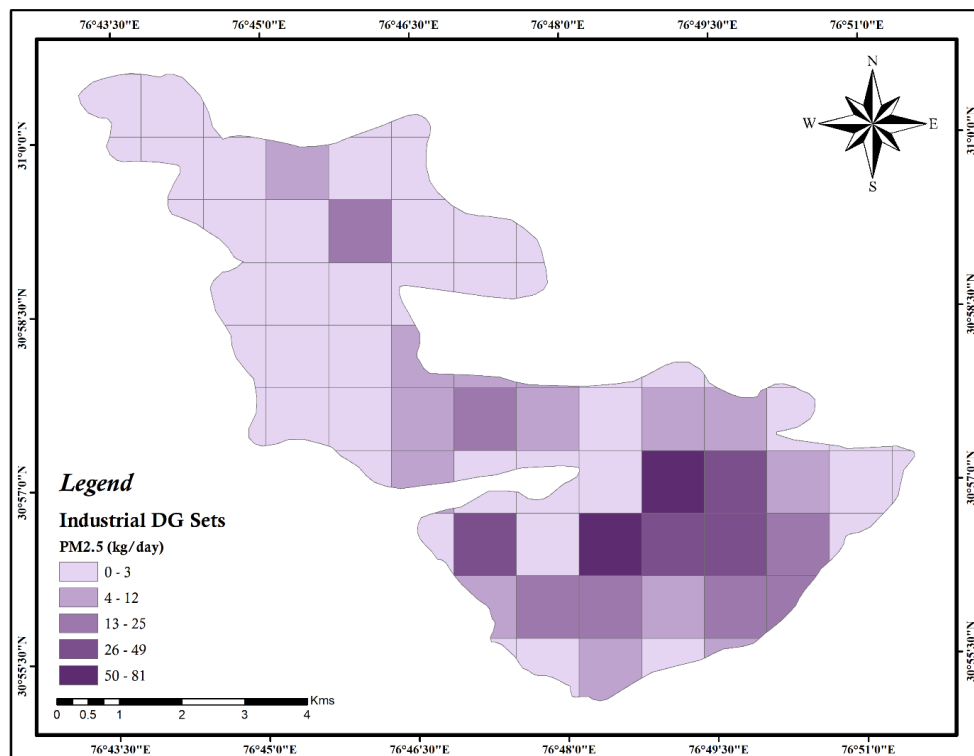


Figure 4.34: Spatial Distribution of PM_{2.5} Emissions from Industrial DG sets

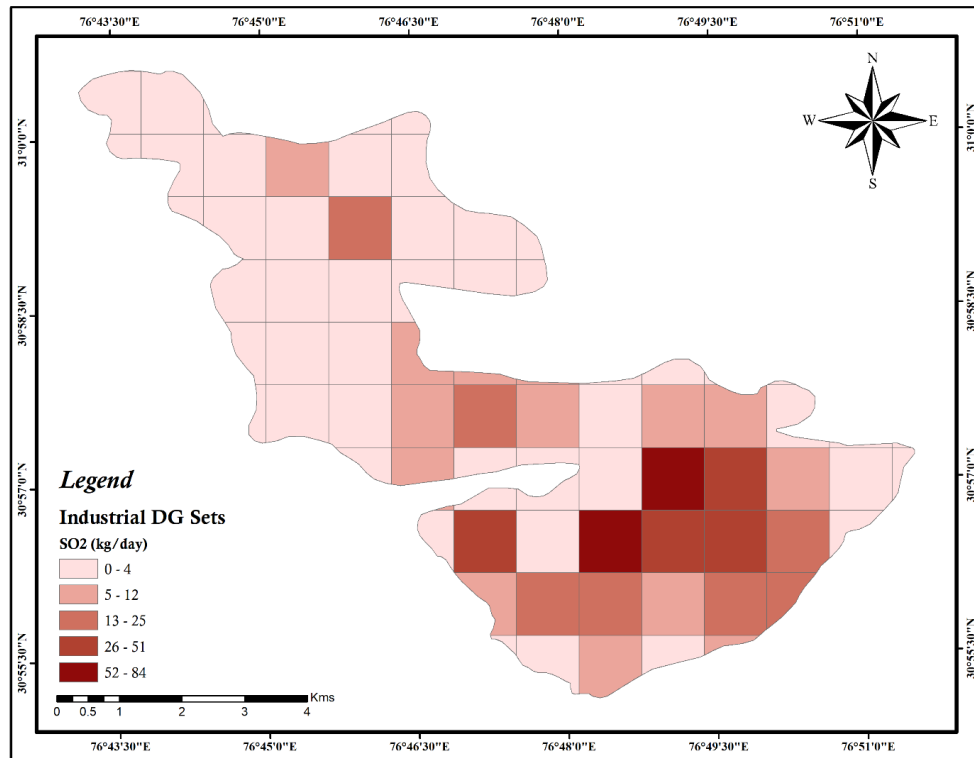


Figure 4.35: Spatial Distribution of SO₂ Emissions from Industrial DG sets

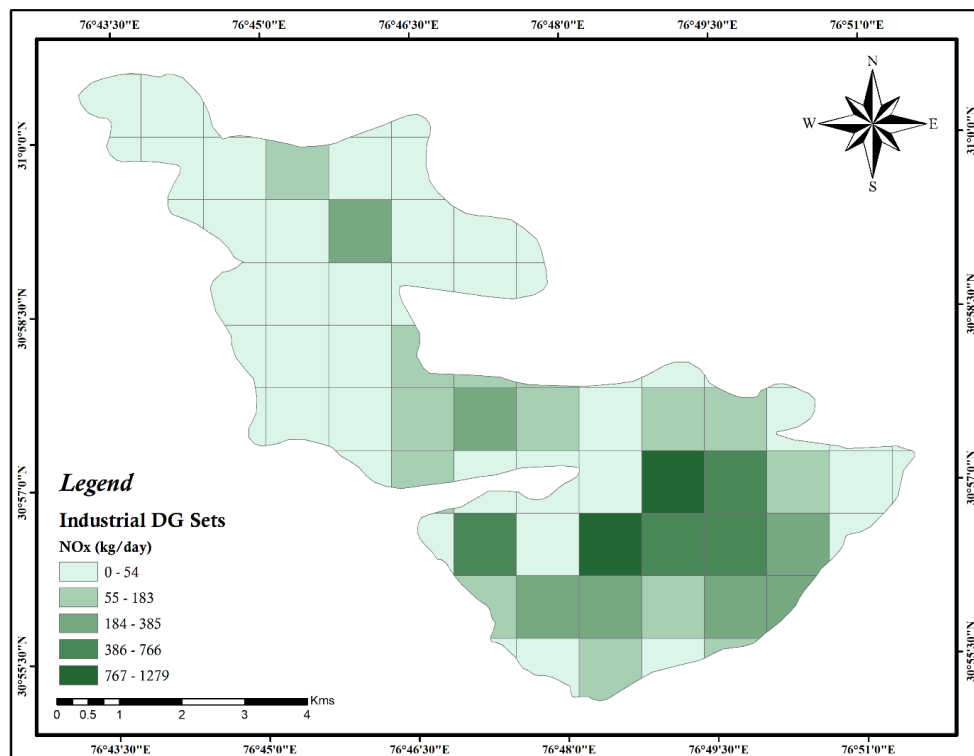


Figure 4.36: Spatial Distribution of NO_x Emissions from Industrial DG sets

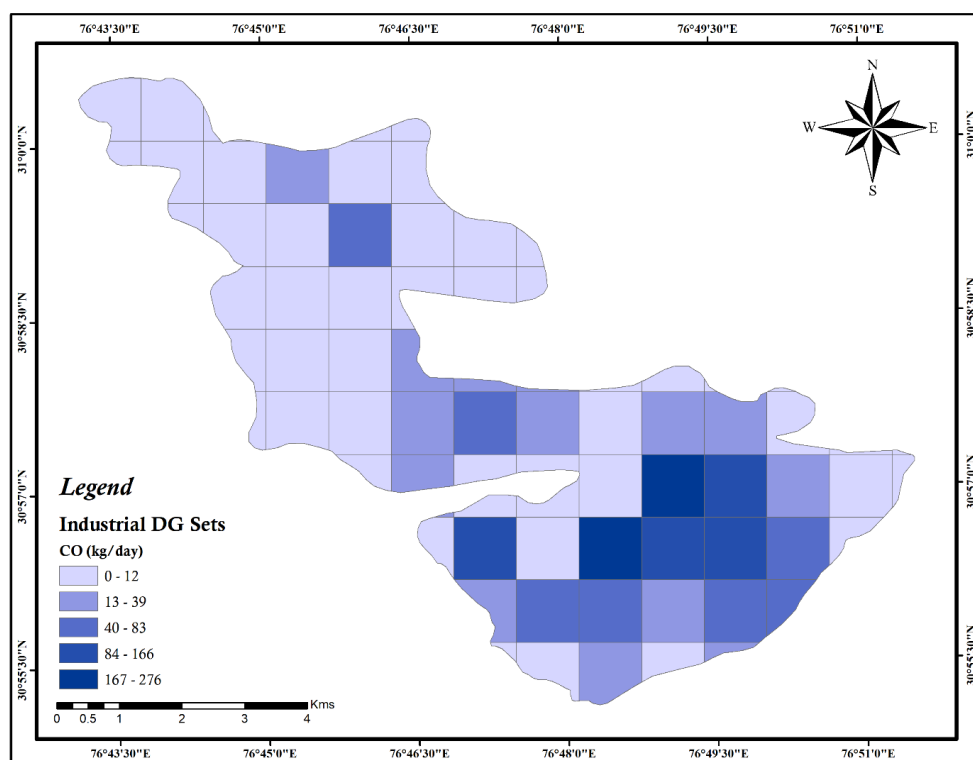


Figure 4.37: Spatial Distribution of CO Emissions from Industrial DG sets

4.2.8 Hotels, Restaurants, Guest Houses (GHs), and Banquet Halls (BHs)

The primary survey was conducted by the IITK team to identify the hotels and restaurants with more than the sitting capacity of ten persons and other eating joints.

During the field survey, it was observed that hotels, restaurants, etc use coal as fuel in tandoors. The total number of Hotels, Restaurants, Guest Houses (GHs), and Banquet Halls (BHs) is found to be approximately 50 (Figure 4.38). It was observed that coal/wood is being used as fuel in the tandoor, the common fuel other than wood is LPG. The average consumption of wood/coal in each establishment is estimated to be 30 kg per day based on a primary survey. The fuel consumption for each fuel type was estimated for each grid. In most of the cases, it was found that there were no control devices installed during these activities. The emissions of various parameters such as PM_{10} , $PM_{2.5}$, SO_2 , NO_x , and CO were estimated from the activity data from each fuel type and then summed up in each grid cell. The overall emission from this area source (Hotels, Restaurants, GHs, and BHs) is shown in Figure 4.39 (a) & (b). The spatial distribution of emissions from Hotels, Restaurants, Guest Houses (GHs), and Banquet Halls (BHs) lying within the boundary is shown in Figure 4.40 to Figure 4.44.

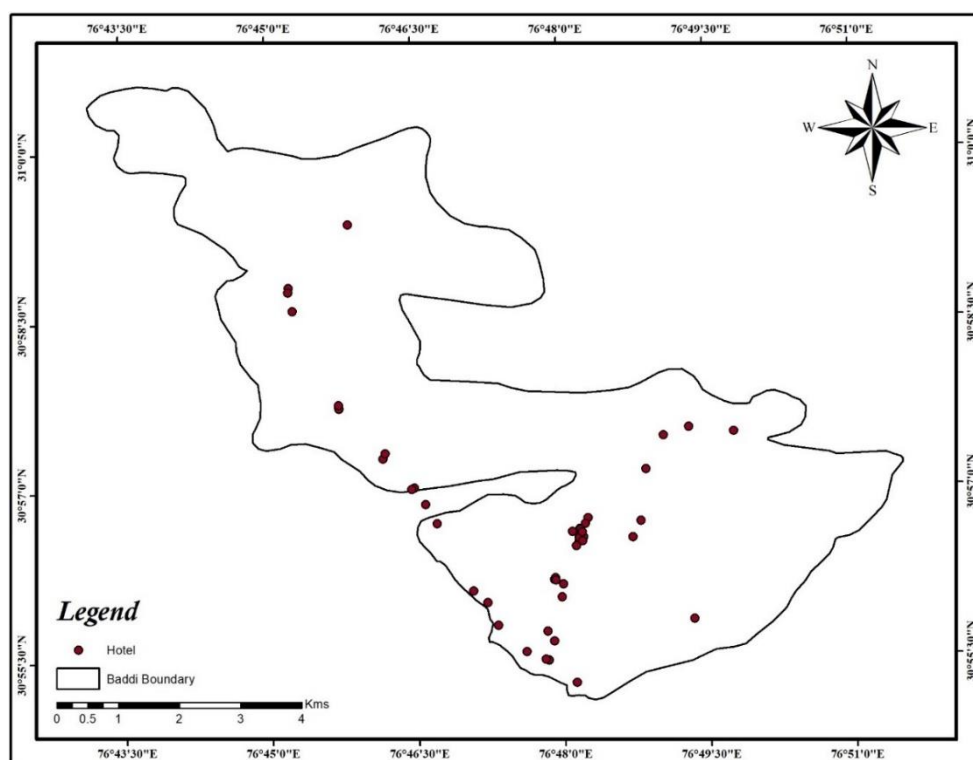
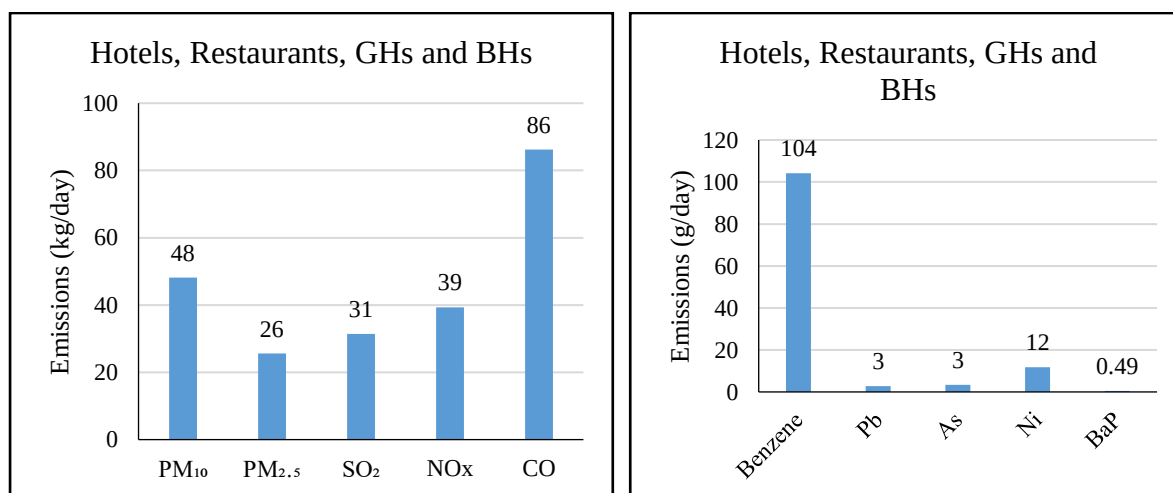


Figure 4.38: Location of Hotels, Restaurants, GHs and BHs



a) PM and Gaseous Emission in kg/day b) Other Pollutants Emission in g/day

Figure 4.39: Emission Load from Hotels, Restaurants, GHs and BHs

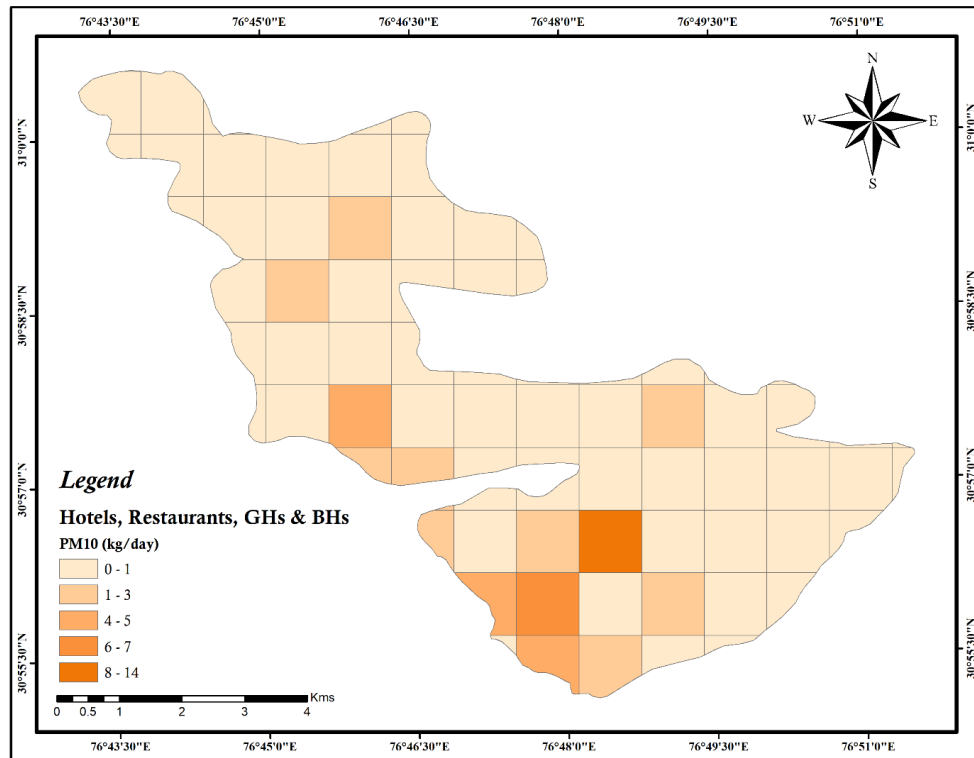


Figure 4.40: Spatial Distribution of PM₁₀ Emissions from Hotels, Restaurants, GHs and BHs

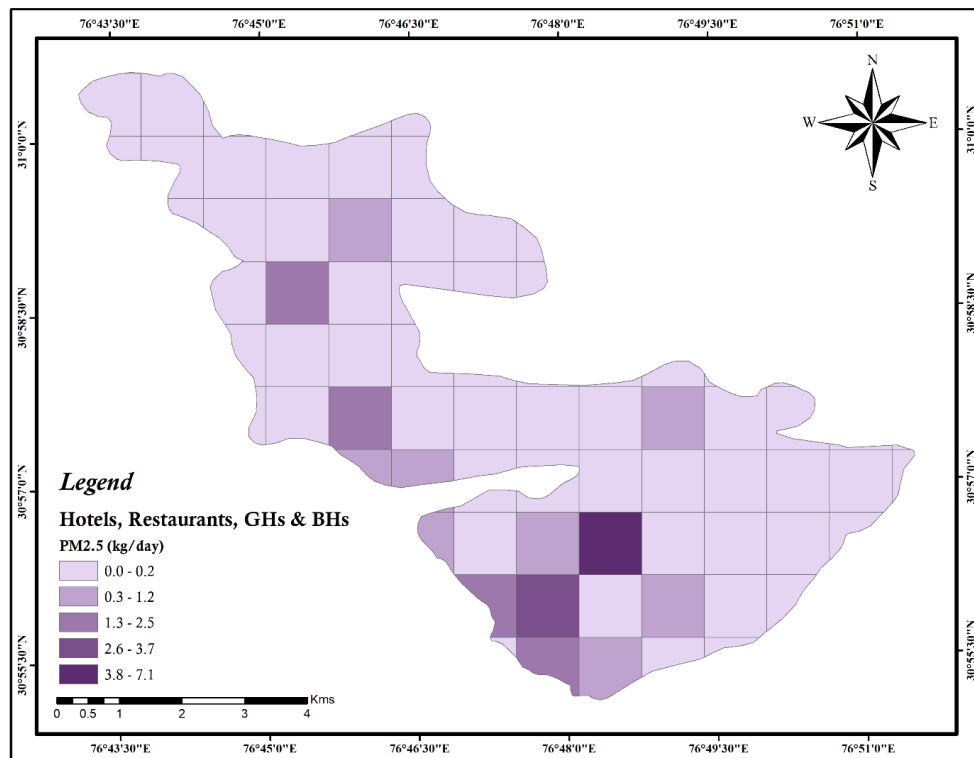


Figure 4.41: Spatial Distribution of PM_{2.5} Emissions from Hotels, Restaurants, GHs and BHs

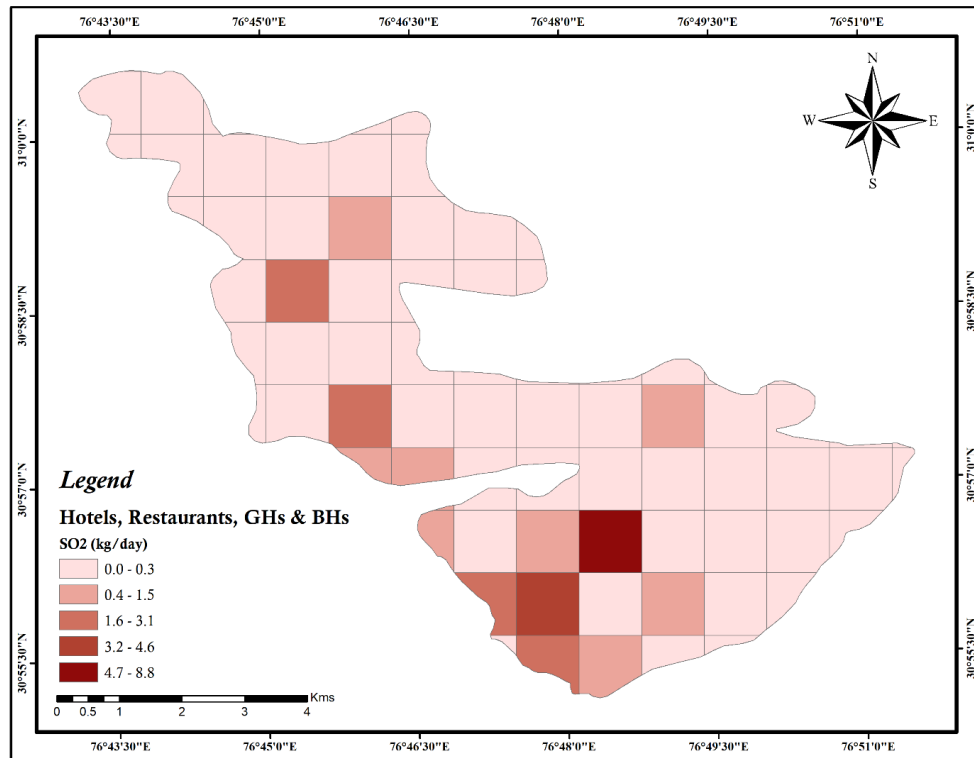


Figure 4.42: Spatial Distribution of SO₂ Emissions from Hotels, Restaurants, GHs and BHs

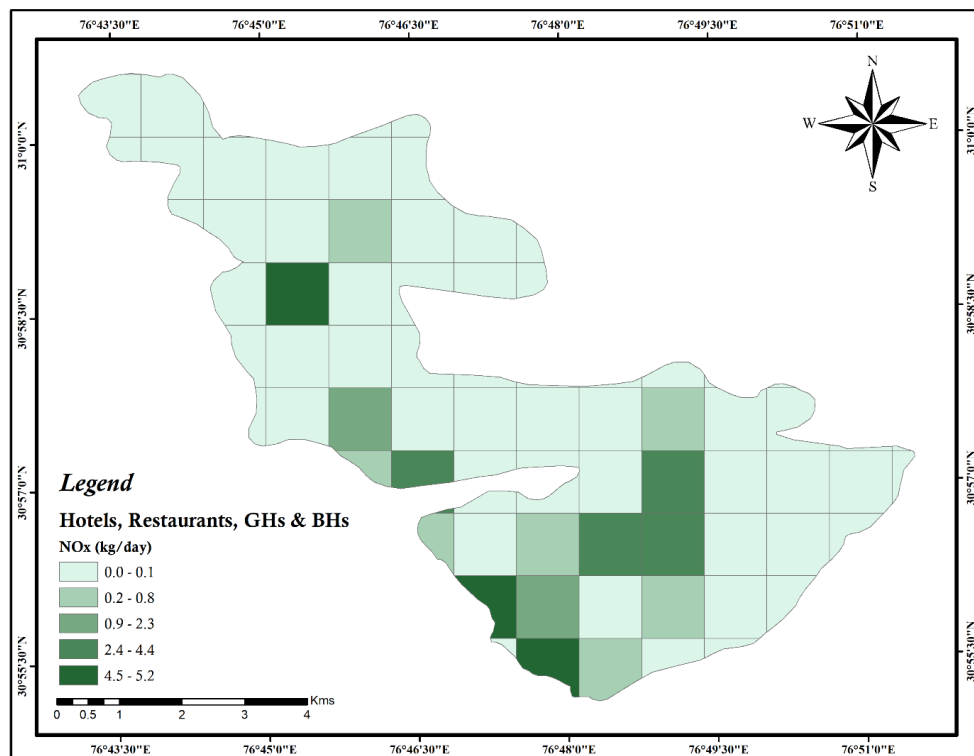


Figure 4.43: Spatial Distribution of NO_x Emissions from Hotels, Restaurants, GHs and BHs

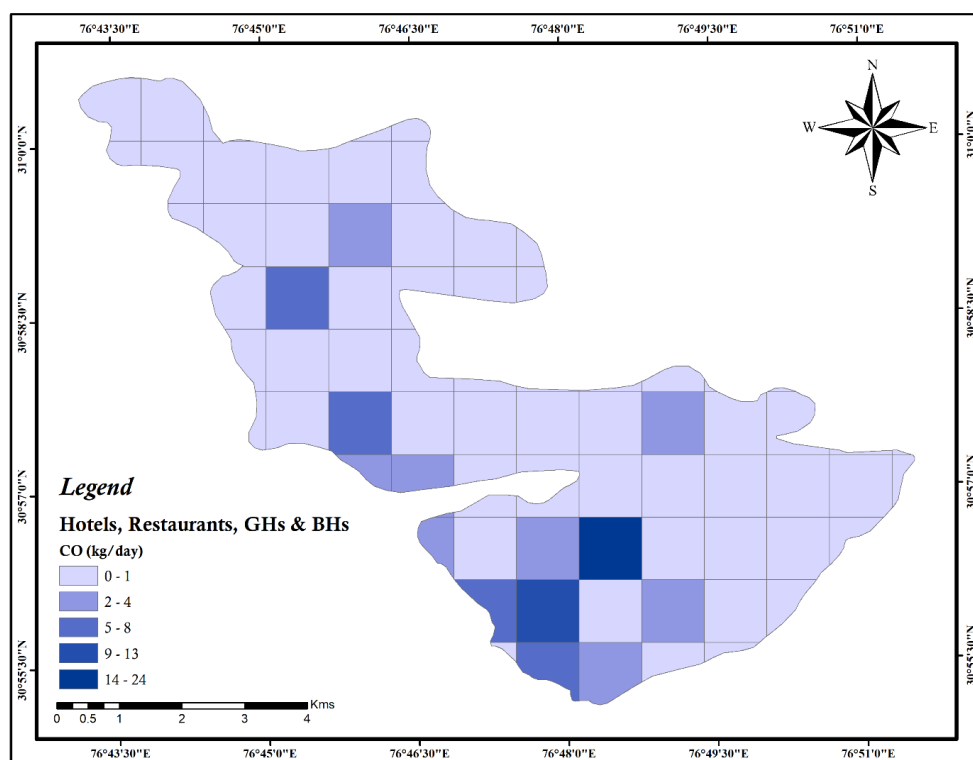


Figure 4.44: Spatial Distribution of CO Emissions from Hotels, Restaurants, GHs and BHs

4.2.9 Brick Kilns

Brick kilns are one of the air-polluting sources. It is important to cover this sector in terms of emissions, although the majority of brick kilns lie outside the city boundary. These brick kiln (outside the city boundary) affects the local air quality of the city. A detailed survey was conducted by the IITK team and activity data were collected. There are approximately 12 brick kilns present in Baddi (Figure 4.45). Some brick kilns were present just at the border of the city, we have also accounted for these brick kilns as well, in the present study. This kiln uses wood and coal as fuel. The emissions of various parameters such as PM_{10} , $PM_{2.5}$, SO_2 , NO_x , and CO were estimated from the activity data from each fuel type and then summed up in each grid cell. The emission factors given by CPCB (2011) were used. The overall emission from brick kilns is shown in Figure 4.46 (a) & (b). The spatial distribution of emissions from brick kilns lying within the boundary is shown in Figure 4.47 to Figure 4.51.

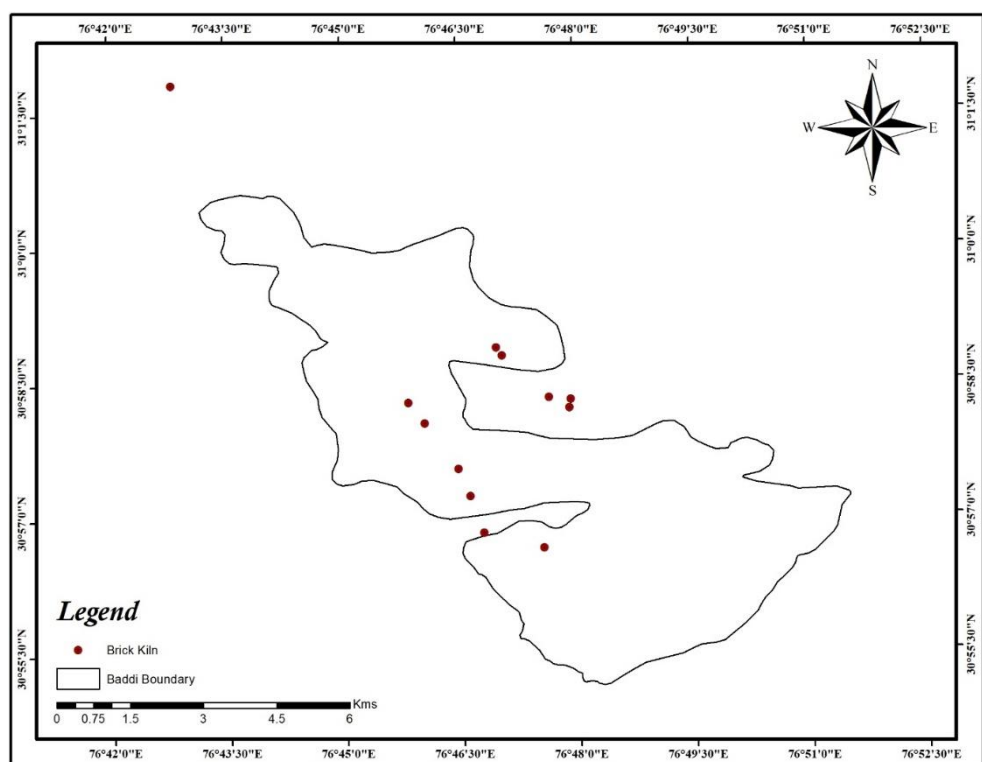
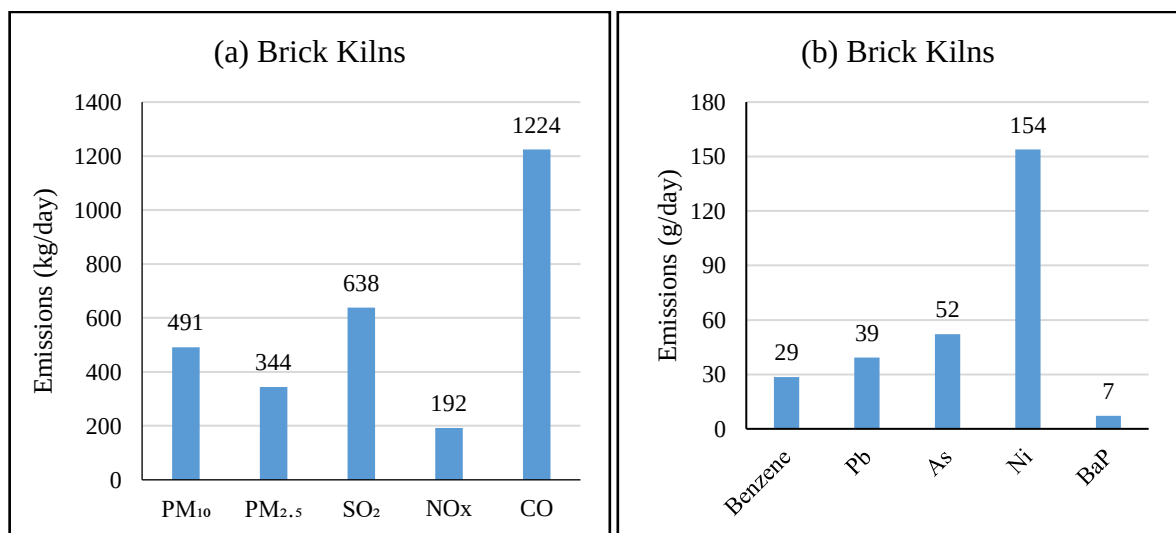


Figure 4.45: Location of Brick kilns in Baddi



(a) PM and Gaseous Emission in kg/day (b) Other Pollutants Emission in g/day

Figure 4.46: Emission Load from Brick kilns

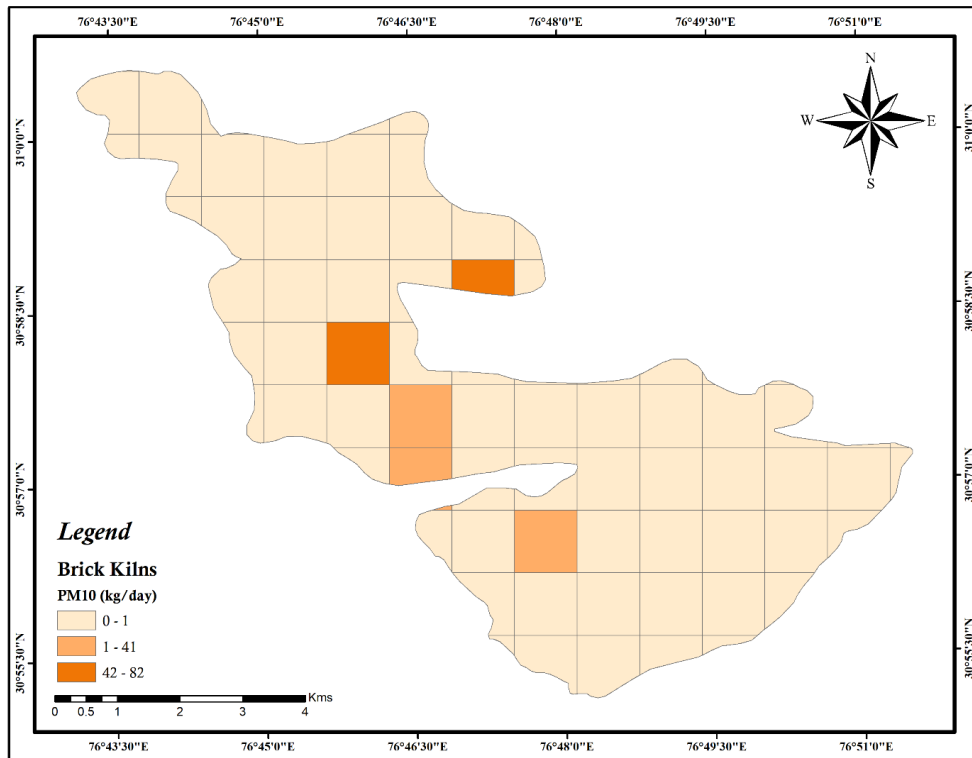


Figure 4.47: Spatial Distribution of PM₁₀ Emissions from Brick kilns

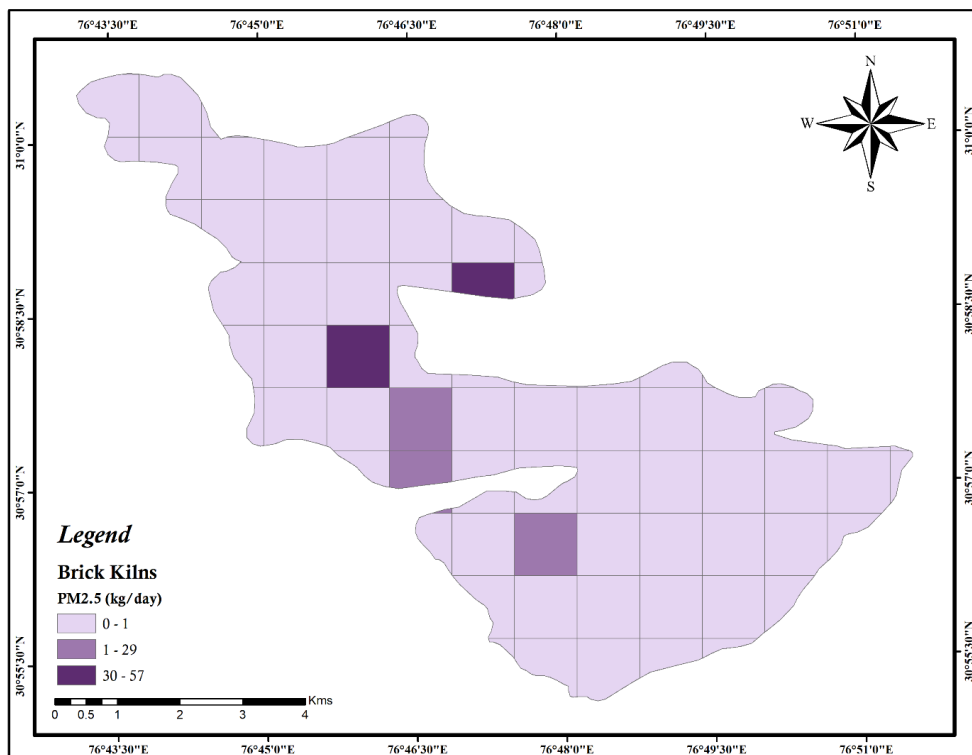


Figure 4.48: Spatial Distribution of PM_{2.5} Emissions from Brick kilns

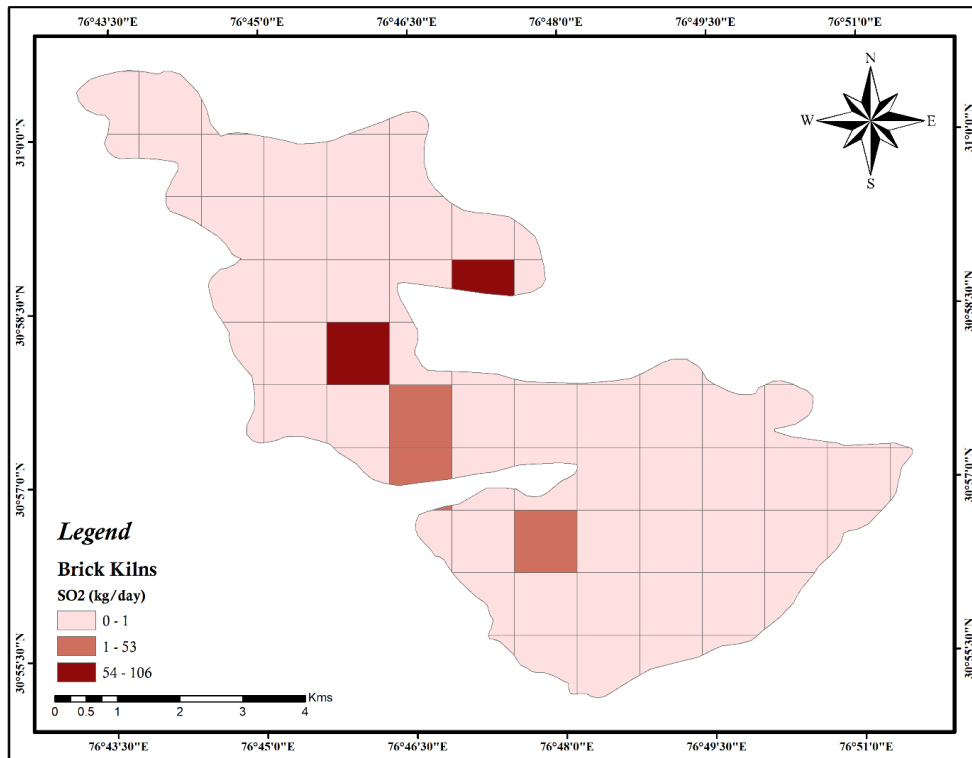


Figure 4.49: Spatial Distribution of SO₂ Emissions from Brick kilns

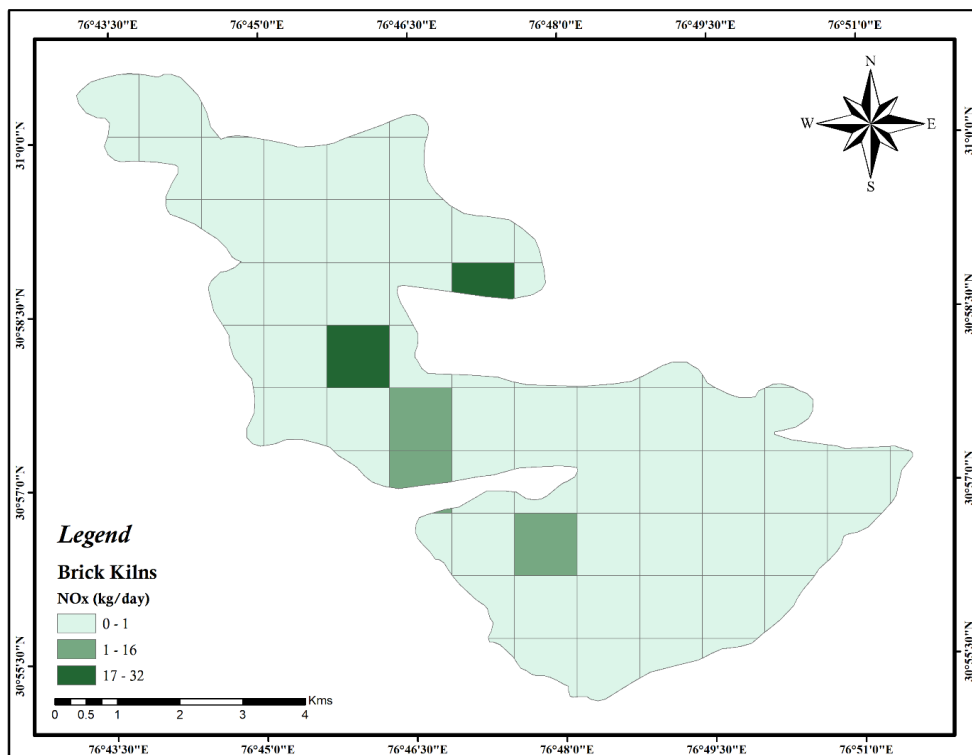


Figure 4.50: Spatial Distribution of NO_x Emissions from Brick kilns

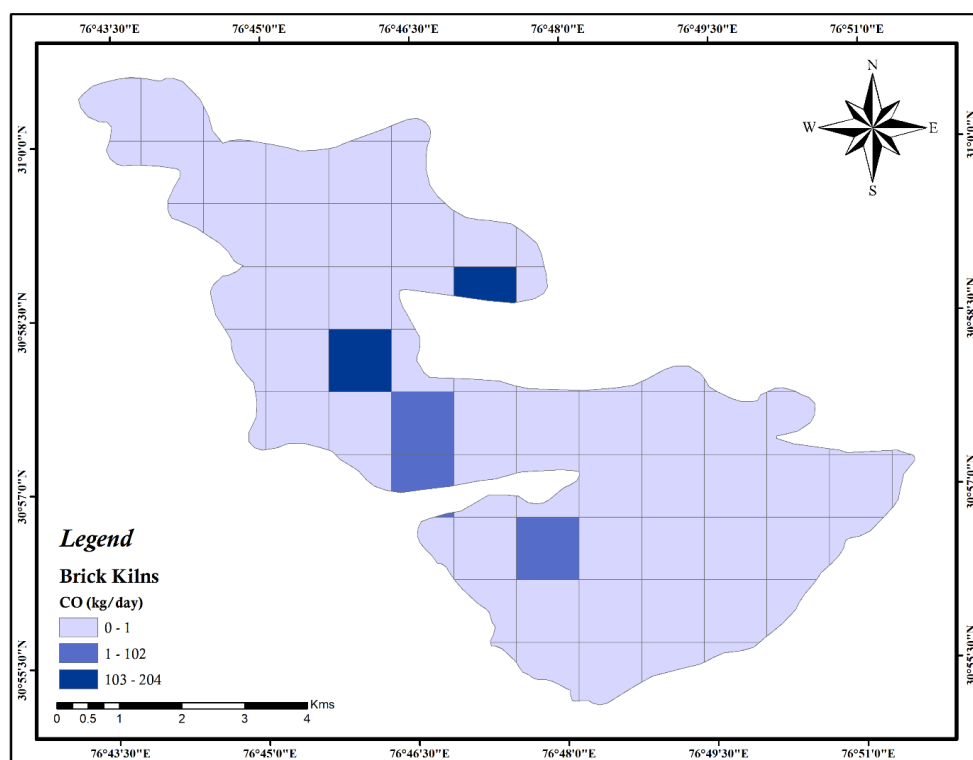


Figure 4.51: Spatial Distribution of CO Emissions from Brick kilns

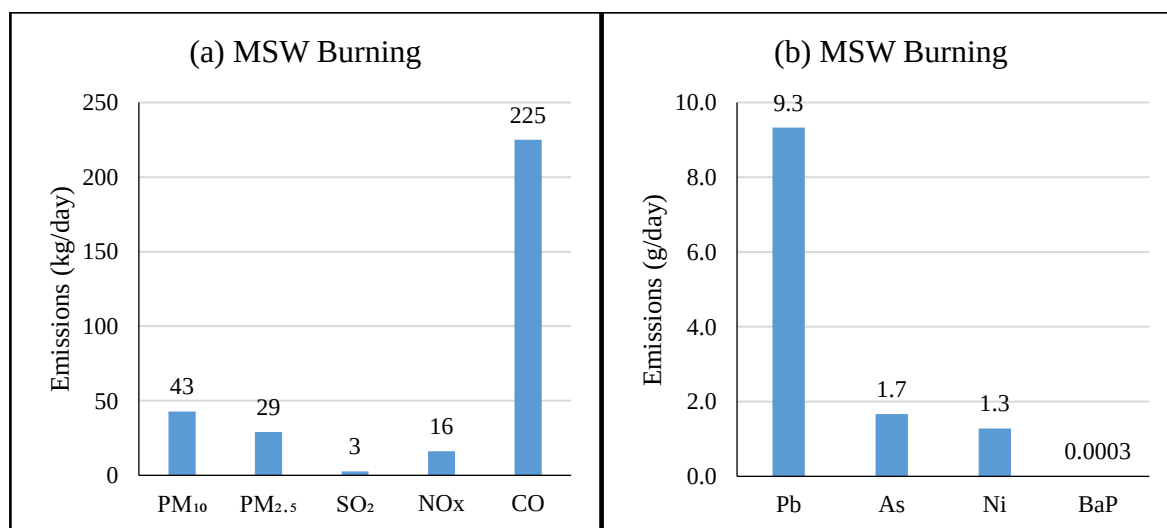
4.2.10 Municipal Solid Waste Burning

Open burning activities are broadly classified into refuse and biomass burning. The refuse or municipal solid waste (MSW) burning depends on solid waste generation and the extent of disposal and infrastructure for collection. The Solid waste generation is around 13.5 MT/day and the waste collected is approx. 8.1 MT/day. This emission is expected to be large in the regions of economically lower strata of the society which do not have proper infrastructure for collection and disposal of MSW. The MSW collection efficiency is 60% in Baddi city (Anchal Sharma, 2018), and several events of MSW burning have been observed during the city survey. The survey was conducted on weekdays and weekends and the frequency of MSW events is calculated in the low-, middle- and higher-income areas. The MSW burning at different locations in Baddi city is shown in Figure 4.52.



Figure 4.52: MSW Burning in several parts of Baddi city

The emission factors are given by CPCB (2011) and AP-42 (USEPA, 2000) were used for estimating the emission from MSW burning using the same procedure of emission density in a ward or village. The emissions from MSW burning are presented in Figure 4.53 (a) & (b) and spatial distribution in Figure 4.54 to Figure 4.58.



a) PM and Gaseous Emission in kg/day

b) Other Pollutants Emission in g/day

Figure 4.53: Emission Load from MSW Burning

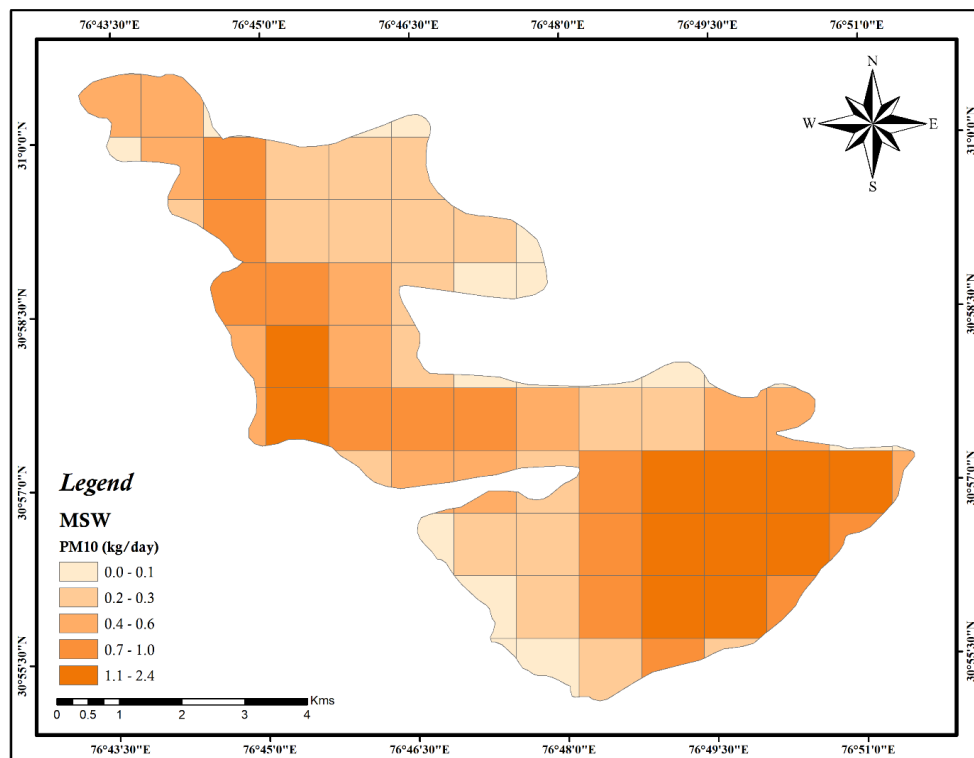


Figure 4.54: Spatial Distribution of PM₁₀ Emissions from MSW Burning

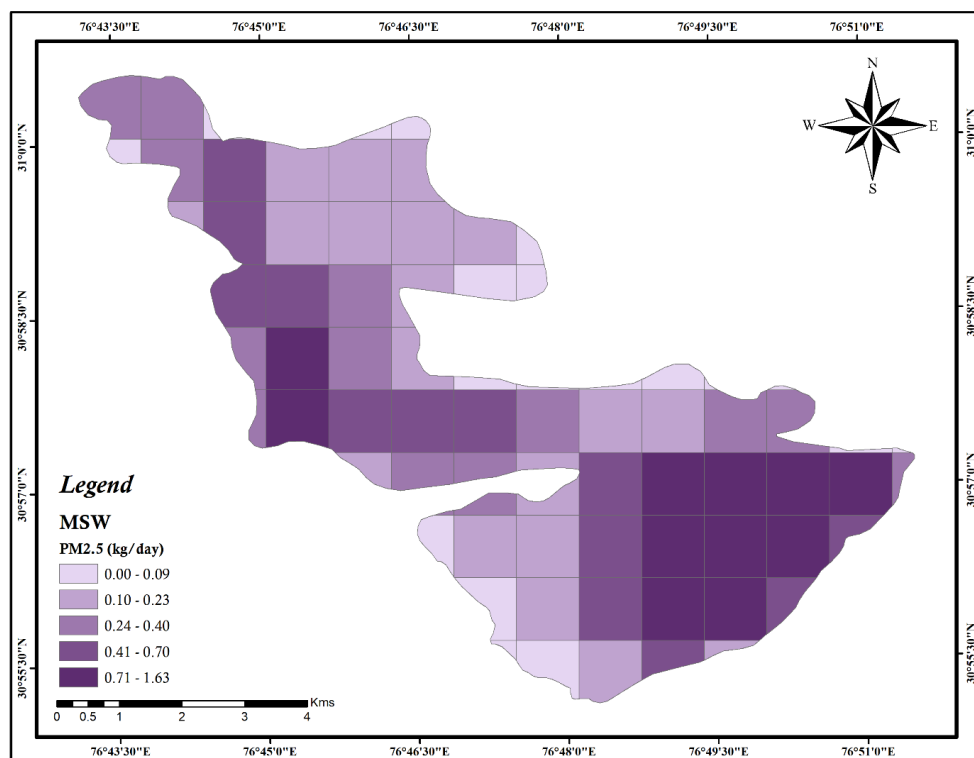


Figure 4.55: Spatial Distribution of PM_{2.5} Emissions from MSW Burning

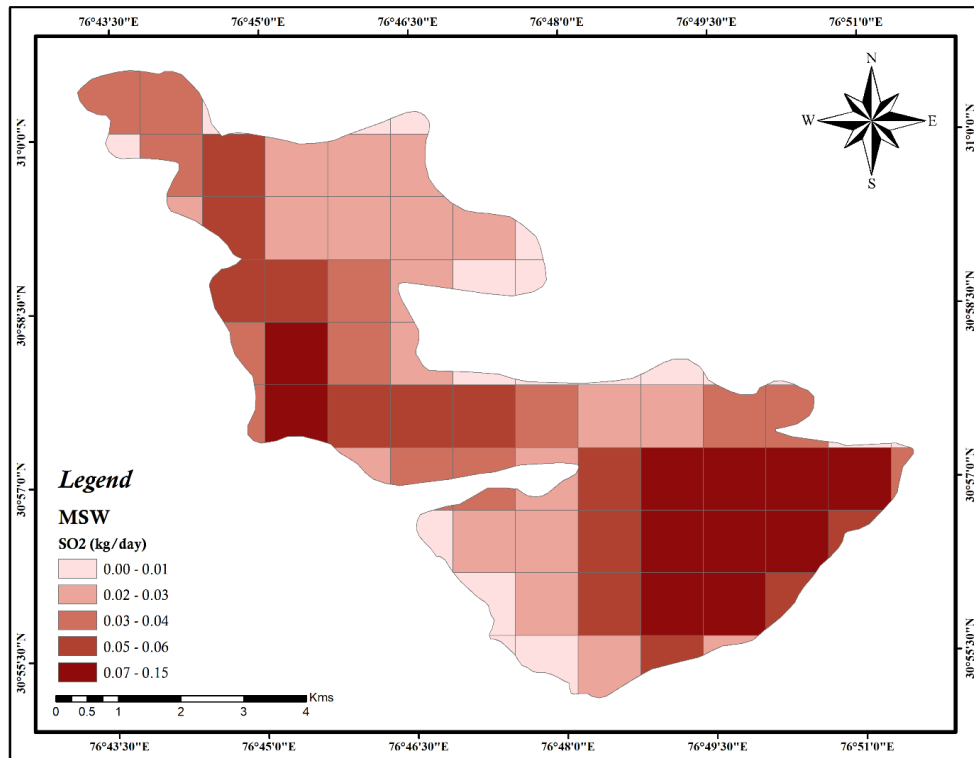


Figure 4.56: Spatial Distribution of SO₂ Emissions from MSW Burning

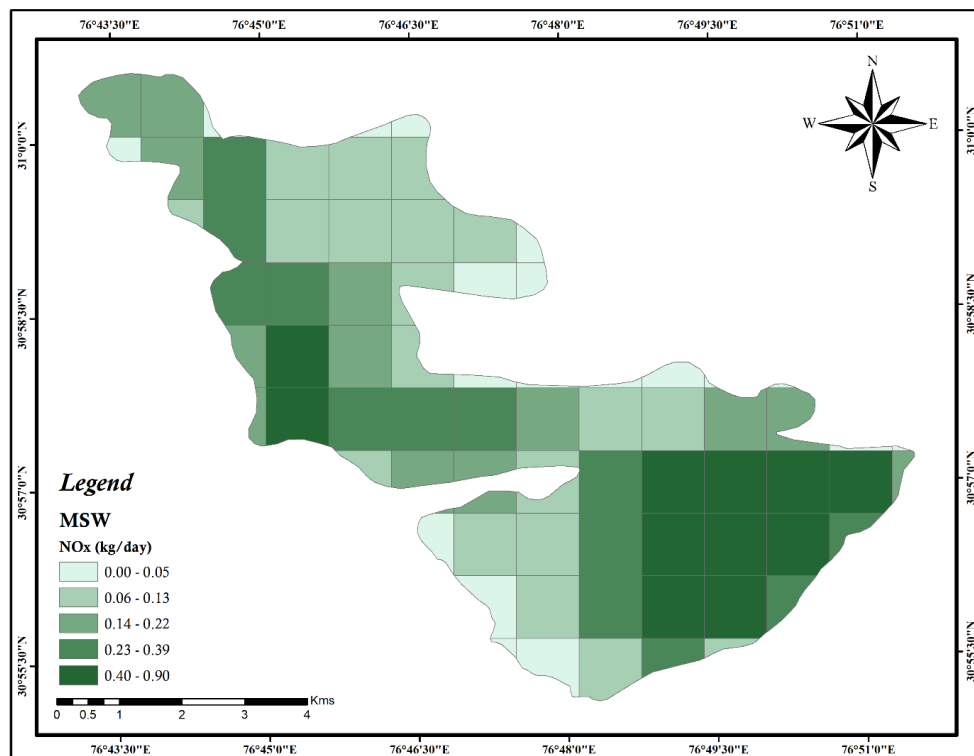


Figure 4.57: Spatial Distribution of NO_x Emissions from MSW Burning

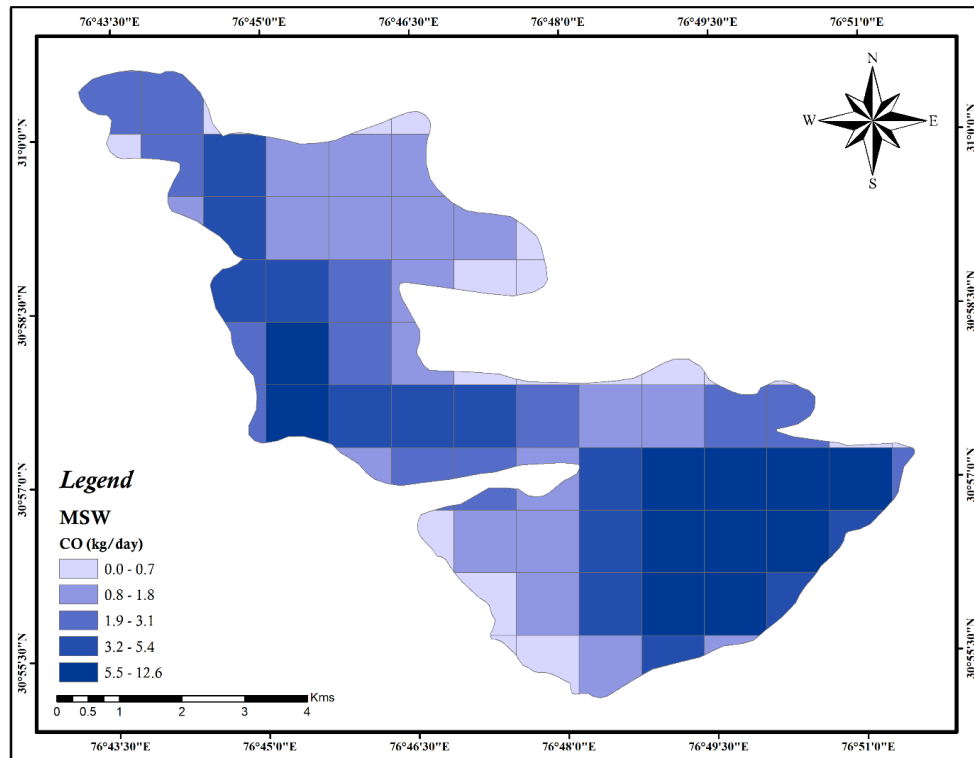


Figure 4.58: Spatial Distribution of CO Emissions from MSW Burning

4.2.11 Hospitals

A detailed survey was undertaken to estimate the emission from hospitals in Baddi City. There are approximately 39 hospitals present in the city. The locations of Hospitals in Baddi are given in Figure 4.59. The emission of pollutants from hospitals is shown in Figure 4.60 (a) & (b). The overall emissions from hospitals along with their average DG set capacity and running hours are presented in Table 4.1.

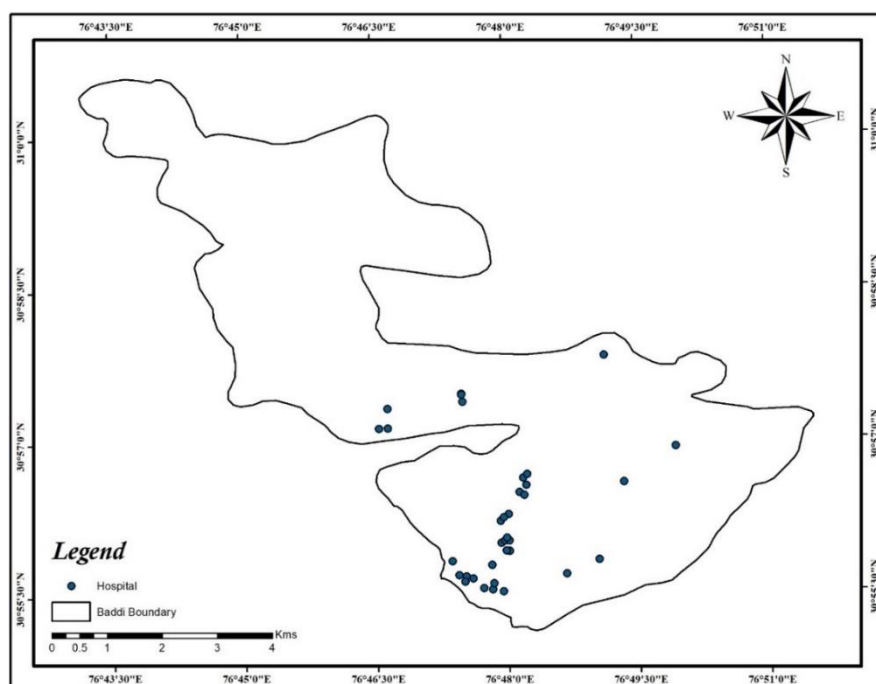
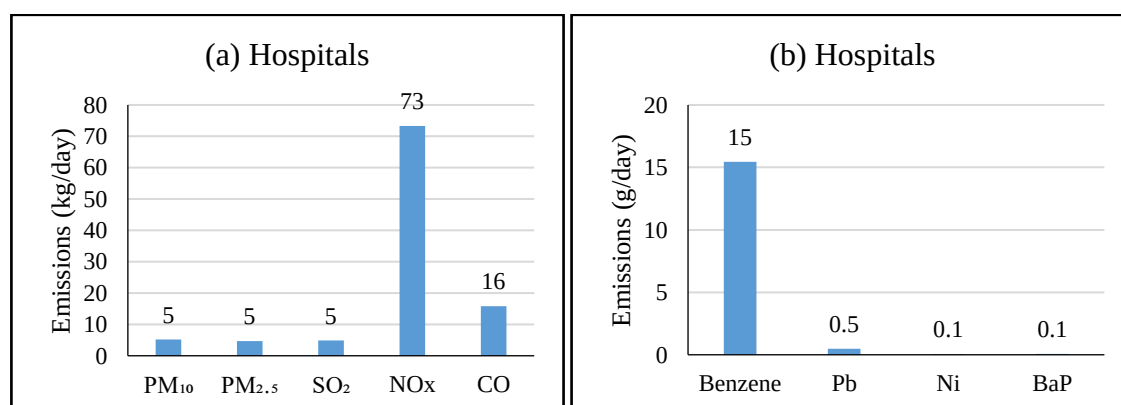


Figure 4.59: Locations of Hospitals in Baddi City

Table 4.1: Hospitals Details in Baddi city (emissions in kg/day and g/day)

No. of Hospitals	DG set Average Capacity		PM ₁₀	PM _{2.5}	SO ₂	NO _x	CO	Benzene	Pb	As	Ni	BaP
	KVA	Running Hour	(kg/d)	(kg/d)	(kg/d)	(kg/d)	(kg/d)	(g/d)	(g/d)	(g/d)	(g/d)	(g/d)
39	62.5	2	5	5	5	73	16	15.4	0.47	0	5.6 $\times 10^{-2}$	6.91 $\times 10^{-2}$

Data Source: Consent Data



a) PM and Gaseous Emission in kg/day b) Other Pollutants Emission in g/day

Figure 4.60: Emission Load from Hospitals

4.2.12 Industries

There are approximately 299 industrial units in Baddi City (Table 4.2) having boilers and furnaces (electric and melting furnaces) and other air-polluting units out of 428 industrial units (as per consent data), that contribute to particulate as well as gaseous emissions. Major fuels that contribute to emissions are HSD, F.O., Wood, Pet coke, Rice Husk, Bio-Fuel, Diesel, and Electricity. The industrial locations are given in Figure 4.61. The information on stacks, fuel, and their consumption was obtained from HPSPCB. The AP-42 (USEPA, 2000) emission factors were used to calculate the emission. For further analysis, the industries are categorized based on stack height as an area source (stack height < 20 m) and as a point source (stack height > 20 m).

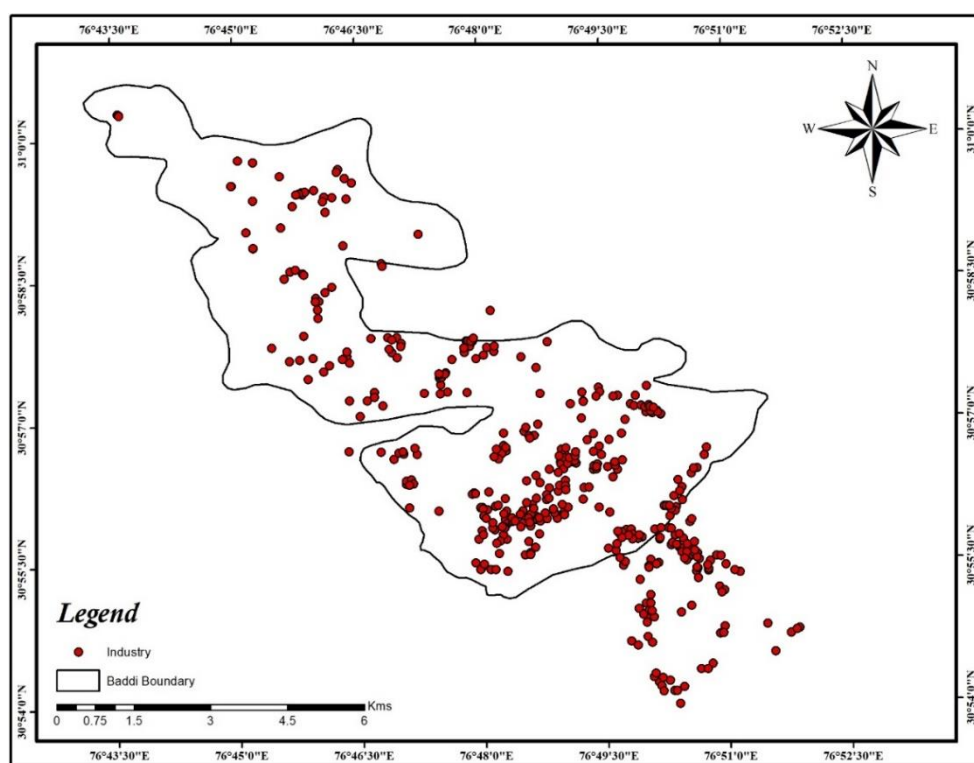


Figure 4.61: Location of Industries in Baddi city

Table 4.2: Furnace/Boiler Details in Baddi city (emissions in kg/day and g/day)

Boiler/Furnace Type	Fuel	No of Furnaces / Boilers	PM₁₀ (kg/d)	PM_{2.5} (kg/d)	SO₂ (kg/d)	NOx (kg/d)	CO (kg/d)	Benzene (g/d)	Pb (g/d)	As (g/d)	Ni (g/d)	BaP (g/d)
Baby Boiler	HSD, F.O.	27	17	15	72	46	153	19	0.36	1.84 x10 ⁻²	0.04	0.1
Boiler	HSD, F.O., Wood, Pet-coke, Rice Husk, Bio-Fuel, Diesel, Electricity	227	2402	2161	3417	2648	38016	449	3.59	0.45	0.27	1.75
Comblock Thermax	F.O.	1	0.01	0.01	8	2	0.15	0	0	0	0	0
Fire Tube Boiler	HSD	6	0.4	0.4	26	16	1.4	7.4	2.54 x10 ⁻³	0	3.02 x10 ⁻⁴	3.72 x10 ⁻²
Fluid Heater	Coal, HSD, F.O.	2	0.05	0.04	0.60	0.84	0.08	0.51	4.42 x10 ⁻³	0	5.25 x10 ⁻⁴	2.54 x10 ⁻³
Furnace	F.O., HSD, Electricity, Coal	8	6	5	160	36	4	1.79	1.13 x10 ⁻²	5.85 x10 ⁻⁵	1.33 x10 ⁻³	7.99 x10 ⁻³
Heater	F.O., Coal	3	18	16	110	67	2	3.3	9.48 x10 ⁻²	3.16 x10 ⁻²	0	8.73 x10 ⁻⁴
Induction Furnace	Electricity	6	0.4	0.3	11	2	0.2	0	0	0	0	0
Non-IBR	Pet Coke	2	0.1	0.1	0.8	1.1	0.1	0.63	6.43 x10 ⁻⁴	2.14 x10 ⁻⁴	0	2.57 x10 ⁻⁵
Steam Boiler	HSD, Wood, Pet coke	5	23	21	55	70	251	11.7	0.06	6.11 x10 ⁻⁴	6.78 x10 ⁻³	6.24 x10 ⁻²
Thermic Fuel Heater	Rice Husk	7	267	240	6	24	2818	0	0	0	0	0
Thermopack (Heater)	Pet Coke	1	0.3	0.3	27	32	0.7	0	0	0	0	0
Uncategorized Heaters/ Boilers	Wood, Electricity	4	0.9	0.8	0.02	0.13	13	0	4.67 x10 ⁻³	1.56 x10 ⁻³	0	1.87 x10 ⁻⁴
Total		299	2734	2461	3894	2945	41259	494	4.12	0.5	0.31	1.96

Data Source: Consent Data

Industries as Area Source

Figure 4.62 (a) & (b) presents the overall emissions from industries (stack height < 20 m) as an area source. There are around 159 industrial units categorized as area source in Baddi city. The boiler/baby boilers are majorly falling under this category. The spatial distribution of industries (area source) lying within the boundary is shown in Figure 4.63 to Figure 4.67.

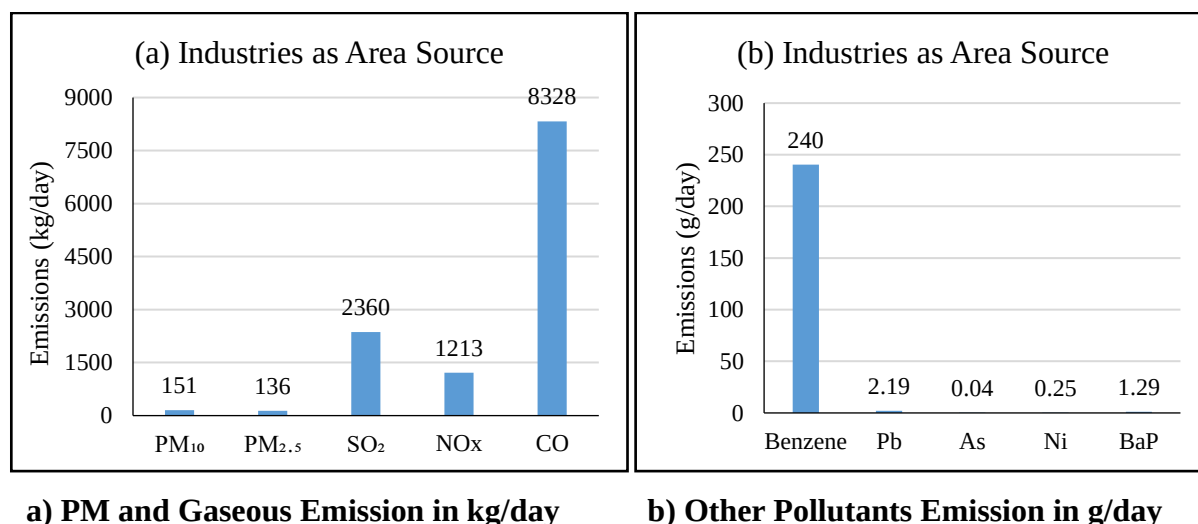


Figure 4.62: Emission Load from Industries as Area Source

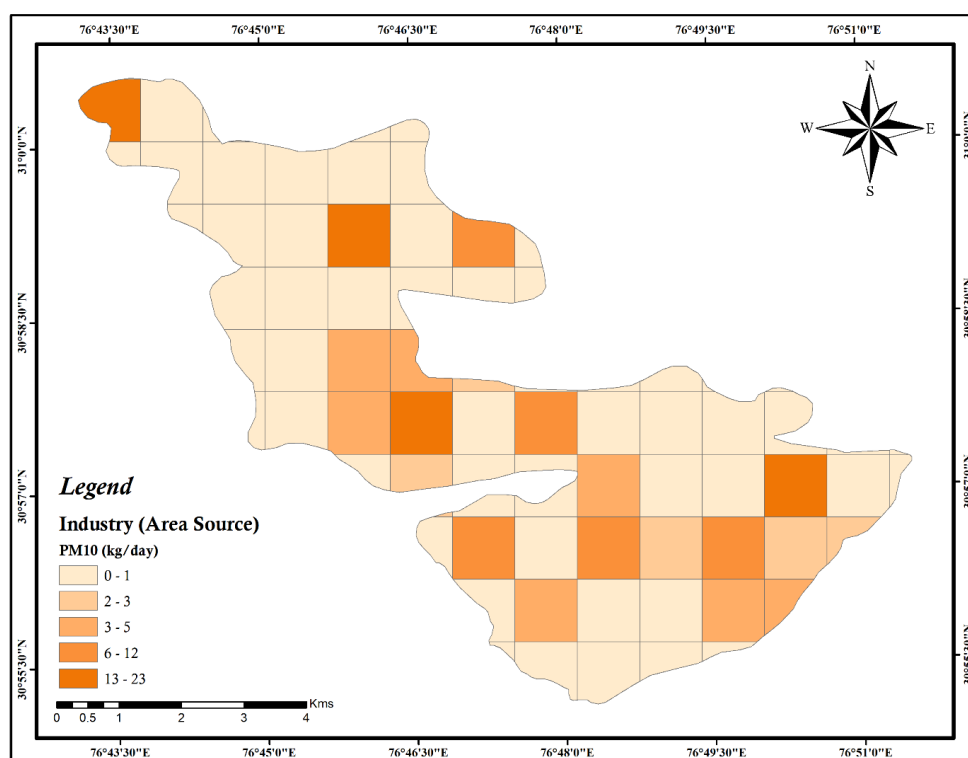


Figure 4.63: Spatial Distribution of PM₁₀ Emissions from Industries as area source

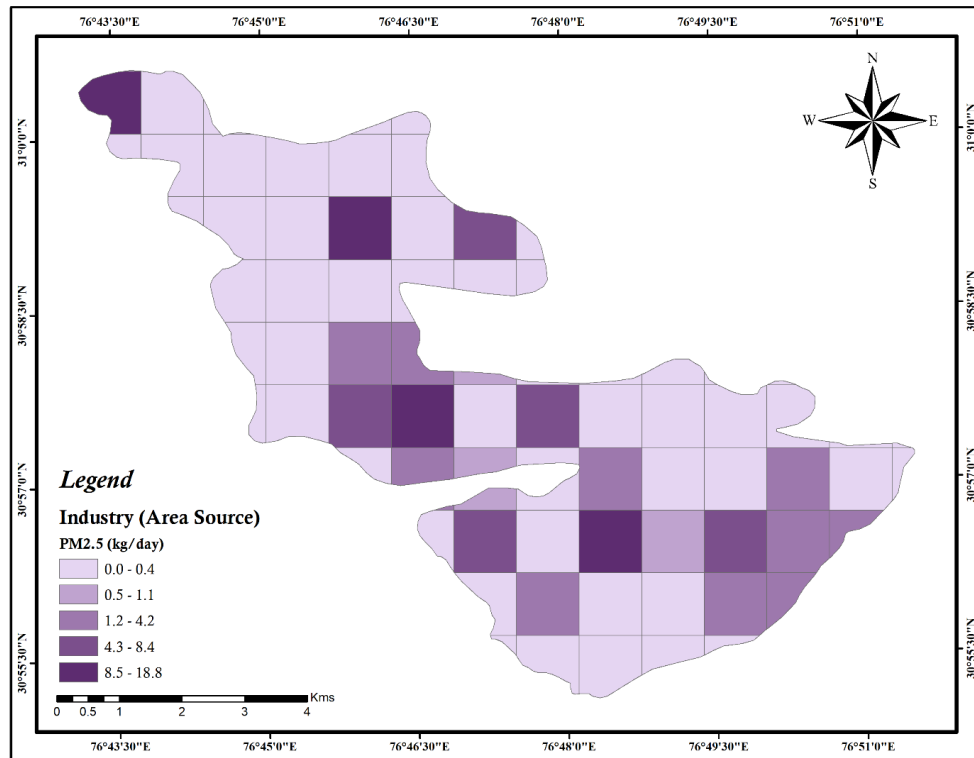


Figure 4.64: Spatial Distribution of PM_{2.5} Emissions from Industries as area source

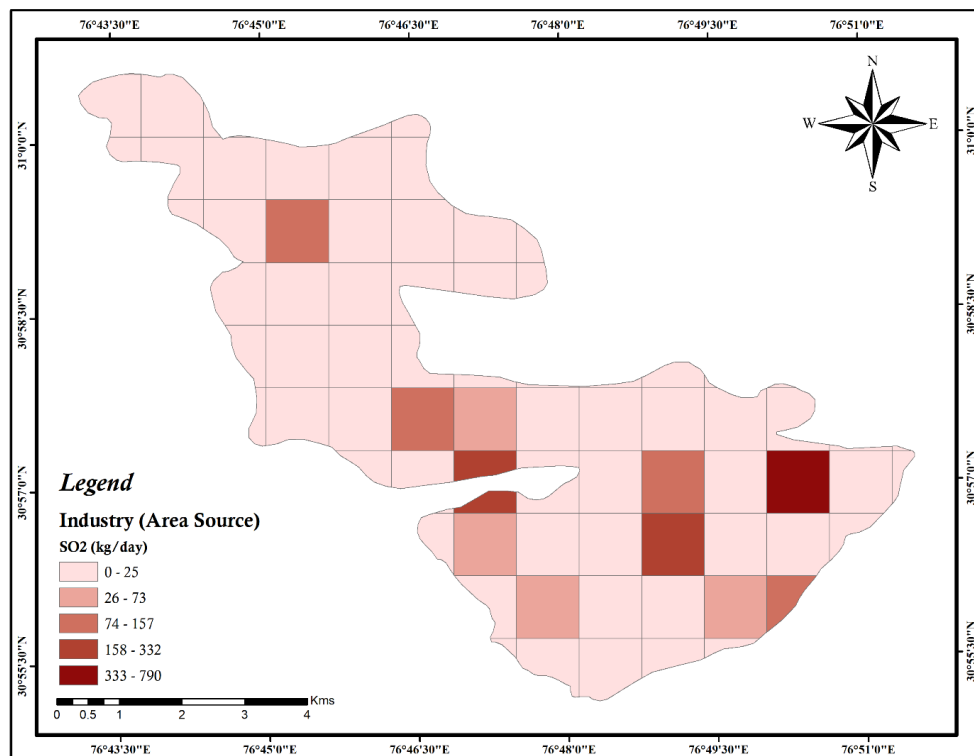


Figure 4.65: Spatial Distribution of SO₂ Emissions from Industries as area source

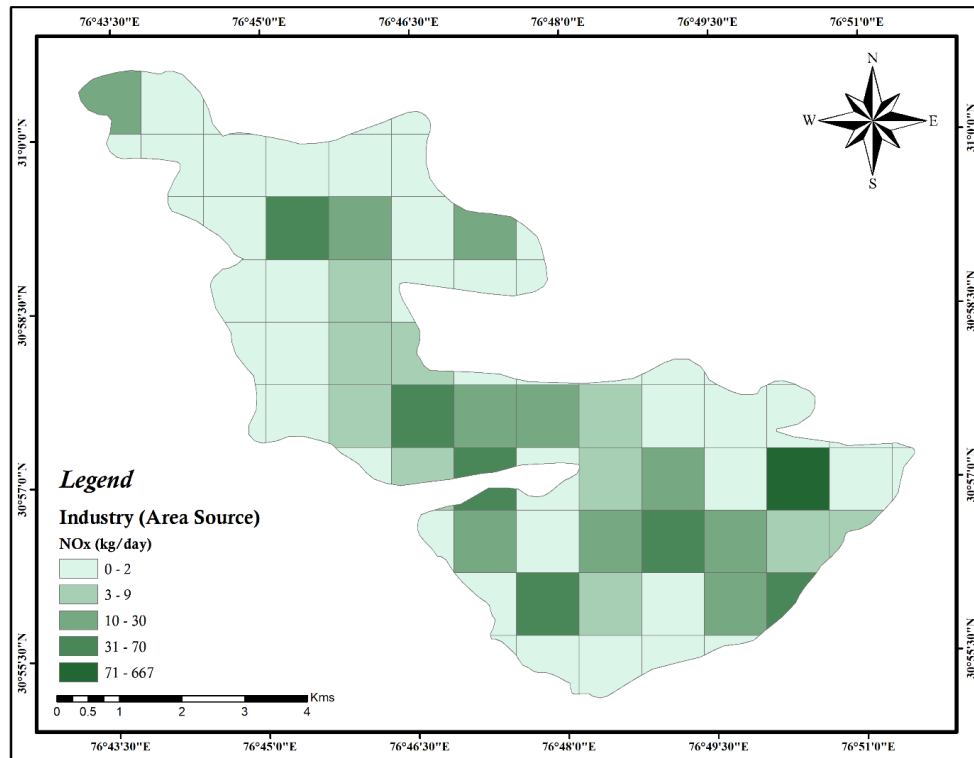


Figure 4.66: Spatial Distribution of NO_x Emissions from Industries as area source

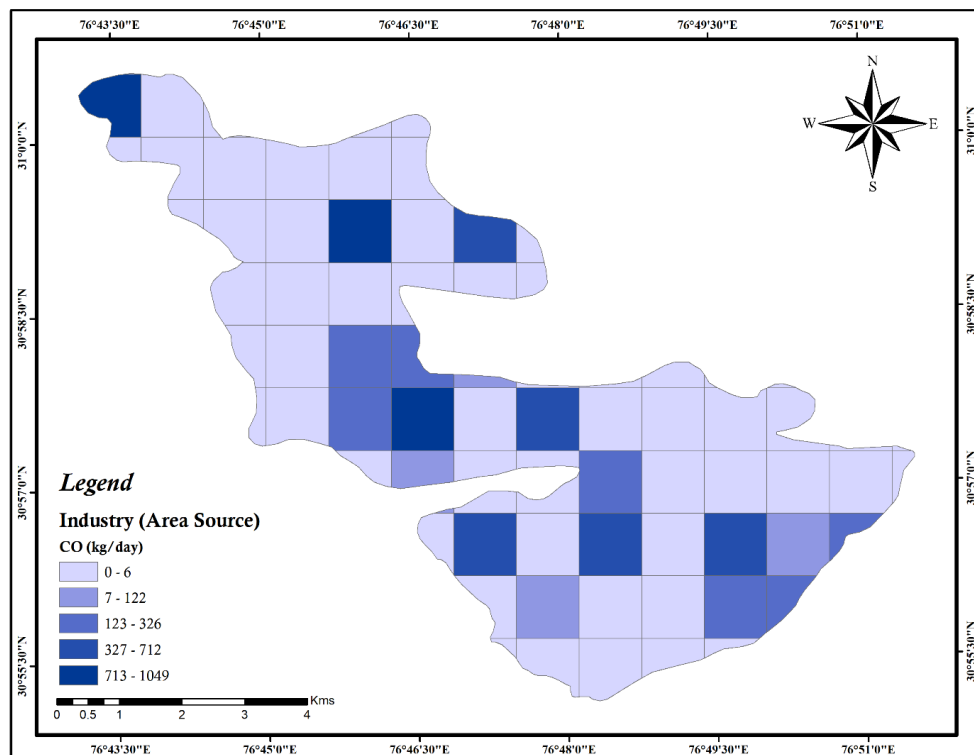


Figure 4.67: Spatial Distribution of CO Emissions from Industries as area source

Industries as Point Source

The industries having a stack height of more than 20 m have been taken as a point source. There are approximately 140 industries that are having stack heights of more than 20 meters. The emission of pollutants from industries as a point source is shown in Figure 4.68 (a) & (b). The spatial distribution of emissions from industries (point source) lying within the boundary and is presented in Figure 4.69 to Figure 4.73.

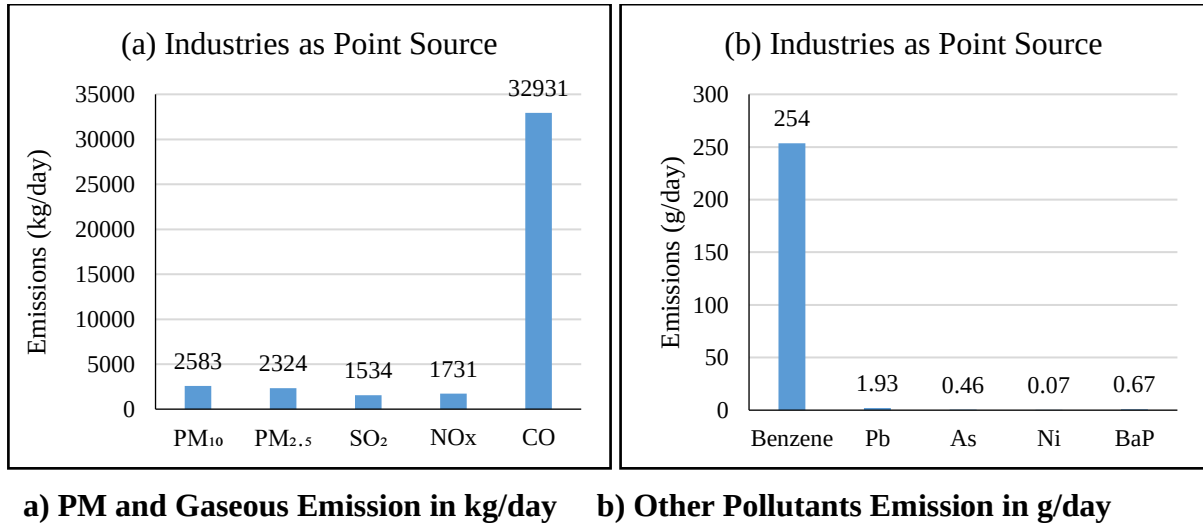


Figure 4.68: Emission Load from Industrial Point Source

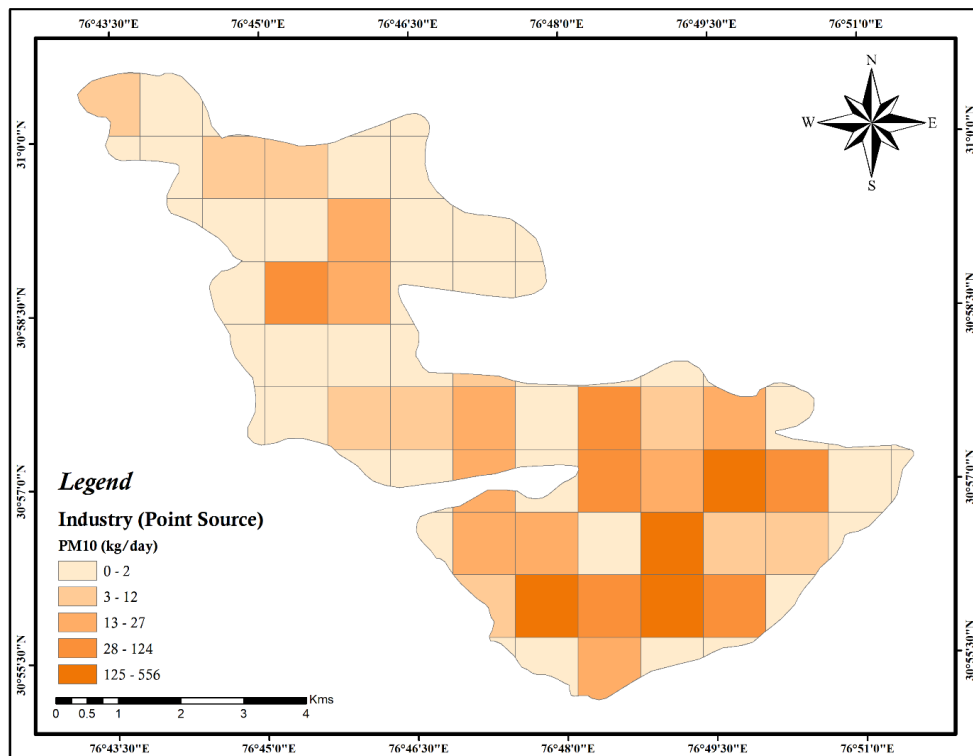


Figure 4.69: Spatial Distribution of PM₁₀ Emissions from Industries as point source

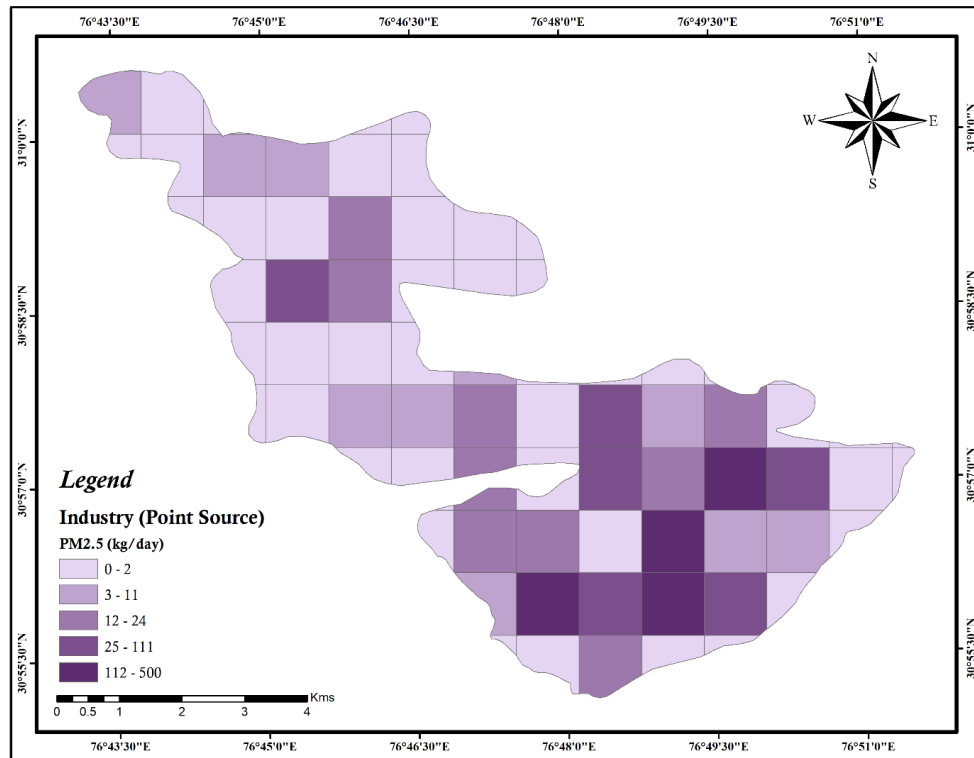


Figure 4.70: Spatial Distribution of PM_{2.5} Emissions from Industries as point source

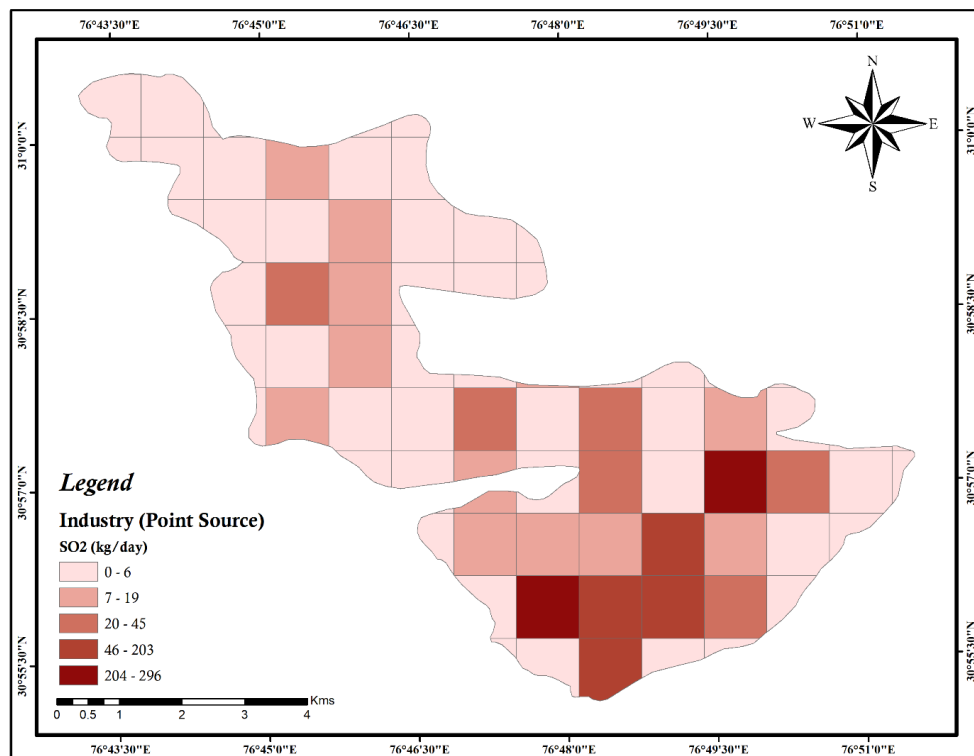


Figure 4.71: Spatial Distribution of SO₂ Emissions from Industries as point source

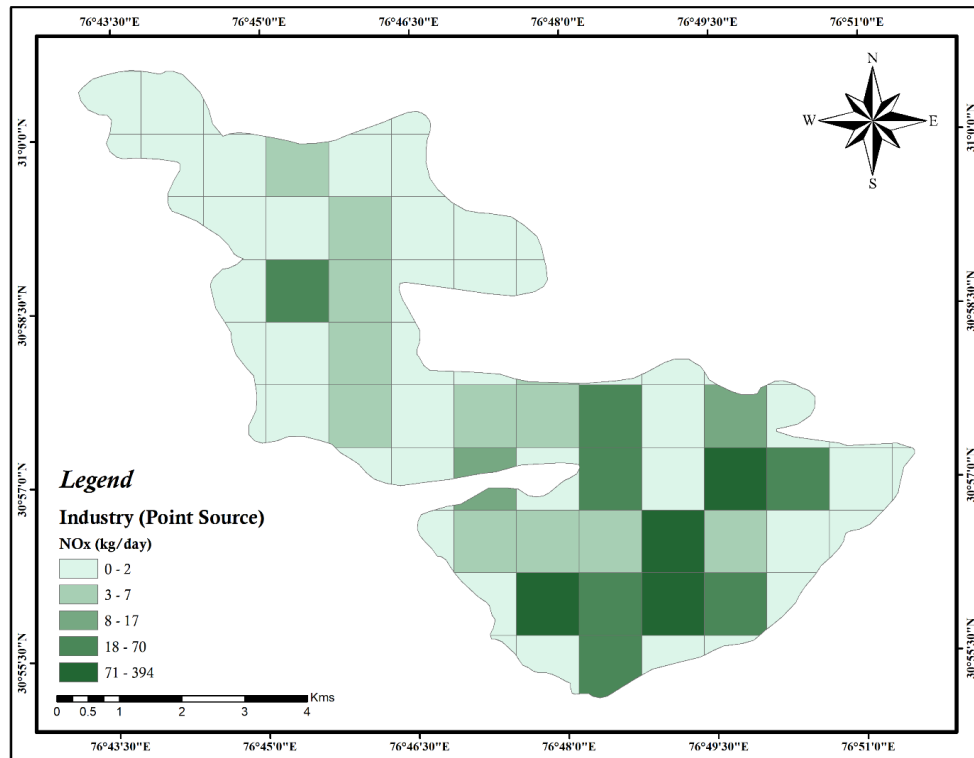


Figure 4.72: Spatial Distribution of NOx Emissions from Industries as point source

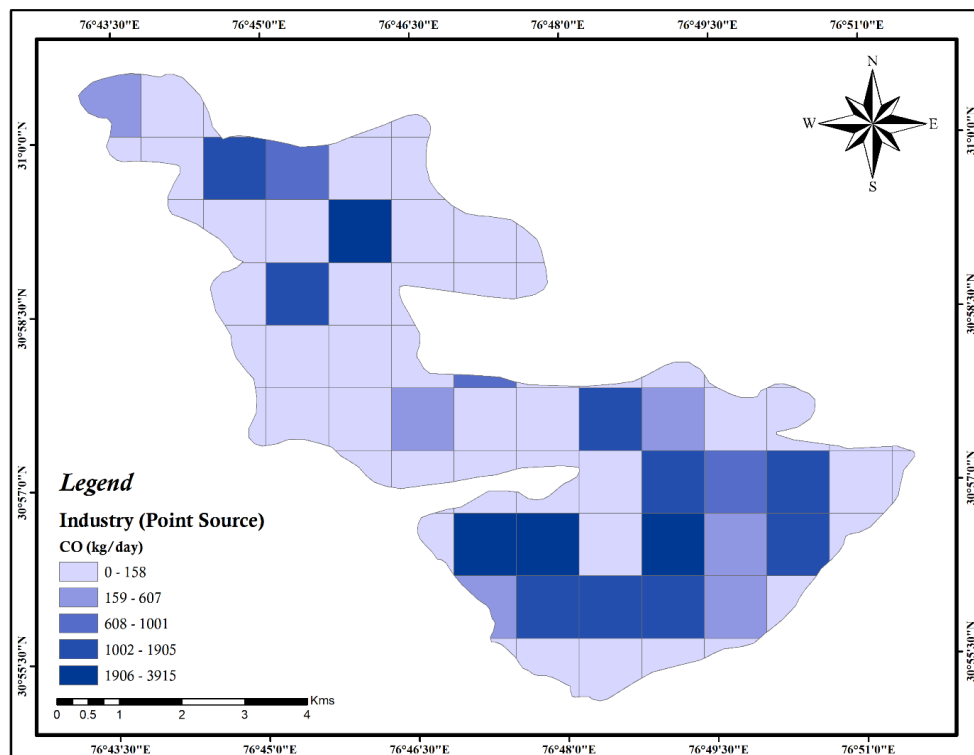


Figure 4.73: Spatial Distribution of CO Emissions from Industries as point source

4.2.13 Parking Lot Survey

To obtain the 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 done at 7 locations (Nagar Nigam, Gol Market Chauraha, Maluk Majara, Hotel Legend, Vardhman Chowk, Samsung Plaza, Sikka Hotel Chowk) in the city of Baddi. ARAI (2011) and CPCB (2011) emission factors were used to calculate the emissions. Figure 4.74 and Figure 4.75 present parking lane survey results for 2Ws and 4Ws 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 use, and age of the vehicles.

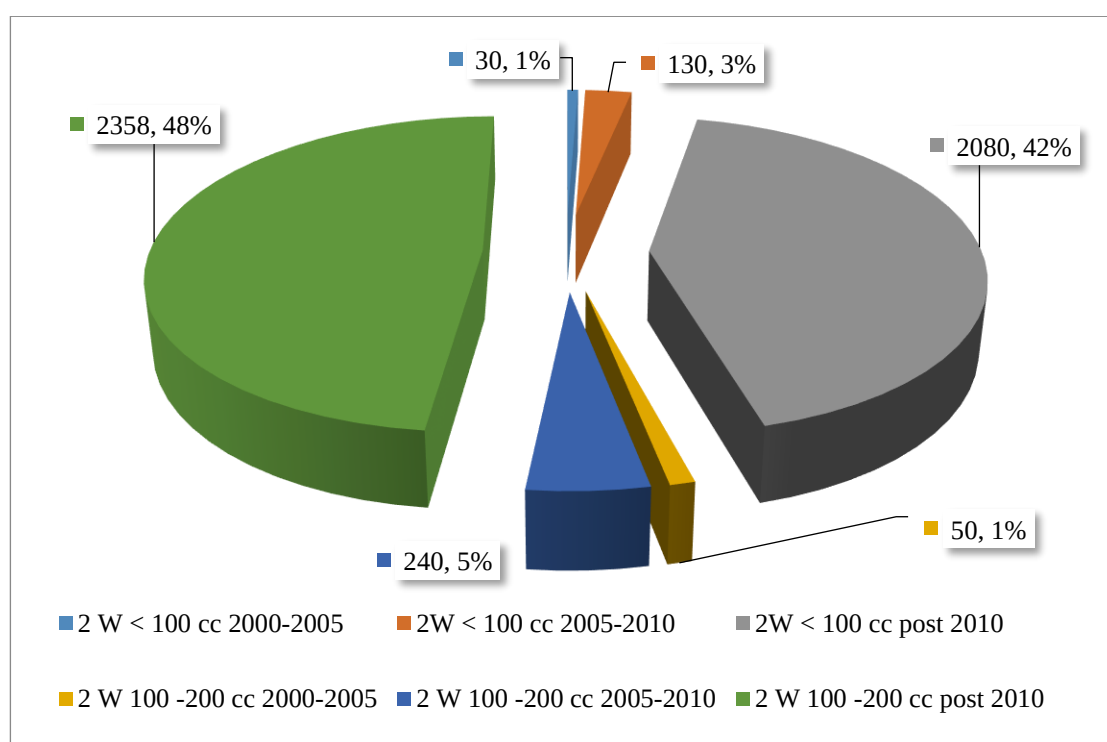


Figure 4.74: Distribution of 2-Ws in the study area (parking lot survey)

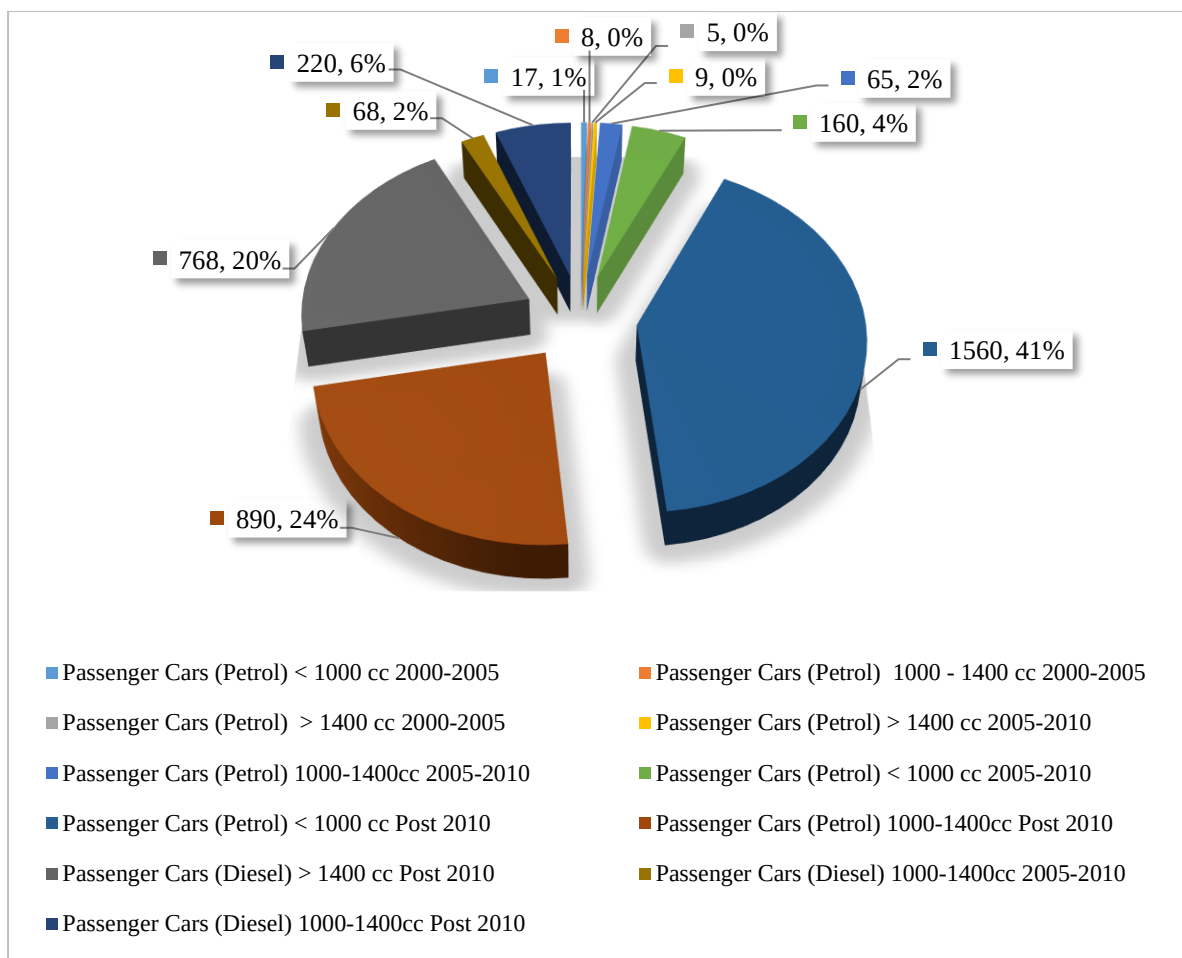


Figure 4.75: Distribution of 4-Ws in the study area (parking lot survey)

4.2.14 Vehicular-Line Sources

The average daily flow of vehicles in each hour for 2Ws, 3Ws, 4Ws, LCVs, Buses, and Trucks at 7 locations was obtained by video recording at crossings (Figure 4.76). From these 7 traffic locations, the data were extrapolated for the remaining grid cells. Road lengths in each cell 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 are estimated and summed up.

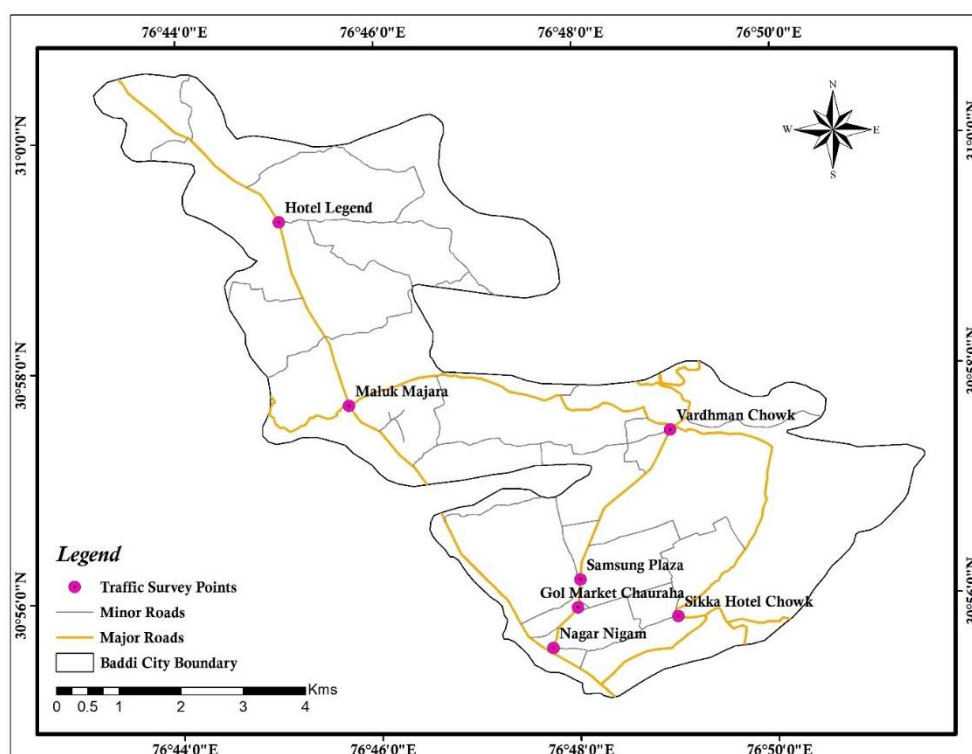
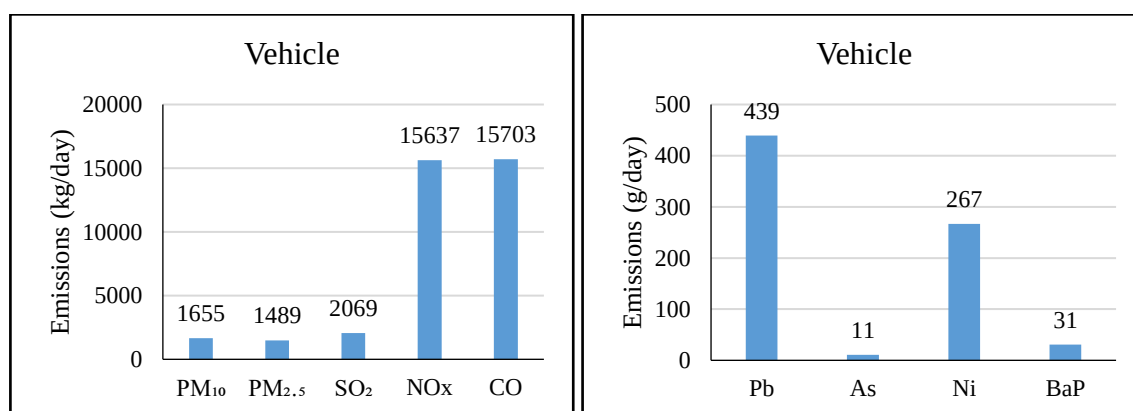


Figure 4.76: Traffic location considered for vehicle emission in the city of Baddi.

The emissions from railway locomotives are not taken into consideration, as the emissions are negligible in comparison with the vehicles and other sources. The emission from vehicles is shown in Figure 4.77 (a) & (b).

The emission contribution of each vehicle type in the city of Baddi city is presented in Figure 4.78 to Figure 4.82. The spatial distribution of emissions from vehicles is presented in Figure 4.83 to Figure 4.87.



a) PM and Gaseous Emission in kg/day

b) Other Pollutants Emission in g/day

Figure 4.77: Emission Load from Vehicles

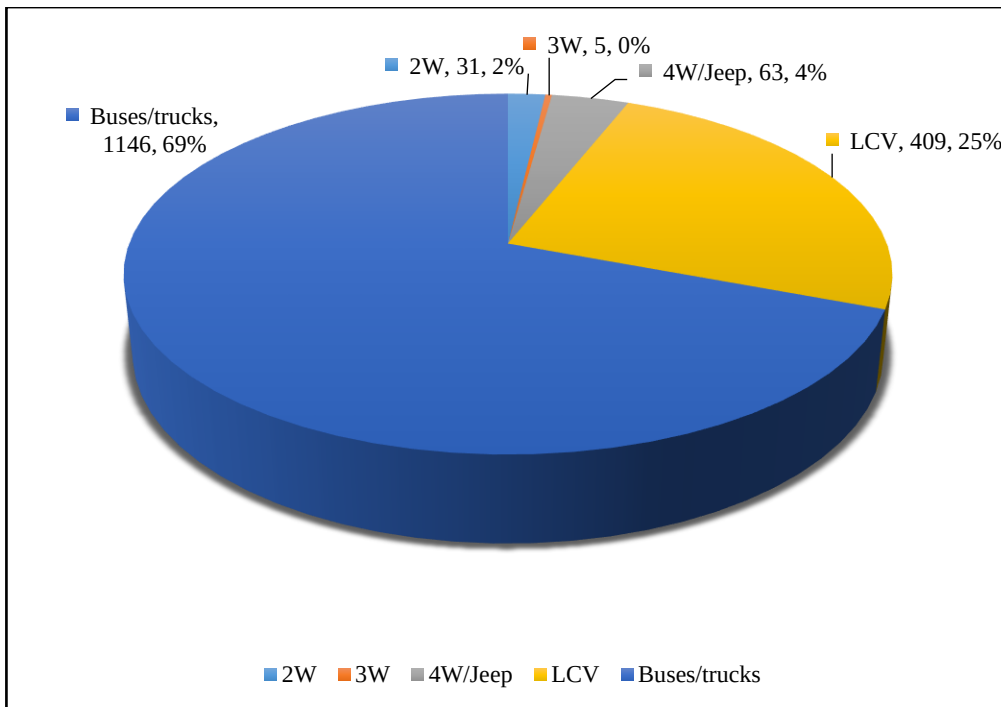


Figure 4.78: PM₁₀ Emission Load contribution of each vehicle type (kg/day)

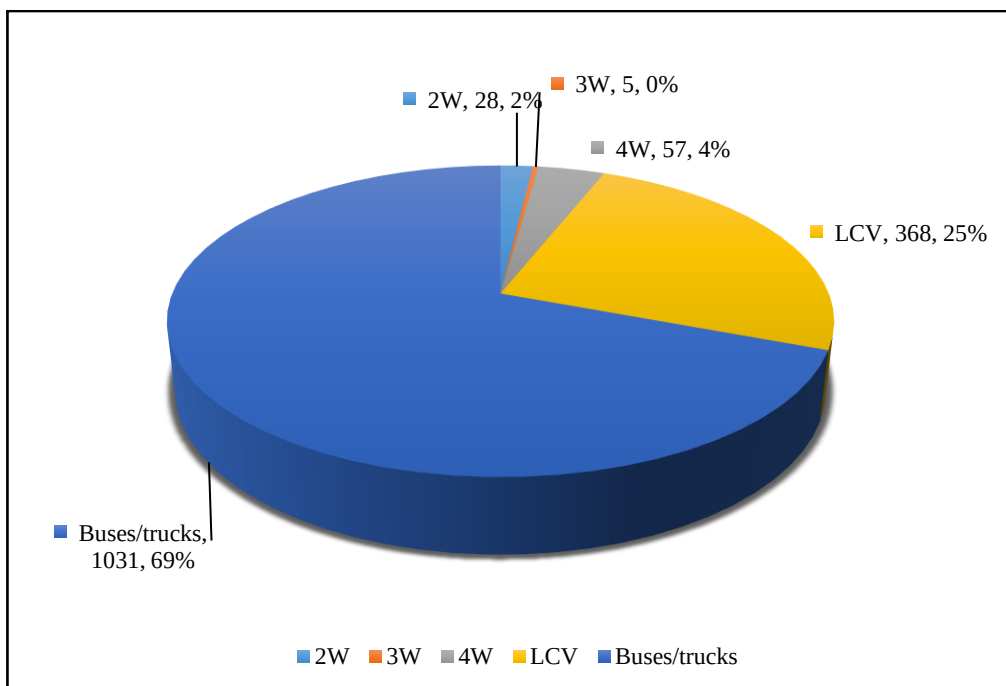


Figure 4.79: PM_{2.5} Emission Load contribution of each vehicle type (kg/day)

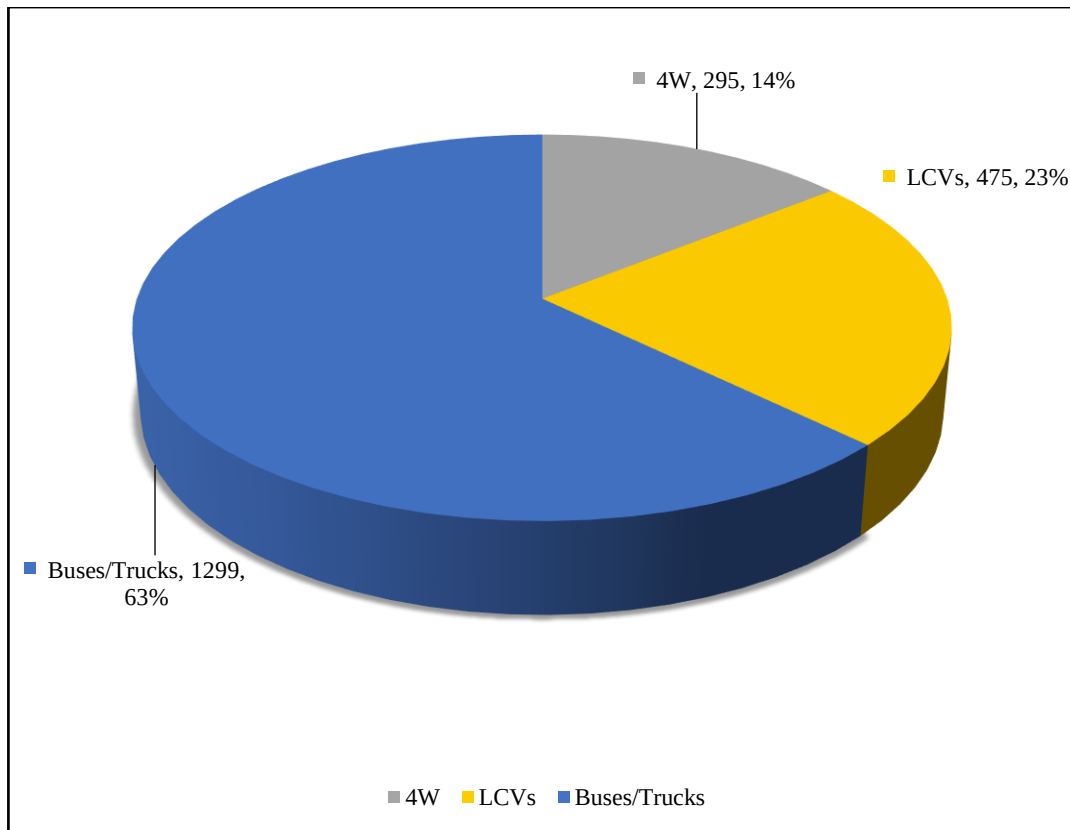


Figure 4.80: SO₂ Emission Load contribution of each vehicle type (kg/day)

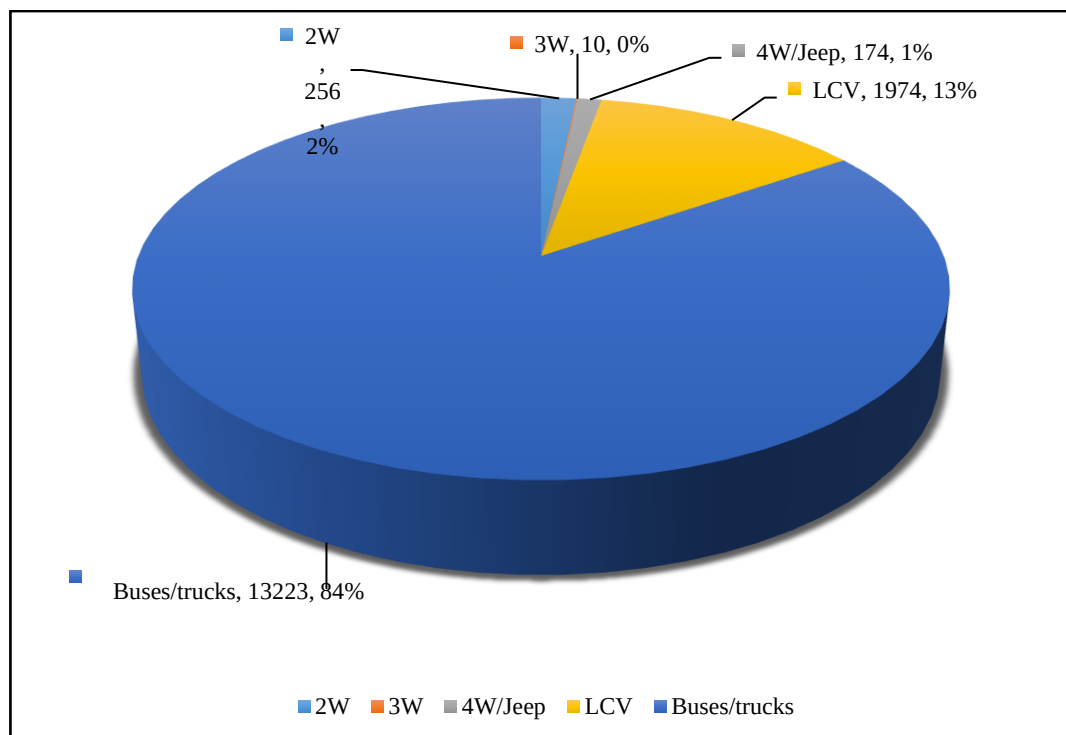


Figure 4.81: NO_x Emission Load contribution of each vehicle type (kg/day)

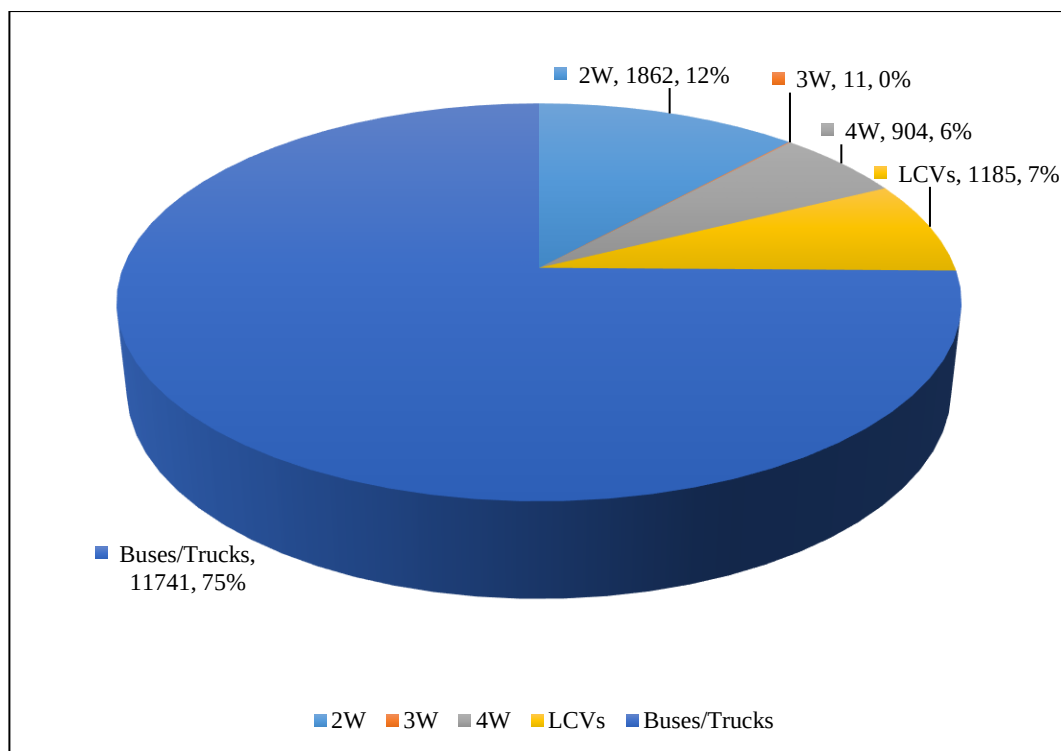


Figure 4.82: CO Emission Load contribution of each vehicle type (kg/day)

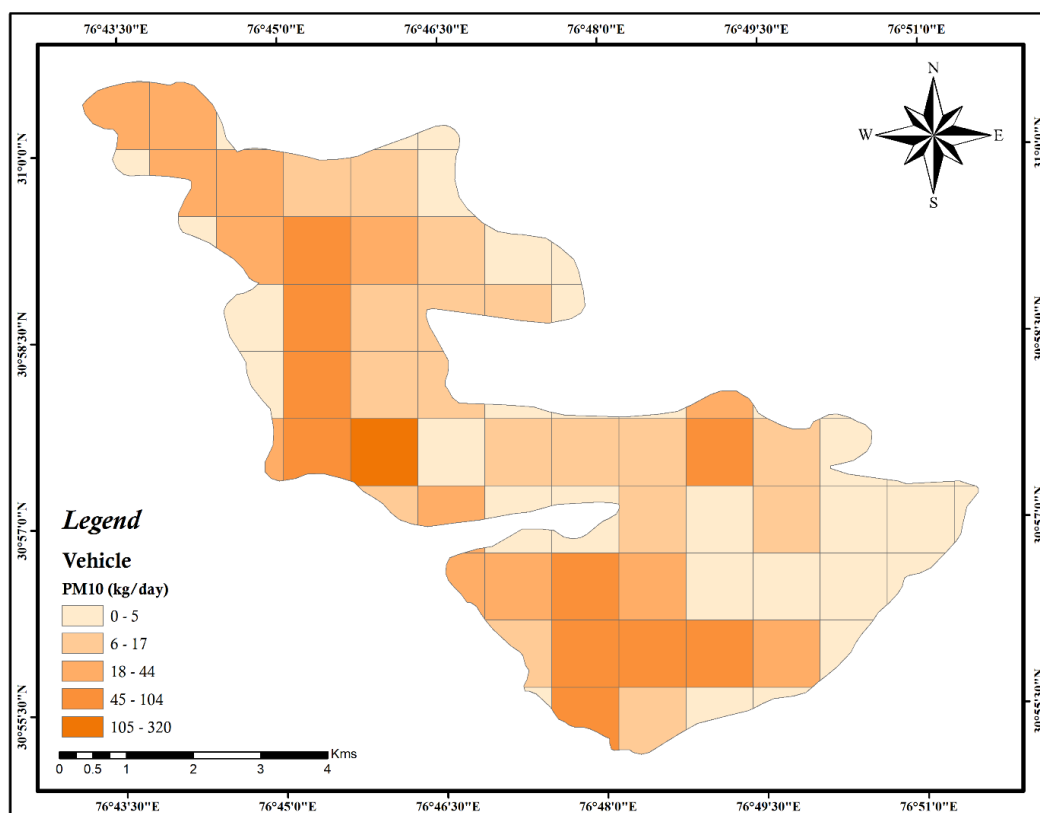


Figure 4.83: Spatial Distribution of PM₁₀ Emissions from Vehicles

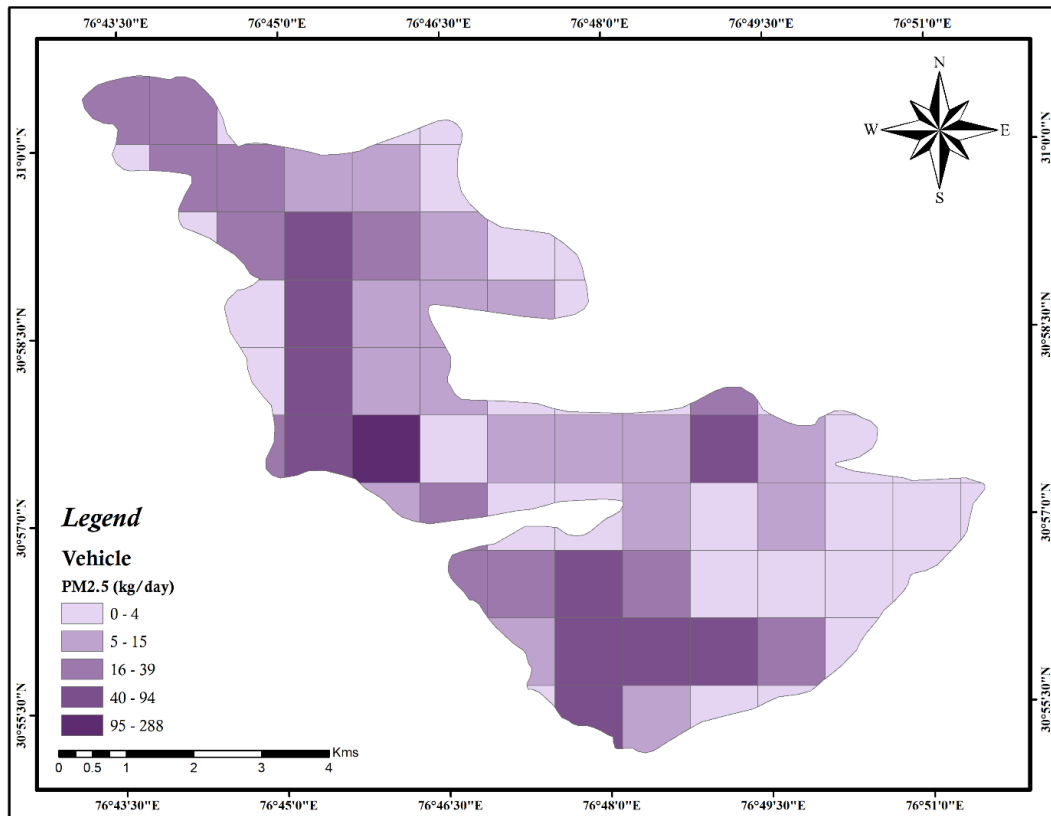


Figure 4.84: Spatial Distribution of PM_{2.5} Emissions from Vehicles

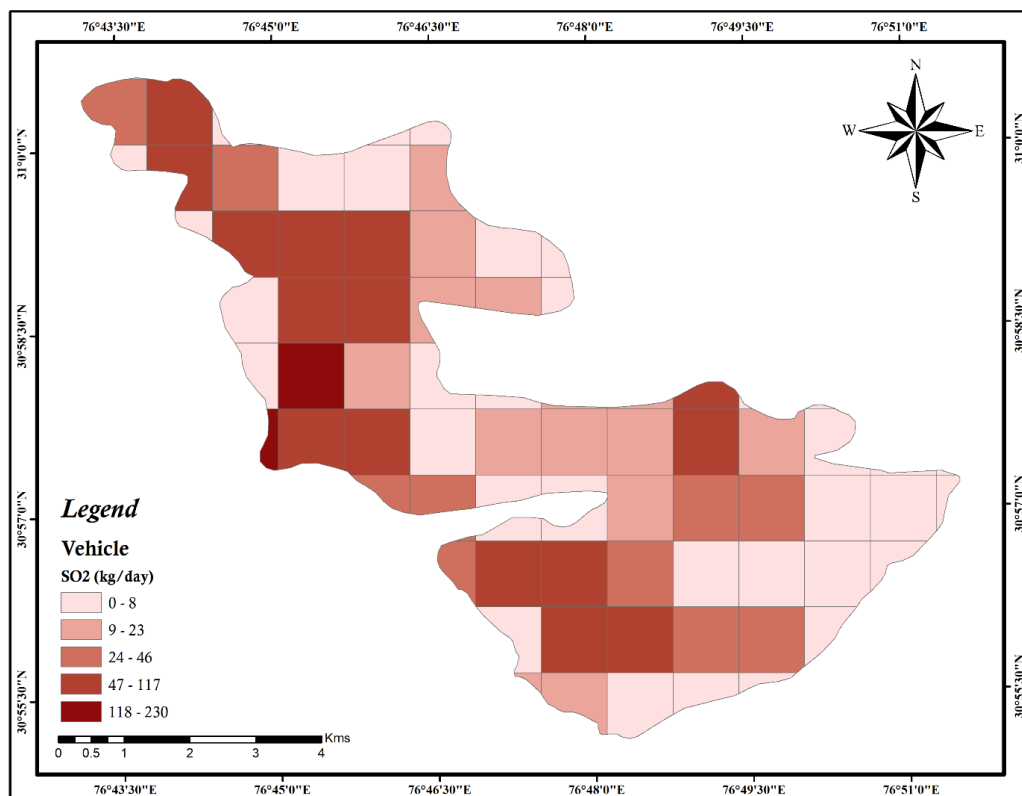


Figure 4.85: Spatial Distribution of SO₂ Emissions from Vehicles

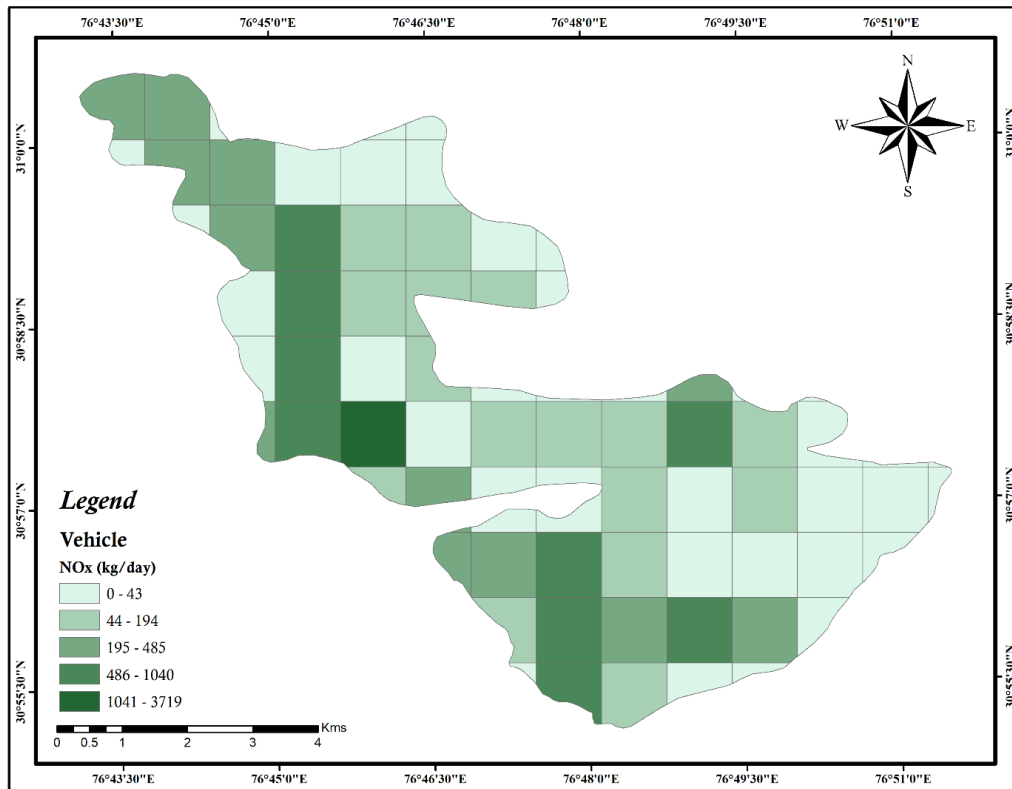


Figure 4.86: Spatial Distribution of NOx Emissions from Vehicles

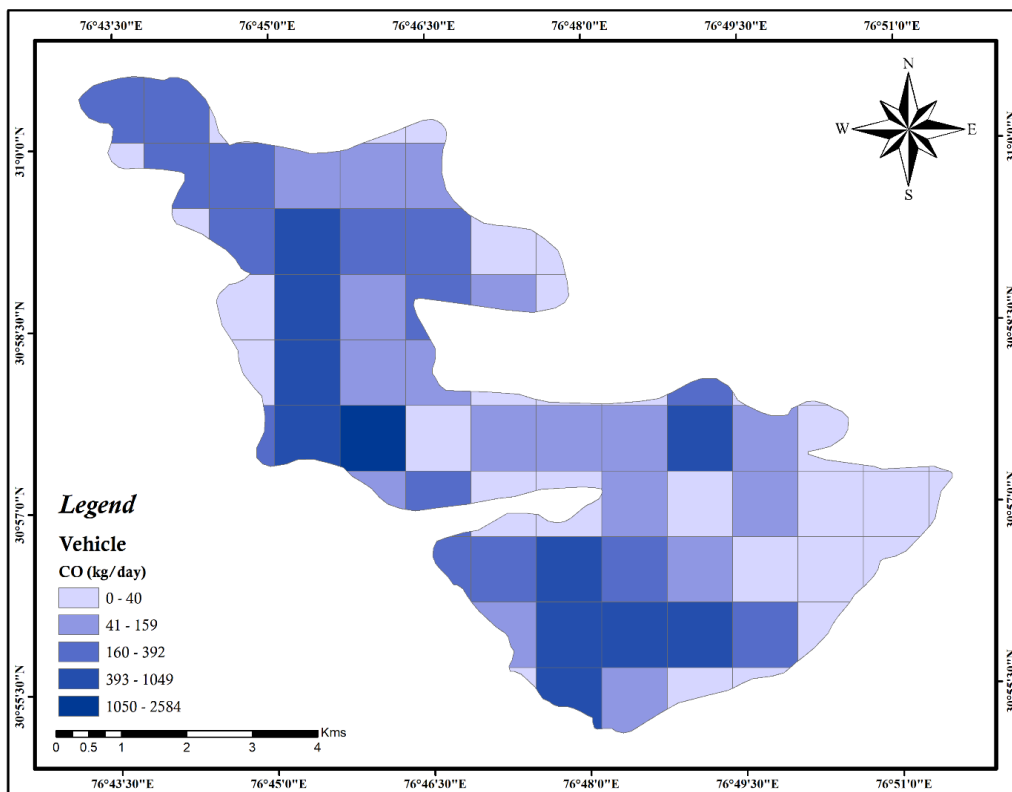


Figure 4.87: Spatial Distribution of CO Emissions from Vehicles

4.2.15 Traffic Congestion

The typical Traffic conditions at different locations for Baddi are given in Figure 4.88. Consequently, the major Traffic bottlenecks are mentioned in Table 4.3. The figure depicts the traffic report of Baddi for seven traffic hotspots of the city for the seven days of the week. The colour coding used here is Red, Orange, and Green indicating the slow traffic to fast traffic movement respectively. Gol Market Chauraha and Samsung Plaza have been seeing most of the traffic in the morning span on the weekdays, resulting in most of the people accessing roads for the conveyance to their respective working spaces.

Table 4.3: Major Traffic Bottleneck at Baddi

		Hotel Legend	Maluk Majara			Sikka Hotel Chowk		
		Vardhman Chowk	Samsung Plaza			Nagar Nigam		
		Gol Market Chauraha						
S.NO	DAY	Hotel Legeno	Maluk Majara	Vardhman Chowk	Samsung Plaza	Gol Market Chauraha	Nagar Nigam	Sikka Hotel Chowk
1	Sunday	8am-10am	8am-10am	8am-10am	8am-10am	8am-10am	8am-10am	8am-10am
		10am-12pm	10am-12pm	10am-12pm	10am-12pm	10am-12pm	10am-12pm	10am-12pm
		12pm-2pm	12pm-2pm	12pm-2pm	12pm-2pm	12pm-2pm	12pm-2pm	12pm-2pm
		2pm-4pm	2pm-4pm	2pm-4pm	2pm-4pm	2pm-4pm	2pm-4pm	2pm-4pm
		4pm-6pm	4pm-6pm	4pm-6pm	4pm-6pm	4pm-6pm	4pm-6pm	4pm-6pm
2	Monday	6pm-8pm	6pm-8pm	6pm-8pm	6pm-8pm	6pm-8pm	6pm-8pm	6pm-8pm
		8am-10am	8am-10am	8am-10am	8am-10am	8am-10am	8am-10am	8am-10am
		10am-12pm	10am-12pm	10am-12pm	10am-12pm	10am-12pm	10am-12pm	10am-12pm
		12pm-2pm	12pm-2pm	12pm-2pm	12pm-2pm	12pm-2pm	12pm-2pm	12pm-2pm
		2pm-4pm	2pm-4pm	2pm-4pm	2pm-4pm	2pm-4pm	2pm-4pm	2pm-4pm
3	Tuesday	4pm-6pm	4pm-6pm	4pm-6pm	4pm-6pm	4pm-6pm	4pm-6pm	4pm-6pm
		6pm-8pm	6pm-8pm	6pm-8pm	6pm-8pm	6pm-8pm	6pm-8pm	6pm-8pm
		8am-10am	8am-10am	8am-10am	8am-10am	8am-10am	8am-10am	8am-10am
		10am-12pm	10am-12pm	10am-12pm	10am-12pm	10am-12pm	10am-12pm	10am-12pm
		12pm-2pm	12pm-2pm	12pm-2pm	12pm-2pm	12pm-2pm	12pm-2pm	12pm-2pm
4	Wednesday	2pm-4pm	2pm-4pm	2pm-4pm	2pm-4pm	2pm-4pm	2pm-4pm	2pm-4pm
		4pm-6pm	4pm-6pm	4pm-6pm	4pm-6pm	4pm-6pm	4pm-6pm	4pm-6pm
		6pm-8pm	6pm-8pm	6pm-8pm	6pm-8pm	6pm-8pm	6pm-8pm	6pm-8pm
		8am-10am	8am-10am	8am-10am	8am-10am	8am-10am	8am-10am	8am-10am
		10am-12pm	10am-12pm	10am-12pm	10am-12pm	10am-12pm	10am-12pm	10am-12pm
5	Thursday	12pm-2pm	12pm-2pm	12pm-2pm	12pm-2pm	12pm-2pm	12pm-2pm	12pm-2pm
		2pm-4pm	2pm-4pm	2pm-4pm	2pm-4pm	2pm-4pm	2pm-4pm	2pm-4pm
		4pm-6pm	4pm-6pm	4pm-6pm	4pm-6pm	4pm-6pm	4pm-6pm	4pm-6pm
		6pm-8pm	6pm-8pm	6pm-8pm	6pm-8pm	6pm-8pm	6pm-8pm	6pm-8pm
		8am-10am	8am-10am	8am-10am	8am-10am	8am-10am	8am-10am	8am-10am
6	Friday	10am-12pm	10am-12pm	10am-12pm	10am-12pm	10am-12pm	10am-12pm	10am-12pm
		12pm-2pm	12pm-2pm	12pm-2pm	12pm-2pm	12pm-2pm	12pm-2pm	12pm-2pm
		2pm-4pm	2pm-4pm	2pm-4pm	2pm-4pm	2pm-4pm	2pm-4pm	2pm-4pm
		4pm-6pm	4pm-6pm	4pm-6pm	4pm-6pm	4pm-6pm	4pm-6pm	4pm-6pm
		6pm-8pm	6pm-8pm	6pm-8pm	6pm-8pm	6pm-8pm	6pm-8pm	6pm-8pm
7	Saturday	8am-10am	8am-10am	8am-10am	8am-10am	8am-10am	8am-10am	8am-10am
		10am-12pm	10am-12pm	10am-12pm	10am-12pm	10am-12pm	10am-12pm	10am-12pm
		12pm-2pm	12pm-2pm	12pm-2pm	12pm-2pm	12pm-2pm	12pm-2pm	12pm-2pm
		2pm-4pm	2pm-4pm	2pm-4pm	2pm-4pm	2pm-4pm	2pm-4pm	2pm-4pm
		4pm-6pm	4pm-6pm	4pm-6pm	4pm-6pm	4pm-6pm	4pm-6pm	4pm-6pm
		6pm-8pm	6pm-8pm	6pm-8pm	6pm-8pm	6pm-8pm	6pm-8pm	6pm-8pm

Green = smooth traffic, Orange = slow-moving traffic, Red = Heavy traffic with congestion

Figure 4.88: Typical Traffic conditions at different locations in Baddi

4.2.16 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 travelling on the road. The term silt loading (sL) refers to the mass of the silt-sized 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:

$$E_{ext} = [k (sL)^{0.91} \times (W)^{1.02}] (1 - P/4N) \dots\dots\dots (Eq. 4.5)$$

Where

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

sL = road surface silt loading (grams per square meter) (g/m²); varies from 8 to 63 g/m² in Baddi,

W = average weight (tons) of the vehicles travelling the road.

E_{ext} = annual or other long-term average emission factor 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; 61 days for Baddi

N = number of days in the averaging period, and

k: constant (a function of particle size) in g VKT⁻¹ (Vehicle Kilometer Travel); PM₁₀ = 0.62 g/VKT, PM_{2.5} = 0.15 g/VKT.

The road dust sampling locations are given in Figure 4.89. The silt loads (sL) samples from 7 locations were collected (Figure 4.90). Then 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 emission rate (g VKT⁻¹) was calculated based on Eq (4.5). 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 Eq (4.5). The road dust deposition can be seen on the roads. It can be seen the roads are broken in patches causing higher road dust emissions (Figure 4.91). There is a need to clean the road on regular basis. In the winter and monsoon season, it is less due to moisture and dew atmospheric conditions. The emission load from road dust in Baddi city is given in Figure 4.92 (a) & (b). The Spatial distribution of Emissions from Road Dust Re-suspension is presented in Figure 4.93 & Figure 4.94.

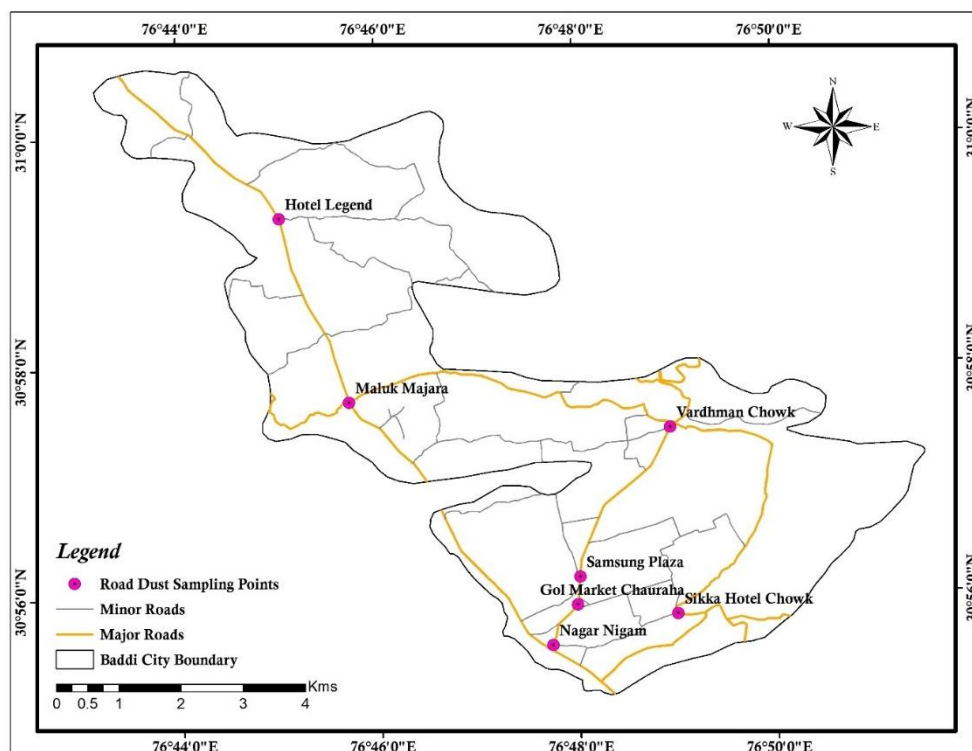


Figure 4.89: Road Dust Sampling Locations



Figure 4.90: Road Dust Sampling in the City of Baddi



Figure 4.91: Road dust deposition on the road

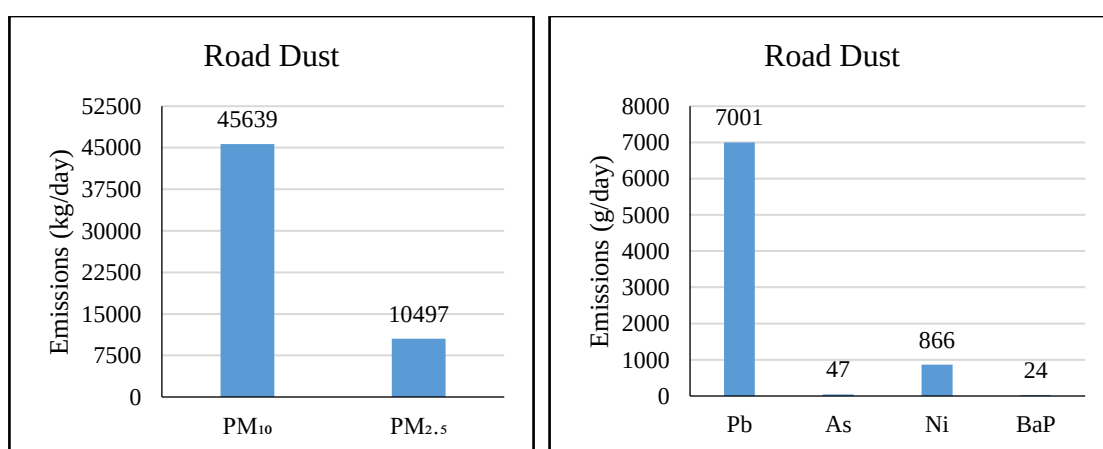


Figure 4.92: Emissions from road dust in Baddi city

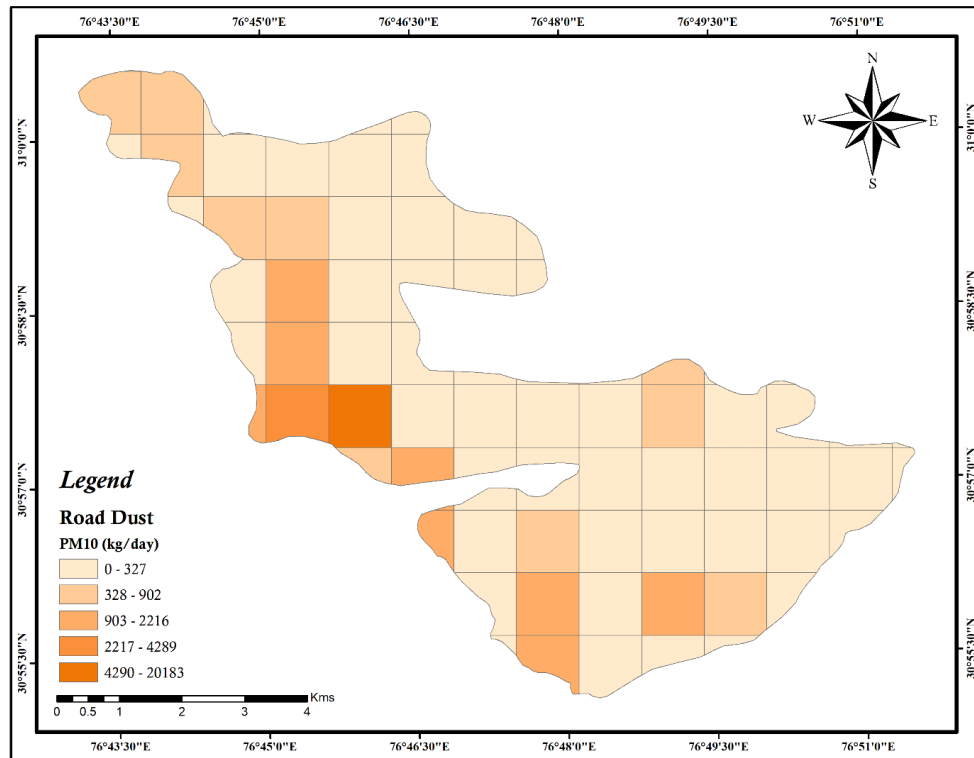


Figure 4.93: Spatial Distribution of PM₁₀ Emissions from Road Dust Re-suspension

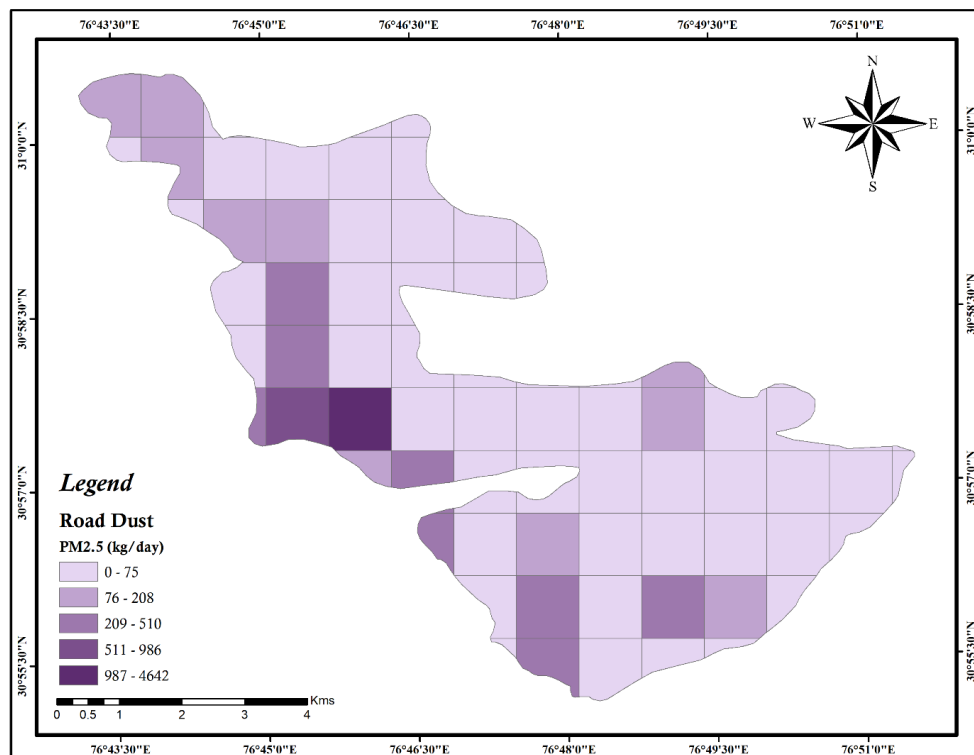


Figure 4.94: Spatial Distribution of PM_{2.5} Emissions from Road Dust Re-suspension

4.3 City Level Emission Inventory

The overall baseline emission inventory for the entire city is presented in Table 4.4. The pollutant wise contribution is shown in Figure 4.95 to Figure 4.99. The spatial distribution of pollutant Emissions from all sources is presented in Figure 4.100 to Figure 4.104. The pollutant wise gridded emissions are provided in Annexure 2.

The total PM₁₀ emission load in the city is estimated to be 51482 kg/day. The top four contributors to PM₁₀ emissions are Road Dust (89%), Industries (5%), Vehicles (3%), and Industrial DG Sets (1%); these are based on annual emissions. 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.

PM_{2.5} emission load in the city is estimated to be 15493 kg/day. The top four contributors to PM_{2.5} emissions are Road Dust (68%), Industries (16%), Vehicles (10%), and Industrial DG sets (4%); these are based on annual emissions. Seasonal and daily emissions could be highly variable.

SO₂ emission load in the city is estimated to be 7235 kg/day. Industrial (54%) and vehicular (29%) emissions accounts for 2/3rd of the total emission. Other sources which contribute for SO₂ emissions are brick kilns (9%) and industrial DG sets (8%).

NO_x emissions load in the city is estimated to be 27812 kg/day. Majority of total emissions are attributed to Vehicular (56%), Industrial DG set (32%), and Industries (11%). Vehicular emissions that occur at ground level, probably making it the most important emission. NO_x apart from being a pollutant itself is an important component in the formation of secondary particles (nitrates) and ozone. NO_x from vehicles and industry are potential sources for controlling NO_x emissions.

The estimated CO emission is about 60608 kg/day. The significant contributors to CO emissions are Industries (68%), Vehicles (26%), Industrial DG set (3%), and Brick Kiln (2%). Industries and Vehicles could be the main target for controlling CO for improving air quality concerning CO. The estimated emissions are for benzene: 2514 g/d, Pb: 7561 g/d, As: 119 g/d, Ni: 1319 g/d and BaP: 73 g/d from all sources.

Table 4.4: Baddi City Level Inventory (emissions in kg/day and g/day)

Sources	PM₁₀ (kg/d)	PM_{2.5} (kg/d)	SO₂ (kg/d)	NO_x (kg/d)	CO (kg/d)	NH₃ (kg/d)	Benzene (g/d)	Pb (g/d)	As (g/d)	Ni (g/d)	BaP (g/d)
Brick Kilns	491	344	638	192	1224		29	39	52	154	7.0
Domestic	41	31	9	22	175		0.3	0.7	0.9	9.0	0.1
MSW Burning	43	29	3	16	225		0	9.3	1.7	1.3	0.0
Hotels, Restaurants, GHs and BHs	48	26	31	39	86		104	2.3	3.0	12	0.5
Construction and Demolition	197	45					0	6.3	2.2	3.3	0.0
Industrial DG Sets	629	566	586	8888	1919		1871	57	0	6.8	8.4
Hospitals	5	5	5	73	16		15	0.5	0	0.1	0.1
Industries	2734	2461	3894	2945	41259		494	4.1	0.5	0.3	2.0
Vehicle	1655	1489	2069	15637	15703		0	439	11	267	31
Road Dust	45639	10497					0	7001	47	866	24
Livestock						360					
Agriculture						513					
Total	51482	15493	7235	27812	60608	873	2514	7561	119	1319	73

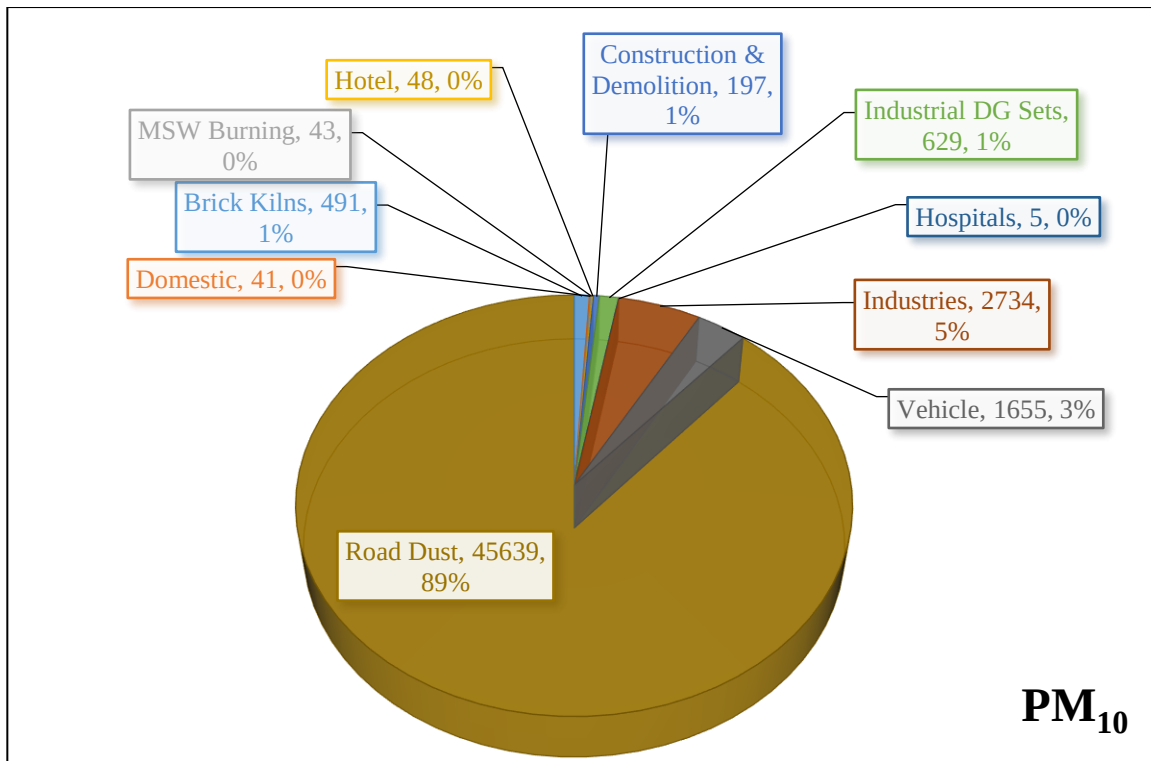


Figure 4.95: PM₁₀ Emission Load of Different Sources

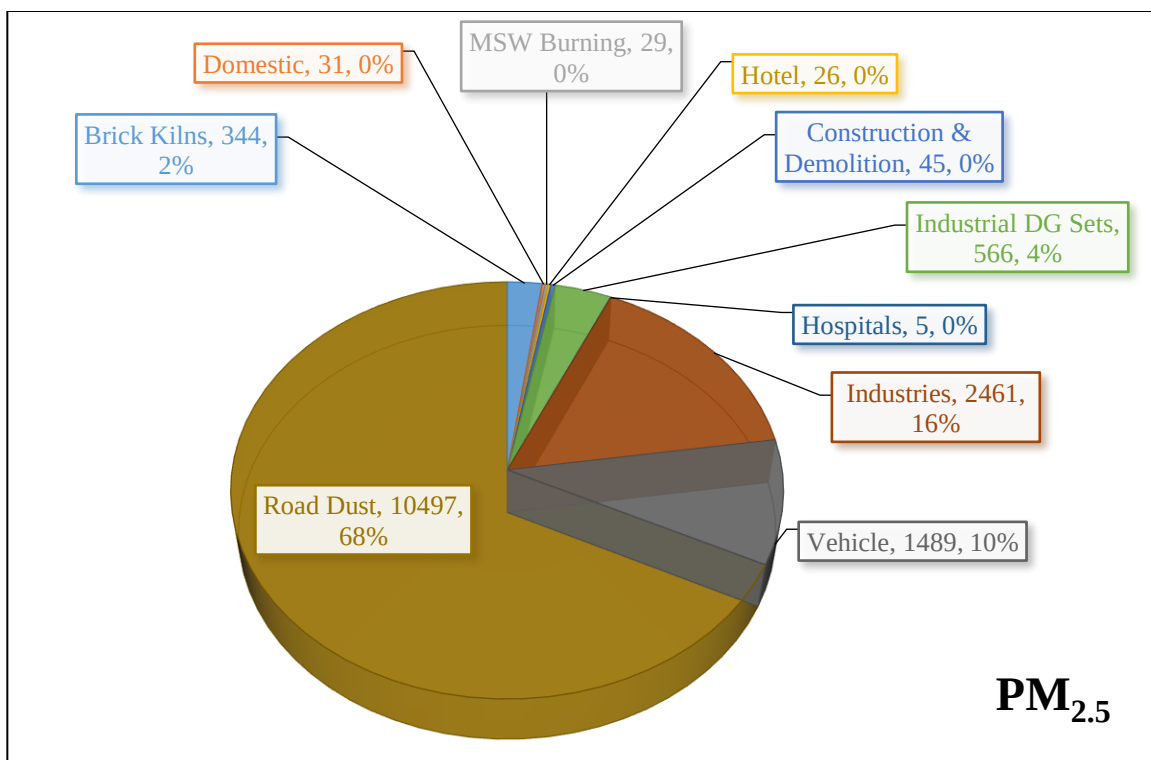


Figure 4.96: PM_{2.5} Emission Load of Different Sources

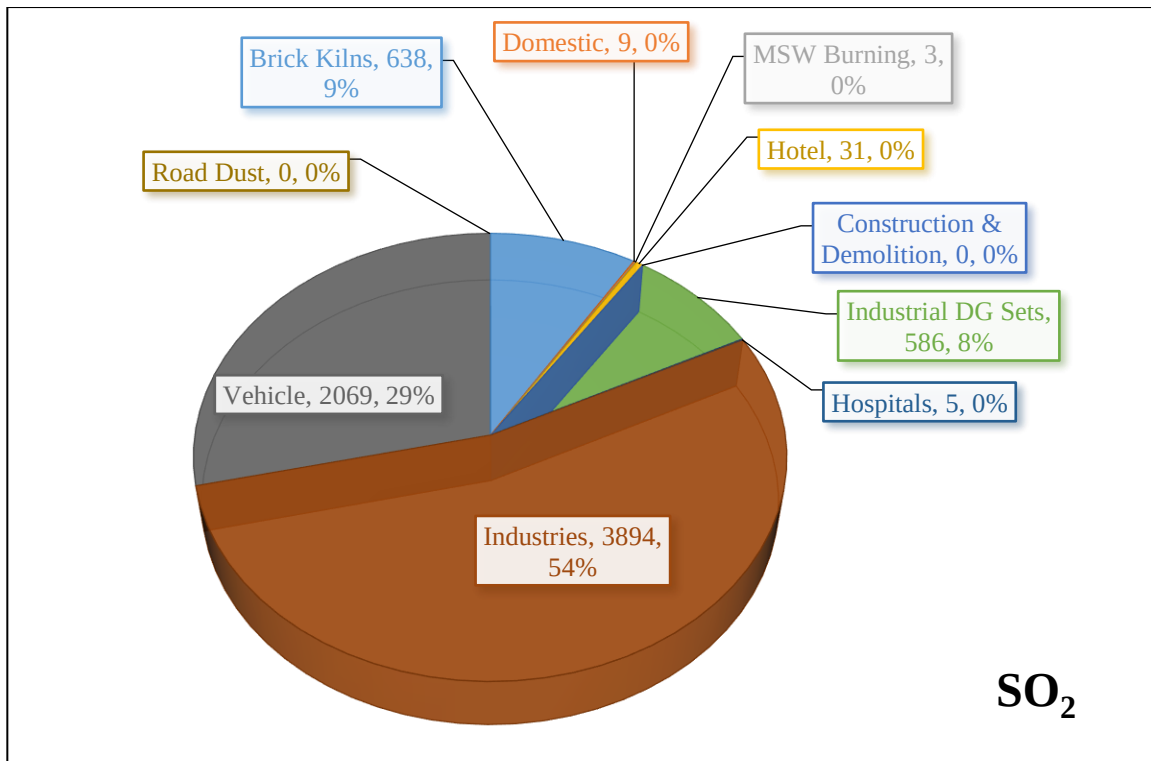


Figure 4.97: SO₂ Emission Load of Different Sources

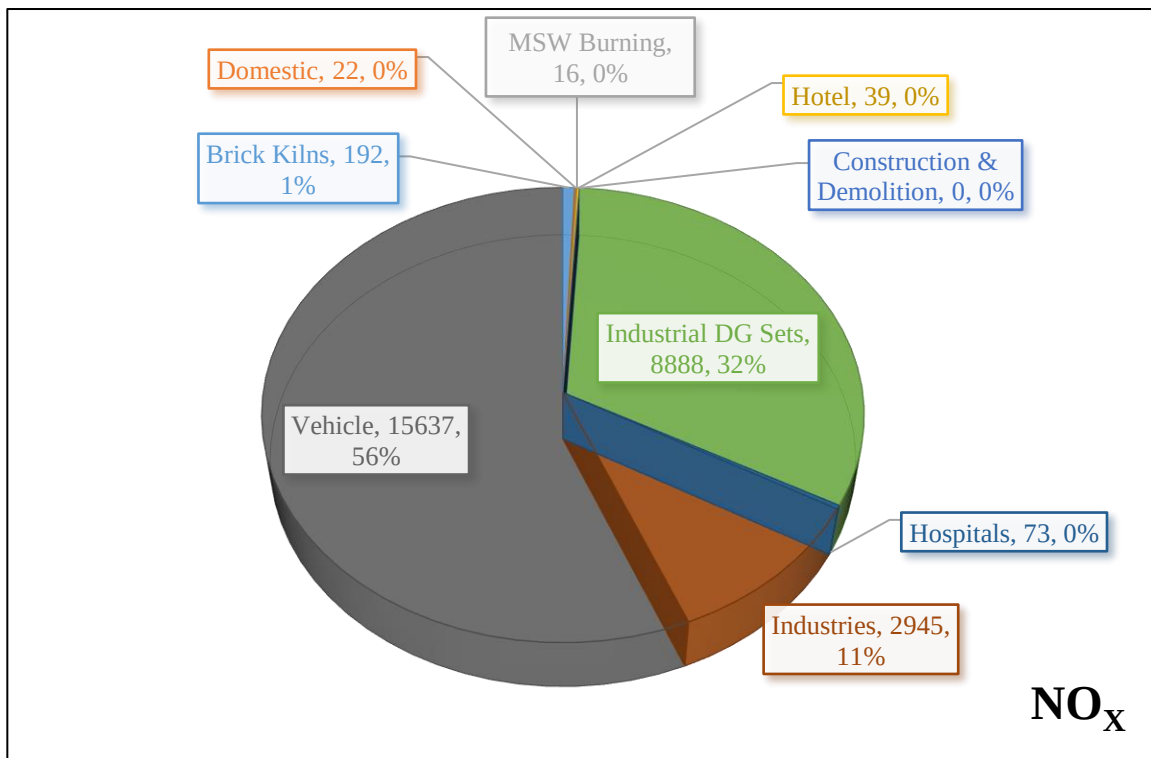


Figure 4.98: NO_x Emission Load of Different Sources

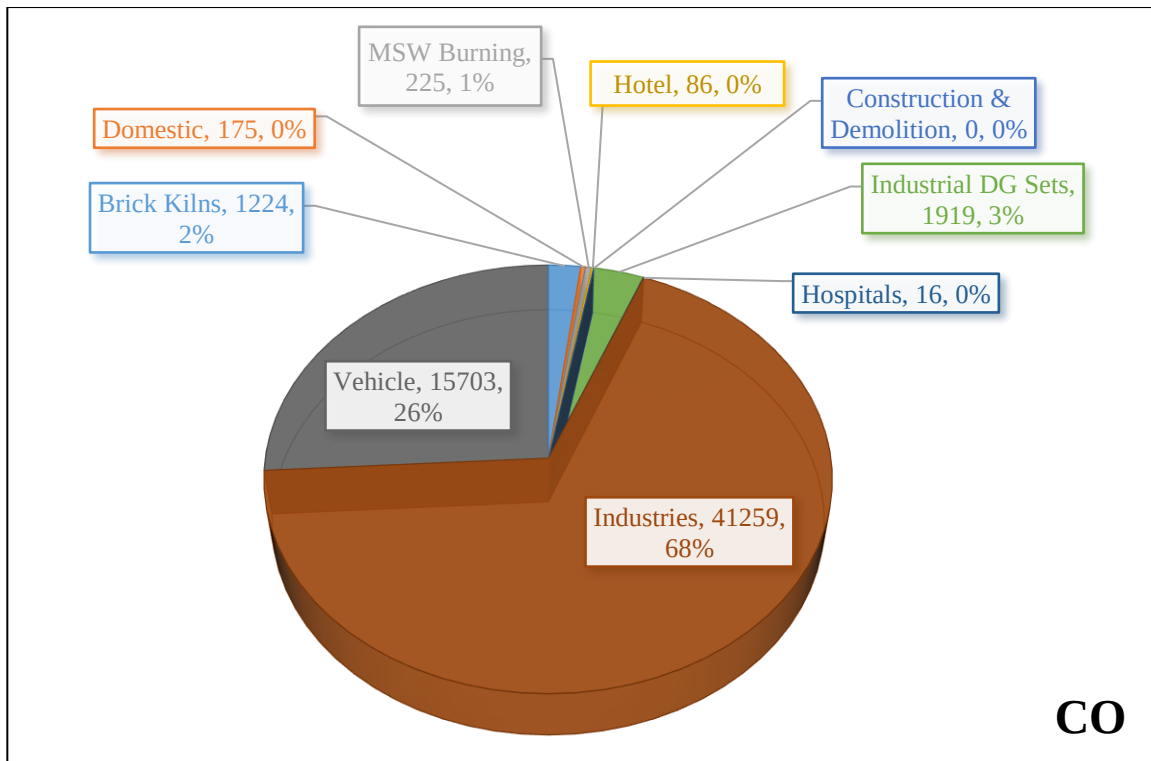


Figure 4.99: CO Emission Load Contribution of Different Sources

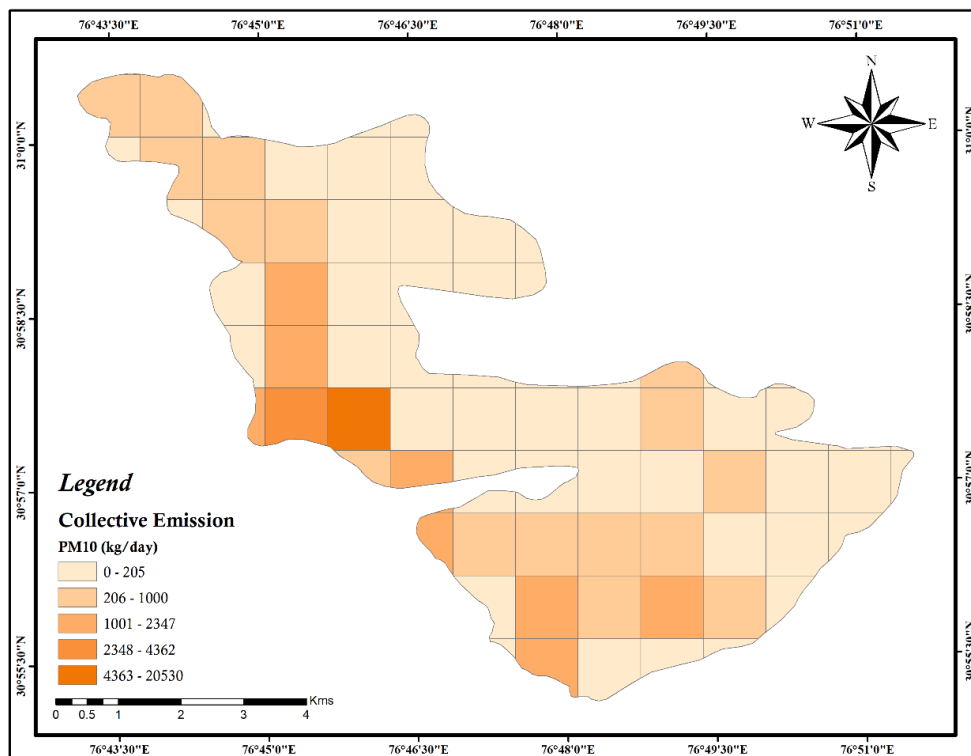


Figure 4.100: Spatial Distribution of PM₁₀ Emissions in the City of Baddi

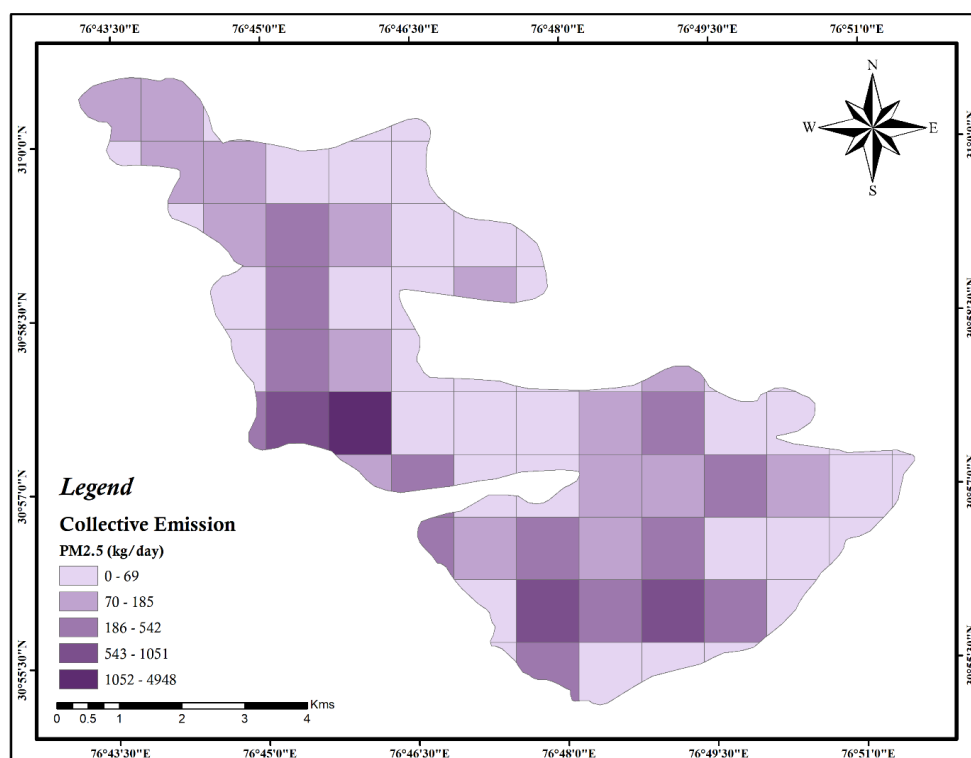


Figure 4.101: Spatial Distribution of PM_{2.5} Emissions in the City of Baddi

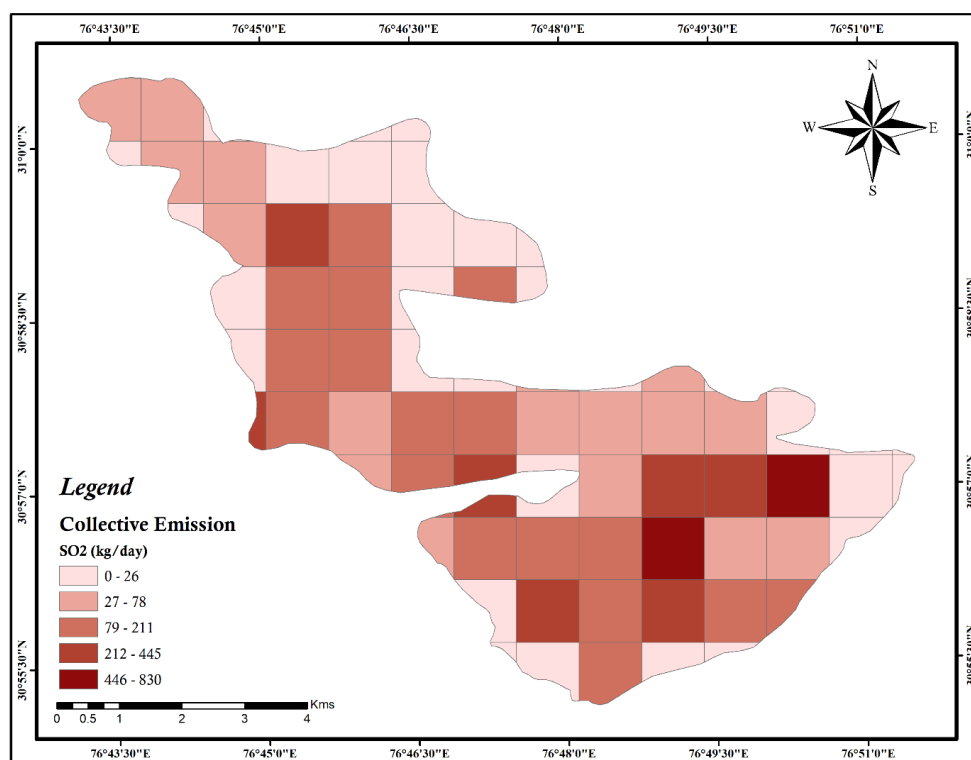


Figure 4.102: Spatial Distribution of SO₂ Emissions in the City of Baddi

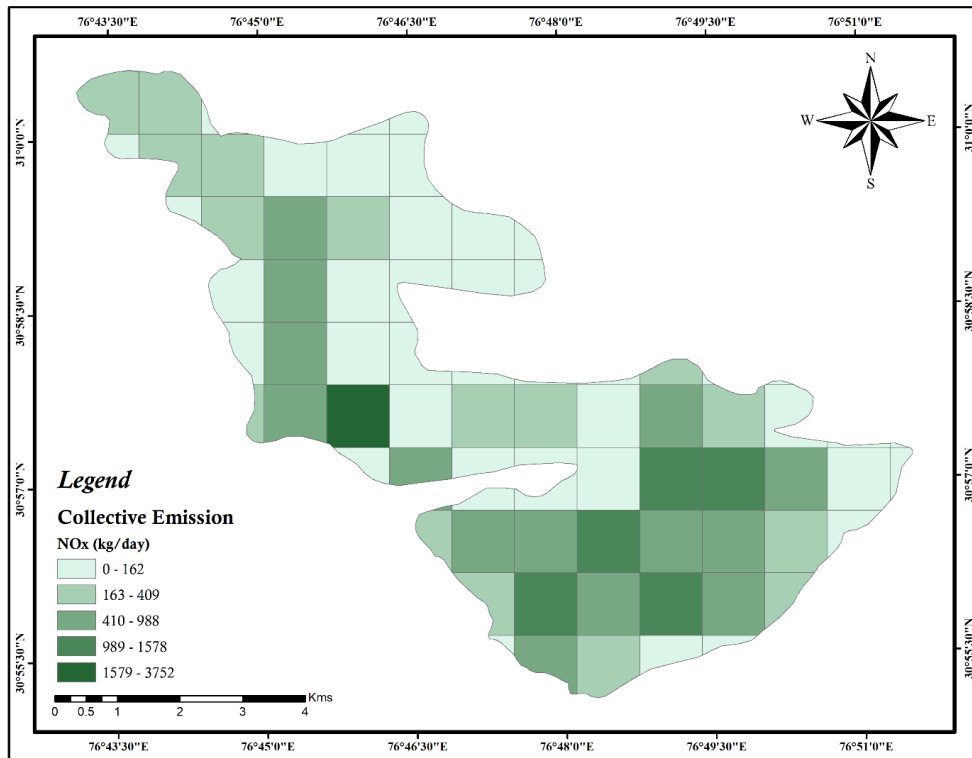


Figure 4.103: Spatial Distribution of NOx Emissions in the City of Baddi

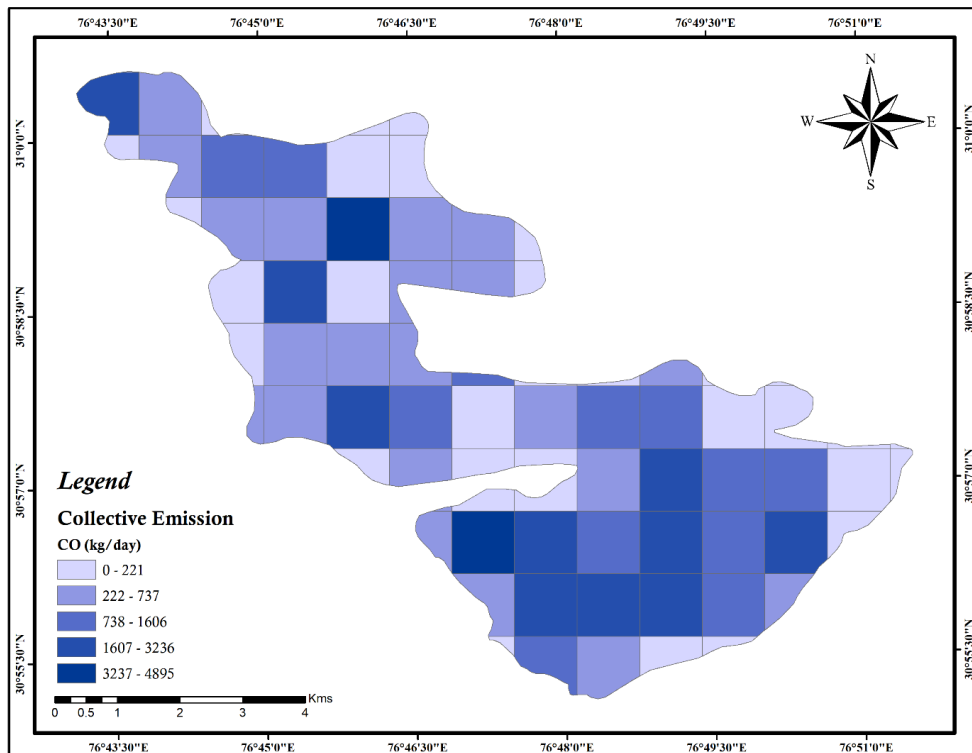


Figure 4.104: Spatial Distribution of CO Emissions in the City of Baddi

5 Receptor Modelling and Source Apportionment

5.1 Receptor Modeling

In a complicated urban atmosphere, to identify and quantify the contribution of multiple emitting sources to air quality is challenging. However, recent advancements in chemical characterization of PM have made it possible to apportion the sources contributing to air pollution, especially of PM. Receptor modeling using source fingerprinting (chemical composition) can be applied quantitatively to know the sources of origin of particles. Mathematical models are frequently used to identify and to adopt the source reductions of environmental pollutants. There are two types of modeling approaches to establish source receptor linkages:

1. Dispersion Modeling and
2. Receptor source Modeling.

The focus of modeling in this chapter is receptor modeling. The receptor model begins with observed ambient airborne pollutant concentrations at a receptor and seeks to apportion the observed concentrations between several source types based on the knowledge of the compositions of the sources and receptor materials (Cooper and Watson, 1980; Watson, 1984; Javitz et al., 1988). There are two generally recognized classes of receptor Models:

- Chemical elemental balance or chemical mass balance (CEM/CMB), and
- Multivariate or a statistical.

In this Chapter, Multivariate Factor analysis tool has been used to fully understand the contribution of each source to ambient air PM₁₀ and PM_{2.5} concentrations.

While (CEM/CMB) methods apportion sources using extensive quantitative source emission profiles, statistical approaches infer source contribution without a prior need of quantitative source composition data (Watson et al., 1994). The CMB method assumes that there is linearity in the concentration of aerosol and their mass is conserved from the time a chemical species is emitted from its source to the time it is measured at a receptor. That is, if p sources are contributing M_j mass of particulates to the receptor (Watson et al., 2004),

$$m = \sum_{j=1}^p M_j$$

$$F'_{ij} = F_{ij}$$

where, m is the total mass of the particulate collected on a filter at a receptor site, F'_{ij} is the fraction of chemical species i in the mass from source j collected at the receptor and F_{ij} is the fraction of chemical i emitted by source j as measured at the source. The mass of the specific species, m_i , is given by the following:

$$m_i = \sum_{j=1}^p M_{ij} = \sum_{j=1}^p F'_{ij} M_j$$

Where, M_{ij} is the mass of element i contributed to the receptor from source j . Dividing both sides of equation by the total mass of the deposit collected at the receptor site, it follows that

$$C_i = \sum_{j=1}^p F_{ij} S_j$$

where, C_i is the concentration of chemical component i measured at the receptor (air filter) and S_j is the source contribution; that is, the ratio of the mass contributed from source j to the total mass collected at receptor site.

If the C_i and F_{ij} at the receptor for all p of the source types suspected of affecting the receptor are known, and $p \leq n$ (n = number of the species), a set of n simultaneous equations exist from which the source type contribution S_j may be calculated by least square methods. The software used for apportioning the sources is PMF5.0, developed by USEPA (2004).

5.2 PMF Modeling: Source Apportionment of PM₁₀ and PM_{2.5}

USEPA's PMF5.0 (USEPA, 2014), is a multivariate factor analysis tool that solves a matrix of speciated data of samples into two matrices: factor contributions (S) and source profiles (F). The resolved source profiles were interpreted to identify the contributing sources at the receptor based on the reported source profiles and emissions inventories. The PMF model derives the source contributions and profiles through minimizing the critical parameter that is called objective function Q (given below) (USEPA, 2014).

$$Q = \sum_{k=1}^n \sum_{i=1}^m \left[\frac{C_{ik} - \sum_{j=1}^p F_{ij} S_{jk}}{u_{ik}} \right]^2$$

Where m is the number of chemical species, n is the number of samples, and P is the number of source factors/profiles.

Ambient PM₁₀ and PM_{2.5} observations with chemical composition were used for apportionment of sources for about 70 samples of PM₁₀ and PM_{2.5} (7 samples at each site for each pollutant) collected from December 29, 2019 – January 19, 2020 in winter at five sites in Baddi.

The PMF identified contributing sources through minimizing the objective function Q within 10% uncertainty. The results with the lowest Q_{robust} are analysed in terms of R-square and percent mass (predicted to measured).

The apportioned factors are assigned to the sources based on their fingerprint species contributing in the factor collected from the literature. The results of PMF5.0 for Baddi are described in the next section.

5.3 PMF Modeling Results and interpretation (Baddi)

It may be noted that vehicles and diesel generators (DGs) include all vehicles powered by gasoline, diesel, CNG, DGs, LPG from domestic cooking. The Coal and fly ash source include coal and residual oil combustion and fly ash. The factors of similar nature are considered as a single entity for better clarity.

The mean contributions of species in the source profiles for PM₁₀ and PM_{2.5} are presented in Figure 5.1. The results showed the R-square was above 0.98 for both PM₁₀ and PM_{2.5} and the percent mass accounted was over 80%. Tables 5.1 and 5.2 presents a summary of the source concentration of PM₁₀ and PM_{2.5} for all the five sites and the overall city. Figures 5.2 and 5.3 present a site-wise comparison of source contribution in terms of concentration and percentage of PM₁₀ and PM_{2.5}.

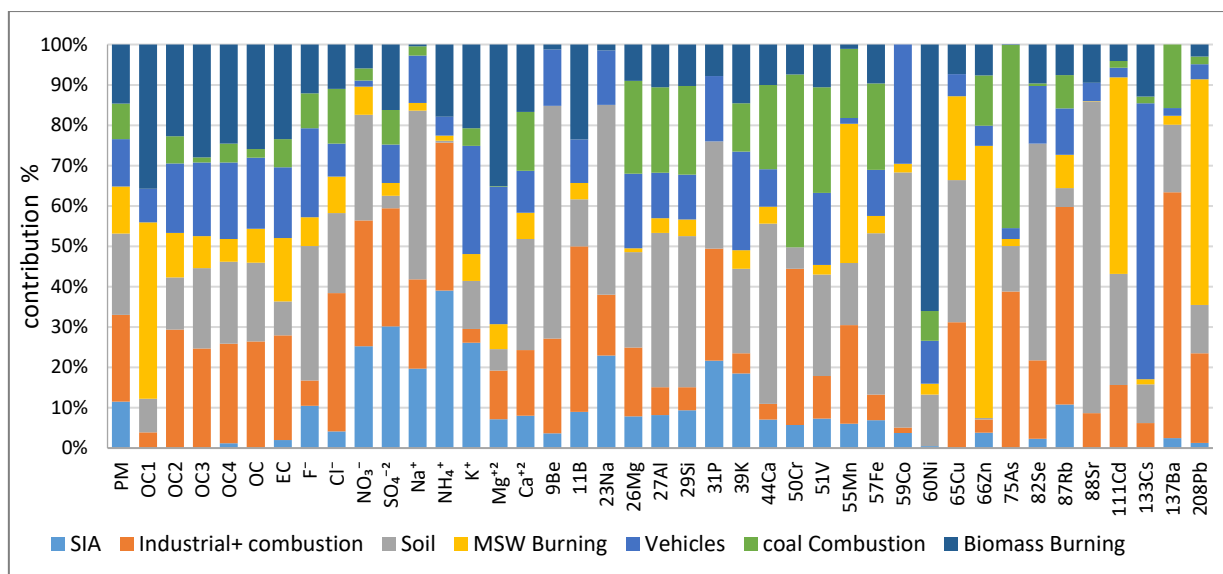


Figure 5.1: PMF-based Source profiles for PM_{10} and $PM_{2.5}$

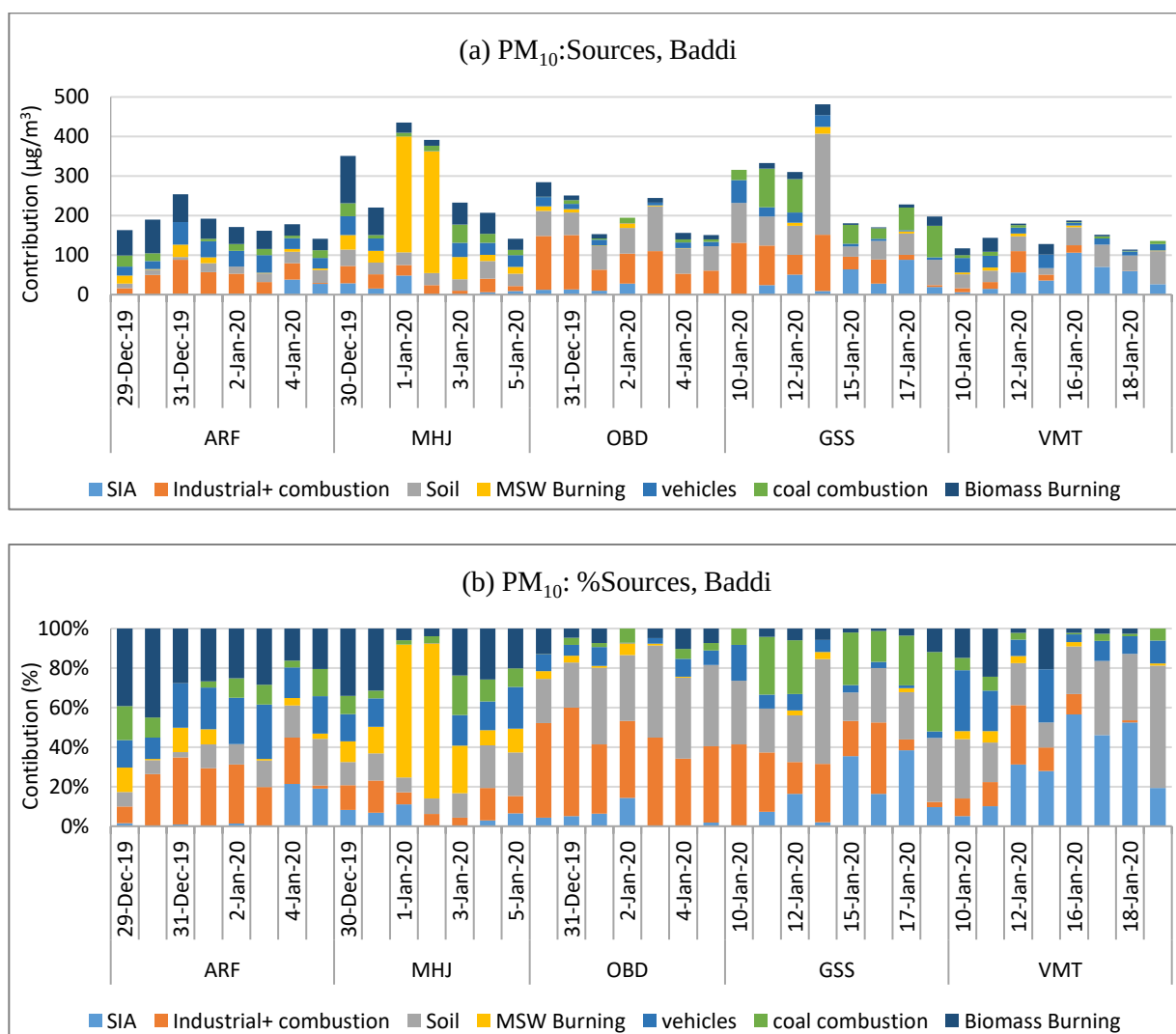


Figure 5.2: PMF modeling Results for PM_{10} at all sites

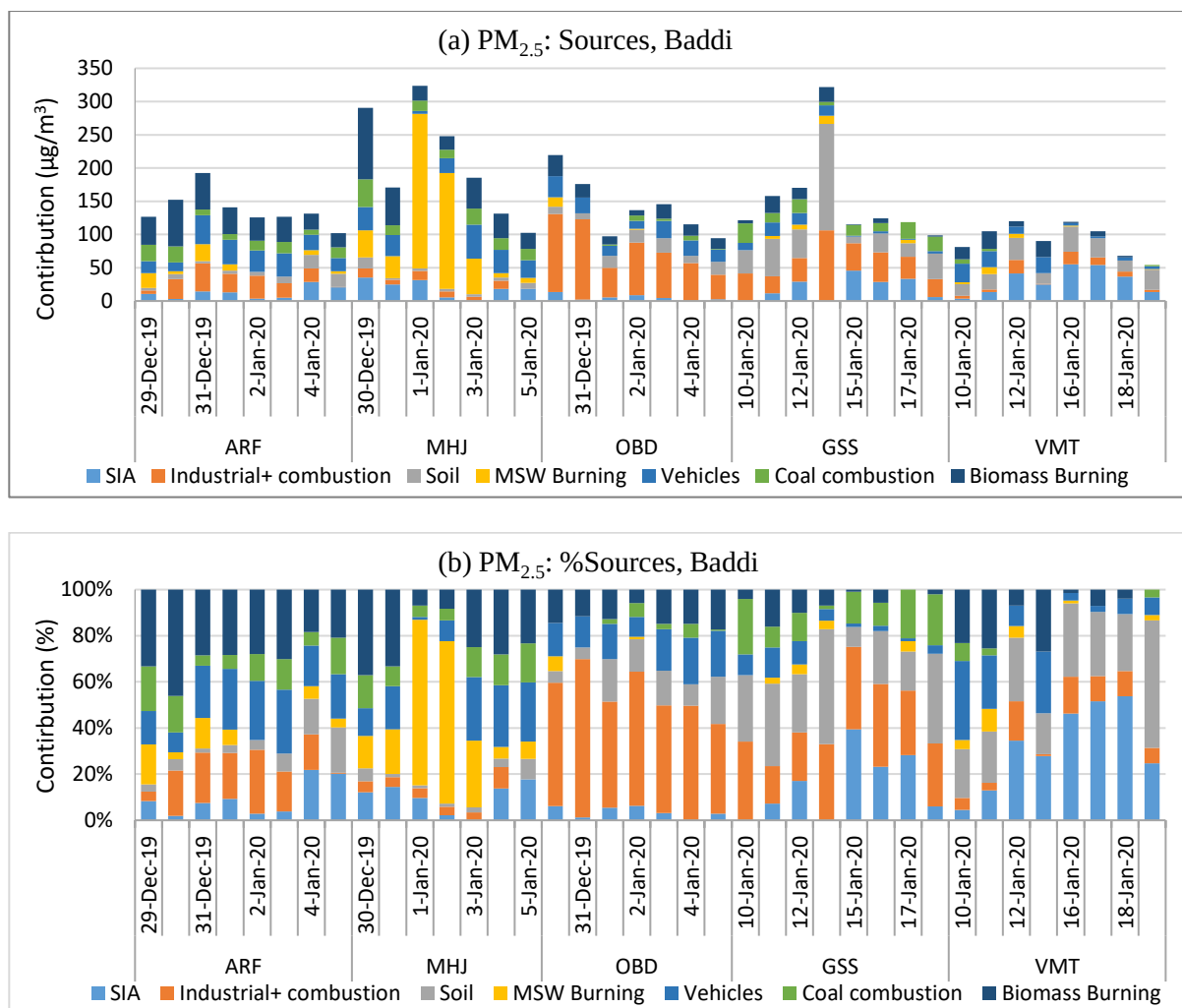


Figure 5.3: PMF modeling Results for PM_{2.5} at all sites

5.3.1 MHJ

PM₁₀

The average PM₁₀ concentration was 286 µg/m³. Figure 5.2 represents PM₁₀ contribution of sources in terms of concentration, and percent contribution of sources at all sites (MHJ represented in 2nd part of the graphs). Figure 5.4(a) represents PM₁₀ overall contribution in terms of the percentage of sources at MHJ. It is observed that the major PM₁₀ source contributing to PM₁₀ was MSW burning (108 µg/m³ – 38%) followed by biomass burning (52 µg/m³ – 19%). The other sources are soil and road dust (34 µg/m³ – 12%), industrial emission (9%), vehicular emission (9%), coal combustion (8%), and secondary inorganic aerosol (SIA; 5%).

PM_{2.5}

The average PM_{2.5} concentration was 210 µg/m³ (i.e., about 0.73 of PM₁₀). Figure 5.3 represents PM_{2.5} contribution of sources in terms of concentration, and percent contribution of sources at all sites (MHJ represented in 2nd part of the graphs). Figure 5.4(b) represents PM_{2.5} overall contribution in terms of the percentage of sources. It is observed that the major PM_{2.5} source contributing to PM_{2.5} was MSW burning (78 µg/m³ – 38%) followed by biomass burning (45 µg/m³ – 22%). The other sources are vehicular emission (29 µg/m³ – 14%), coal combustion (21 µg/m³ – 10%), SIA (9%), industrial emission (4%), soil and road dust (3%) and.

HYSPLIT back trajectories (Figure 5.5) indicate that wind is flowing from NW and SE directions. Winds can pick up the pollutants on the way, especially from large sources (e.g., power plants, open burning) and tall emitting sources but these contributions have not been quantified (this is similar for all sites).

Inferences

- The MSW and biomass burning contribution has significant. It is clearly seen that MSW burning is a major source that contributes to PM₁₀ and PM_{2.5}. MSW burning emission is expected to be large from regions of economically lower strata of society that do not have proper infrastructure for collection and disposal of solid waste. Biomass burning emissions are could be due to the uses of solid fuels (wood, dung) for cooking and heating in winter.
- Vehicle contribution increased to 14% in PM_{2.5} compared to PM₁₀ (9%).
- Soil and road dust contribution reduced to 3% in PM_{2.5} compared to 12% in PM₁₀. These reductions in emissions during the winter season may be due to low wind speed (more calm conditions).
- The secondary particles contribute to PM₁₀ (5%) and PM_{2.5} (9%). These particles are expected to source from precursor gases (SO₂ and NO_x) emitted from far distances. However, the contribution of NO_x from local sources, especially vehicles and power plants can also contribute to nitrates. For sulfates, the major contribution can be attributed to large power plants and refineries from long distances.
- An industrial source has a significant contribution to PM other than coal combustion.

5.3.2 OBD

PM₁₀

The average PM₁₀ concentration was 205 $\mu\text{g}/\text{m}^3$. Figure 5.2 represents PM₁₀ contribution of sources in terms of concentration, and percent contribution of sources at all sites (OBD represented in 3rd part of the graphs). Figure 5.6(a) represents PM₁₀ overall contribution in terms of the percentage of sources at OBD. It is observed that the major PM₁₀ source contributing to PM₁₀ was industrial emission (89 $\mu\text{g}/\text{m}^3$ – 44%) followed by soil and road dust (69 $\mu\text{g}/\text{m}^3$ – 34%). The other sources are biomass burning (14 $\mu\text{g}/\text{m}^3$ – 7%), vehicular emission (6%), SIA (4%), coal combustion (3%) and MSW burning (2%).

PM_{2.5}

The average PM_{2.5} concentration was 137 $\mu\text{g}/\text{m}^3$ (i.e., about 0.67 of PM₁₀). Figure 5.3 represents PM_{2.5} contribution of sources in terms of concentration, and percent contribution of sources at all sites (OBD represented in 3rd part of the graphs). Figure 5.6(b) represents PM_{2.5} overall contribution in terms of the percentage of sources at OBD. It is observed that the major PM_{2.5} source contributing to PM_{2.5} was industrial emission (75 $\mu\text{g}/\text{m}^3$ – 53%) followed by vehicular emission (21 $\mu\text{g}/\text{m}^3$ – 15%). The other sources are biomass burning (18 $\mu\text{g}/\text{m}^3$ – 13%), soil and road dust (15 $\mu\text{g}/\text{m}^3$ – 11%), SIA (4%), MSW burning (2%) and coal combustion (2%).

HYSPLIT back trajectories (Figure 5.7) indicate that wind is flowing from NW and SE directions.

Inferences

Industrial and combustion sources contribute about 44% in PM₁₀ and 53% in PM_{2.5}. Soil and road dust contribution reduced to 11% in PM_{2.5} compared to 34% in PM₁₀. Vehicles and biomass burning contribution increase significantly in PM_{2.5}.

5.3.3 ARF

PM₁₀

The average PM₁₀ concentration was 181 $\mu\text{g}/\text{m}^3$. Figure 5.2 represents PM₁₀ contribution of sources in terms of concentration, and percent contribution of sources at all sites (ARF represented in 1st part of the graphs). Figure 5.8(a) represents PM₁₀ overall contribution in terms of the percentage of sources at ARF. It is observed that the major PM₁₀ source contributing to PM₁₀ was biomass burning (52 $\mu\text{g}/\text{m}^3$ – 29%) followed by industrial emission (42 $\mu\text{g}/\text{m}^3$ – 23%). The other sources are vehicular emission (35 $\mu\text{g}/\text{m}^3$ – 19%), soil and road dust (20 $\mu\text{g}/\text{m}^3$ – 11%), coal combustion (8%) and MSW burning (5%), SIA (5%).

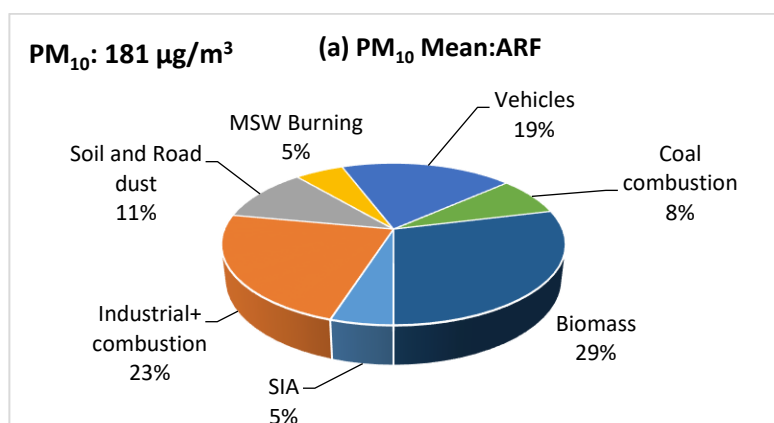
PM_{2.5}

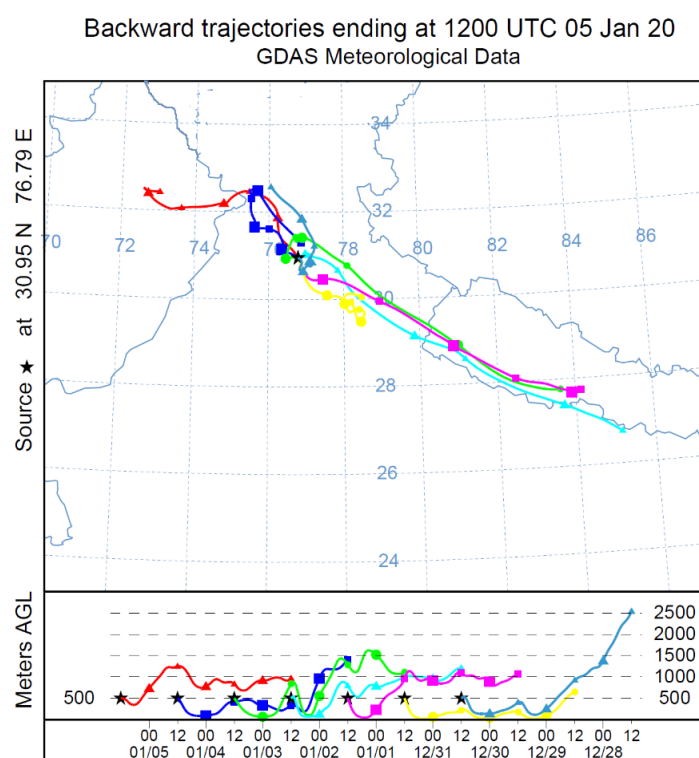
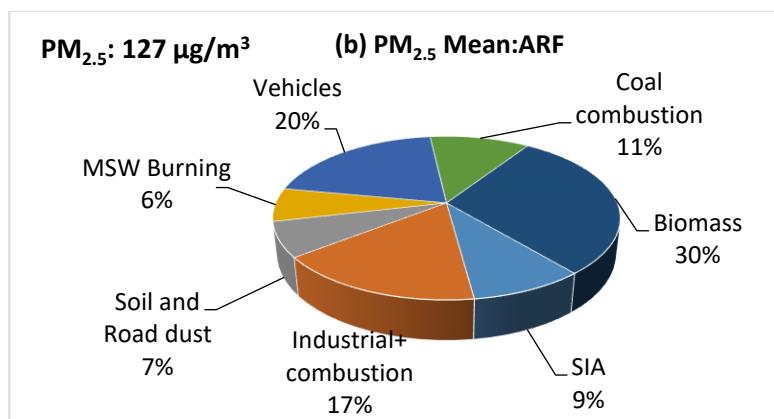
The average PM_{2.5} concentration was 127 $\mu\text{g}/\text{m}^3$ (i.e., about 0.7 of PM₁₀). Figure 5.3 represents PM_{2.5} contribution of sources in terms of concentration, and percent contribution of sources at all sites (ARF represented in 1st part of the graphs). Figure 5.8(b) represents PM_{2.5} overall contribution in terms of the percentage of sources at ARF. It is observed that the major PM_{2.5} source contributing to PM_{2.5} was biomass burning (41 $\mu\text{g}/\text{m}^3$ – 30%) followed by vehicular emission (28 $\mu\text{g}/\text{m}^3$ – 20%). The other sources are industrial emission (23 $\mu\text{g}/\text{m}^3$ – 17%), coal combustion (15 $\mu\text{g}/\text{m}^3$ – 11%), SIA (9%), MSW Burning (7%) and soil and road dust (7%).

HYSPLIT back trajectories (Figure 5.9) indicate that wind is flowing from NW and SE directions.

Inferences

Industrial and combustion sources contribute about 23% in PM₁₀ and 17% in PM_{2.5}. Biomass burning contribution was very high. It could be due to the use of solid fuels (wood). Vehicle contribution is also high in PM₁₀ and PM_{2.5}.





5.3.4 GSS

PM₁₀

The average PM₁₀ concentration was 274 µg/m³. Figure 5.2 represents PM₁₀ contribution of sources in terms of concentration, and percent contribution of sources at all sites (GSS represented in 4th part of the graphs). Figure 5.10(a) represents PM₁₀ overall contribution in terms of the percentage of sources at GSS. It is observed that the major PM₁₀ source contributing to PM₁₀ was soil and road dust (87 µg/m³ – 31%) followed by industrial emission

($67 \mu\text{g}/\text{m}^3$ – 24%). The other sources are coal combustion ($53 \mu\text{g}/\text{m}^3$ – 19%), SIA (13%), vehicular emission (7%), biomass burning (5%) and MSW burning (1%).

PM_{2.5}

The average PM_{2.5} concentration was $146 \mu\text{g}/\text{m}^3$ (i.e., about 0.53 of PM₁₀). Figure 5.3 represents PM_{2.5} contribution of sources in terms of concentration, and percent contribution of sources at all sites (GSS represented in 4th part of the graphs). Figure 5.10(b) represents PM_{2.5} overall contribution in terms of the percentage of sources at GSS. It is observed that the major PM_{2.5} source contributing to PM_{2.5} was soil and road dust ($49 \mu\text{g}/\text{m}^3$ – 32%) followed by industrial emission ($43 \mu\text{g}/\text{m}^3$ – 29%). The other sources are SIA ($20 \mu\text{g}/\text{m}^3$ – 12%), coal combustion (12%), biomass burning (6%), vehicular emission (6%) and MSW burning (2%).

HYSPLIT back trajectories (Figure 5.11) indicate that wind is flowing from NW and SE directions.

Inferences

Soil and road dust contribution was high in PM₁₀ (31%) and PM_{2.5} (32%). Industrial and combustion sources contribute about 24% in PM₁₀ and 29% in PM_{2.5}. Coal combustion reduced to 12% in PM_{2.5} compared to PM₁₀ (19%).

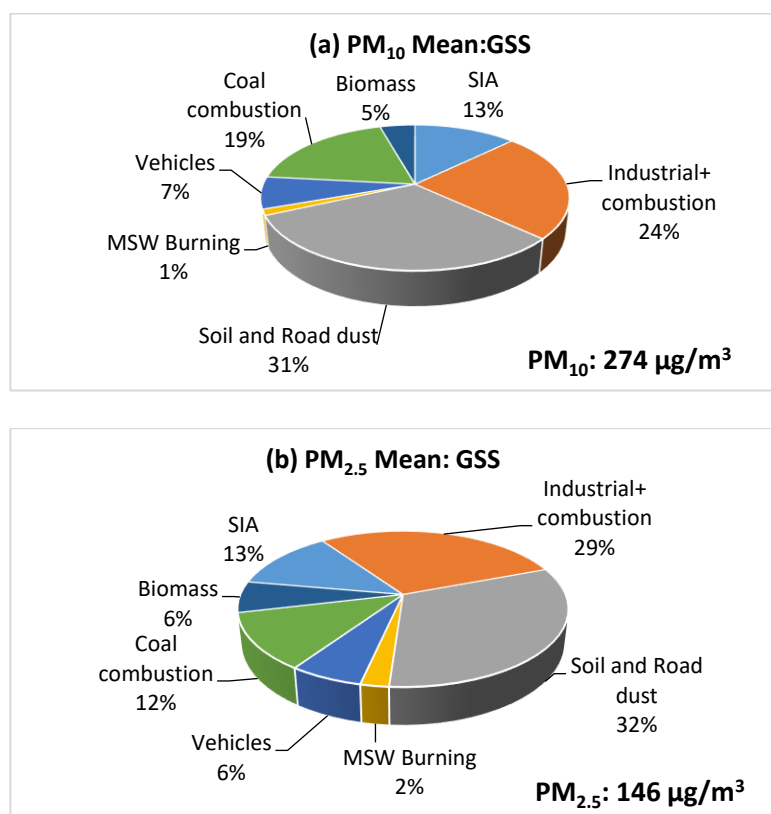


Figure 5.10: PMF modeling for (a) PM₁₀ and (b) PM_{2.5} at GSS

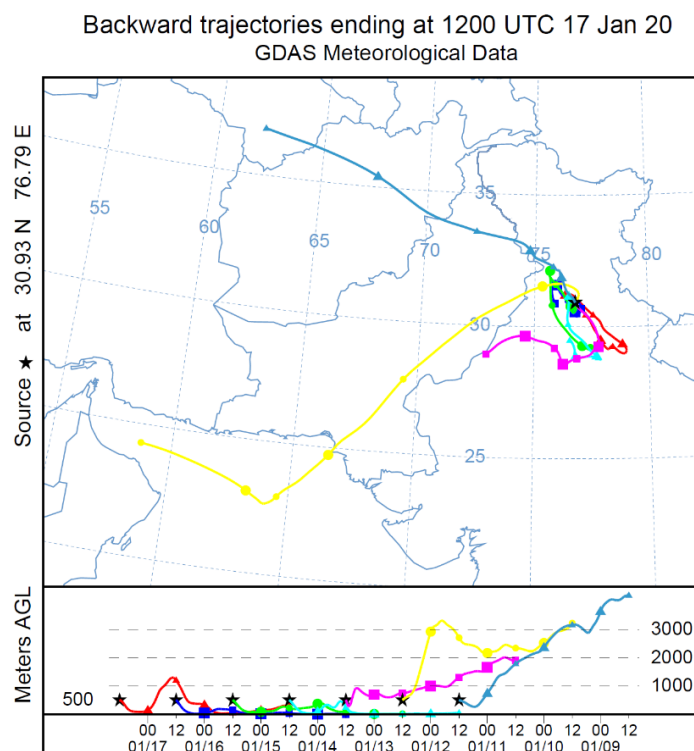


Figure 5.11: Backward trajectories at GSS

5.3.5 VMT

PM₁₀

The average PM₁₀ concentration was 142 $\mu\text{g}/\text{m}^3$. Figure 5.2 represents PM₁₀ contribution of sources in terms of concentration, and percent contribution of sources at all sites (VMT represented in 5th part of the graphs). Figure 5.12(a) represents PM₁₀ overall contribution in terms of the percentage of sources at VMT. It is observed that the major PM₁₀ source contributing to PM₁₀ was SIA (47 $\mu\text{g}/\text{m}^3$ – 32%) followed by soil and road dust (43 $\mu\text{g}/\text{m}^3$ – 30%). The other sources are vehicular emission (20 $\mu\text{g}/\text{m}^3$ – 14%), biomass burning (8%), industrial emission (10%), coal combustion (4%) and MSW burning (2%).

PM_{2.5}

The average PM_{2.5} concentration was 87 $\mu\text{g}/\text{m}^3$ (i.e., about 0.61 of PM₁₀). Figure 5.3 represents PM_{2.5} contribution of sources in terms of concentration, and percent contribution of sources at all sites (VMT represented in 5th part of the graphs). Figure 5.12(b) represents PM_{2.5} overall contribution in terms of the percentage of sources. It is observed that the major PM_{2.5} source contributing to PM_{2.5} was SIA (30 $\mu\text{g}/\text{m}^3$ – 33%) followed by soil and road dust (25 $\mu\text{g}/\text{m}^3$ –

27%). The other sources are vehicular emission ($13 \mu\text{g}/\text{m}^3 - 14\%$), biomass burning (12%), industrial emission (9%), MSW burning (3%) and coal combustion (2%).

HYSPLIT back trajectories (Figure 5.13) indicate that wind is flowing from NW and SE directions.

Inferences

Soil and road dust contribution reduced to 27% (in $\text{PM}_{2.5}$) compared to 30% (of PM_{10}). SIA contributes about 32% to PM_{10} and 33% to $\text{PM}_{2.5}$. Biomass burning increased to 12% in $\text{PM}_{2.5}$ compared to PM_{10} (8%). Vehicles also contribute significantly to PM_{10} (14%) and $\text{PM}_{2.5}$ (14%).

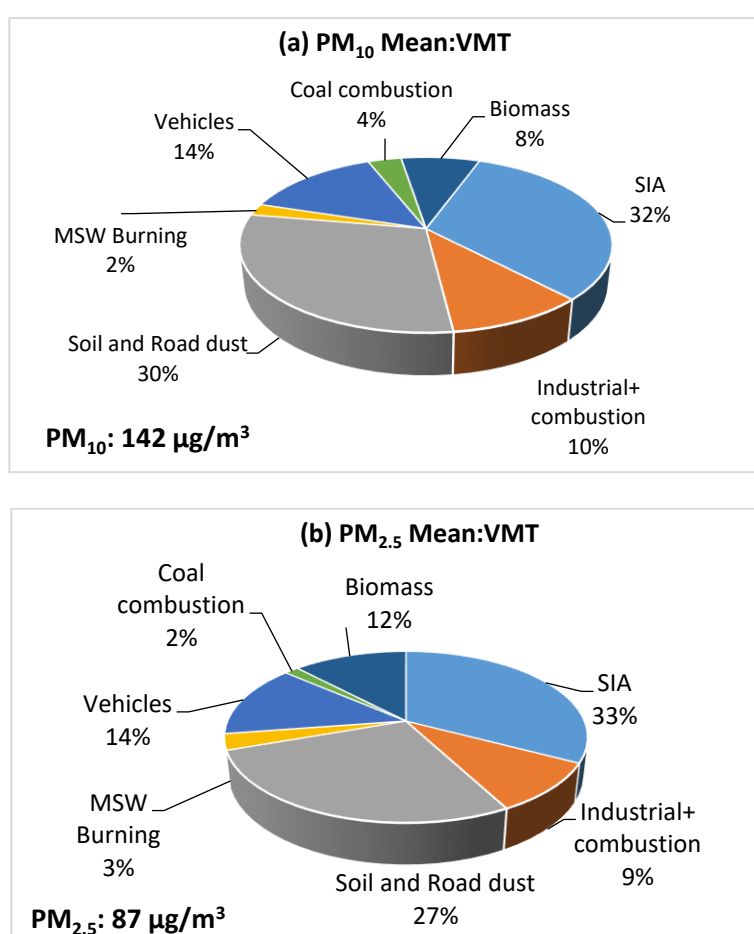


Figure 5.12: PMF modeling for (a) PM_{10} and (b) $\text{PM}_{2.5}$ at VMT

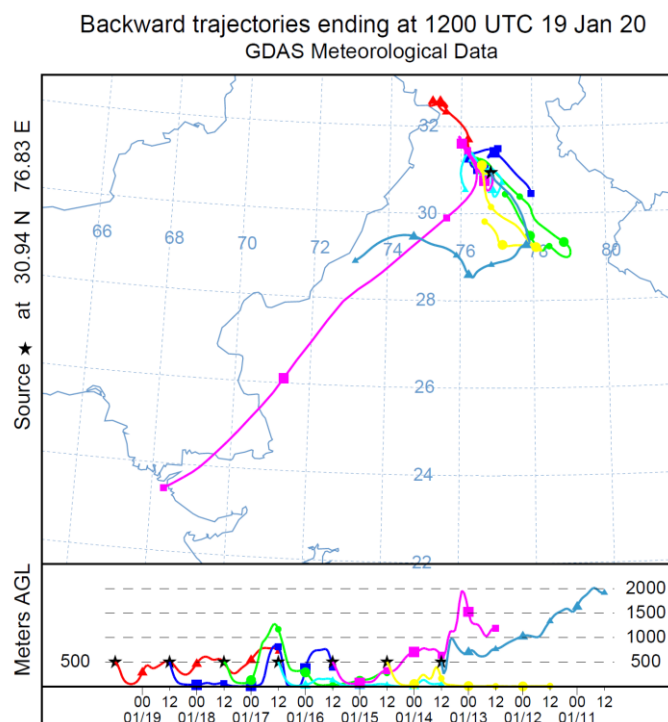


Figure 5.13: Backward trajectories at VMT

5.3.6 Overall

The overall summary of PMF modeling results is shown in Figures 5.14 – 5.15. Tables 5.1 – 5.2 provide a summary of overall statistics.

PM₁₀

The average PM₁₀ concentration was 216 $\mu\text{g}/\text{m}^3$. Figure 5.14(a) represents a site-wise comparison of PM₁₀ contributing sources and Figure 5.15(a) represents the overall contribution in terms of concentration and percentage of sources for the Baddi city. It is observed that the major PM₁₀ source contributing to PM₁₀ was soil and road dust (51 $\mu\text{g}/\text{m}^3 \sim 23\%$) followed by industrial emission (48 $\mu\text{g}/\text{m}^3 \sim 22\%$). The other major sources are biomass burning (29 $\mu\text{g}/\text{m}^3 \sim 13\%$), MSW burning (26 $\mu\text{g}/\text{m}^3 \sim 12\%$), SIA (23 $\mu\text{g}/\text{m}^3 \sim 11\%$), vehicular emission (22 $\mu\text{g}/\text{m}^3 \sim 10\%$) and coal combustion (20 $\mu\text{g}/\text{m}^3 \sim 9\%$).

PM_{2.5}

The average PM_{2.5} concentration was 140 $\mu\text{g}/\text{m}^3$ (i.e., about 0.65 of PM₁₀). Figure 5.14(b) represents a site-wise comparison of PM_{2.5} contributing sources. Figure 5.15(b) represents the overall contribution in terms of concentration and percentage of sources for the city. It is observed that the major PM_{2.5} source contributing to PM_{2.5} was industrial emission (32 $\mu\text{g}/\text{m}^3 \sim 22\%$) followed by biomass burning (25 $\mu\text{g}/\text{m}^3 \sim 17\%$). The other major are sources soil and

road dust ($21 \mu\text{g}/\text{m}^3 \sim 14\%$), vehicular emission ($20 \mu\text{g}/\text{m}^3 \sim 14\%$), MSW burning ($19 \mu\text{g}/\text{m}^3 \sim 13\%$), SIA ($17 \mu\text{g}/\text{m}^3 \sim 12\%$) and coal combustion ($12 \mu\text{g}/\text{m}^3 \sim 8\%$).

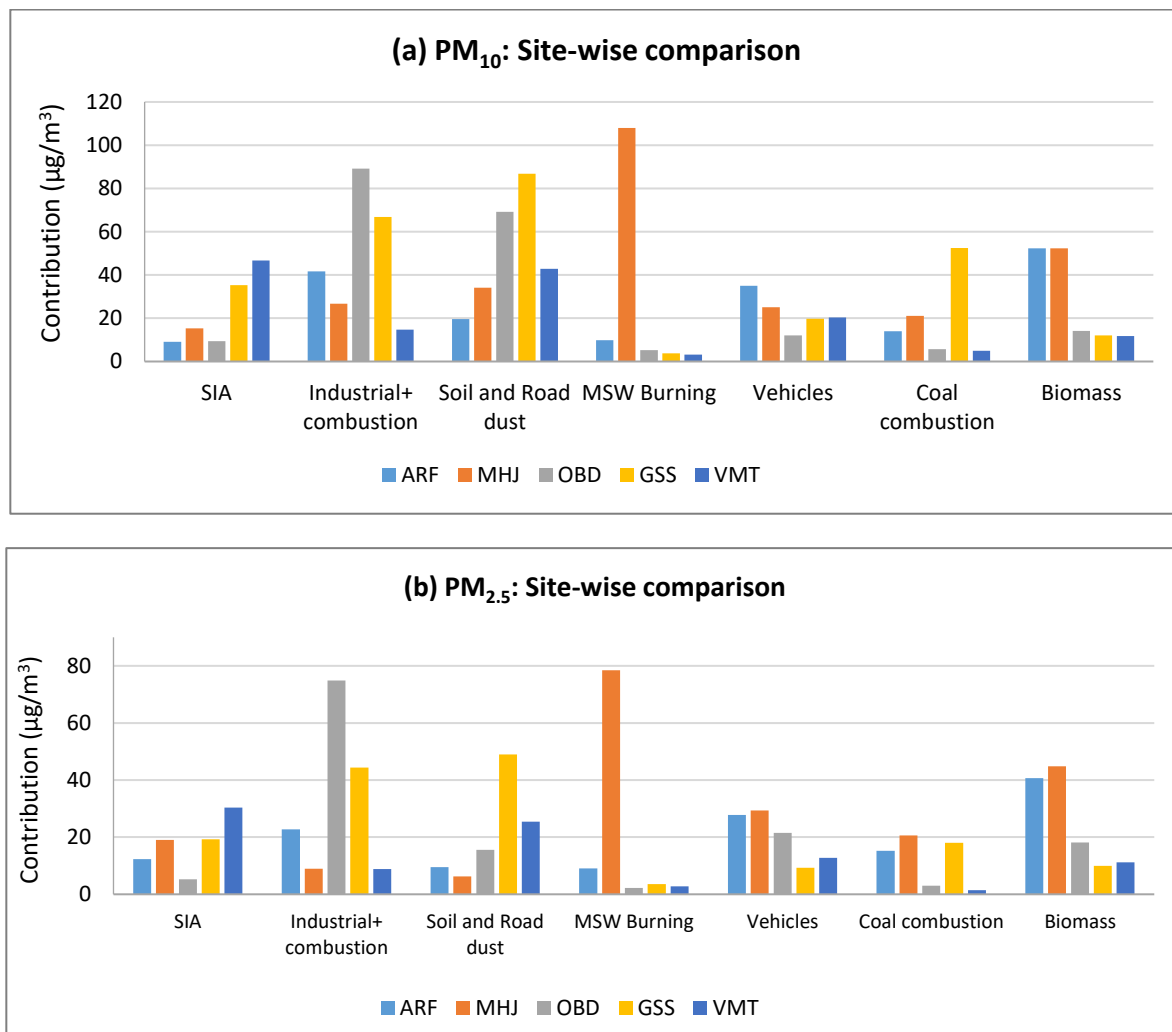
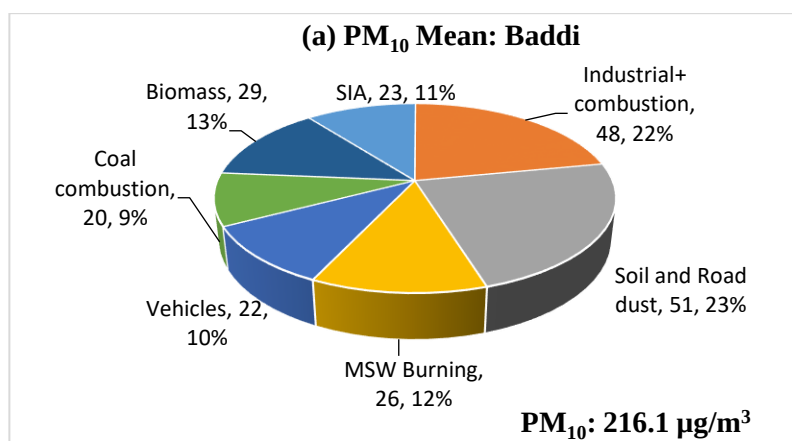


Figure 5.14: source concentration comparison at sites for (a) PM₁₀ and (b) PM_{2.5} at all sites



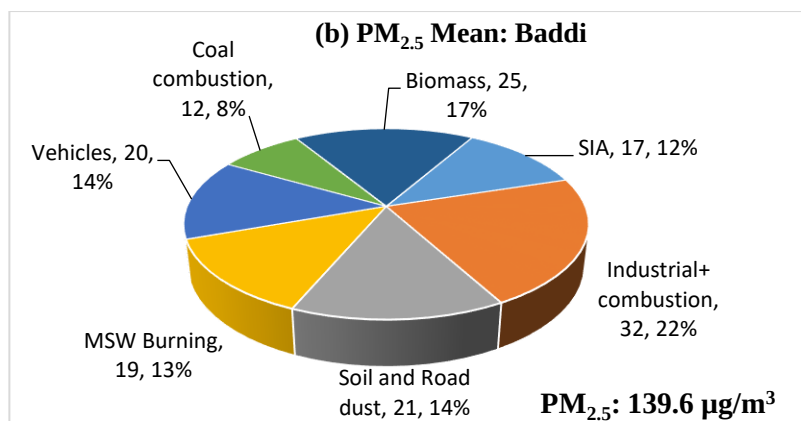


Figure 5.15: PMF modeling for (a) PM₁₀ and (b) PM_{2.5} at Baddi

Table 5.1: Summary of source concentration of PM₁₀: BADDI

Site	Parameter	Measured PM ₁₀	Calculated PM ₁₀	% Mass	% Source Contribution						
					SIA	Industrial+ combustion	Soil and Road dust	MSW Burning	vehicles	coal combustion	Biomass Burning
ARF	Mean	180.87	181.38	101.29	5.54	21.56	11.61	5.02	19.22	8.42	28.63
	SD	42.74	33.50	6.32	9.13	11.25	6.46	5.16	5.58	5.83	9.38
MHJ	Mean	285.76	282.81	99.35	5.09	10.08	13.81	30.51	11.32	8.49	20.70
	SD	106.82	109.34	9.28	4.23	5.02	5.93	29.61	8.08	6.15	11.79
OBD	Mean	205.25	204.78	100.92	4.55	42.07	35.12	2.27	6.11	3.09	6.80
	SD	62.70	54.91	8.14	4.96	7.53	9.42	2.24	3.49	2.57	4.21
GSS	Mean	274.41	276.97	100.84	15.69	22.42	28.62	1.02	6.40	21.55	4.31
	SD	103.63	104.83	4.88	14.43	14.13	11.48	1.47	5.28	12.85	3.69
VMT	Mean	141.80	144.50	102.29	31.09	9.30	30.17	2.08	15.13	3.51	8.71
	SD	28.15	27.10	5.53	19.26	9.88	15.12	2.16	9.75	2.67	9.73
OVERALL	Mean	216.15	216.74	100.98	12.79	20.82	23.83	7.75	11.79	9.18	13.83
	SD	90.29	88.85	6.59	15.55	15.17	13.61	16.47	8.28	9.67	12.39
	CV	0.42	0.41	0.07	1.22	0.73	0.57	2.13	0.70	1.05	0.90
	MAX	482.33	481.29	112.68	56.57	54.96	61.92	78.53	30.88	40.26	45.05
	MIN	105.13	113.72	86.57	0.00	0.00	2.58	0.00	0.00	0.00	0.00

Table 5.2: Summary of source concentration of PM_{2.5}: BADDI

Site	Parameter	Measured PM _{2.5}	Calculated PM _{2.5}	% Mass	% Source Contribution						
					SIA	Industrial+ combustion	Soil and Road dust	MSW Burning	vehicles	coal combustion	Biomass Burning
ARF	Mean	127.17	137.20	109.32	9.46	15.76	7.59	6.18	20.26	11.58	29.16
	SD	32.62	26.54	8.29	7.61	9.11	6.50	6.18	6.56	5.54	8.37
MHJ	Mean	210.09	207.46	99.70	10.01	4.24	3.44	31.04	17.25	10.92	23.10
	SD	84.63	82.45	7.59	6.60	2.71	2.85	28.48	10.15	4.72	11.61
OBD	Mean	136.94	140.67	104.42	3.59	51.67	12.45	1.08	15.70	2.44	13.07
	SD	49.97	44.97	6.76	2.48	9.62	6.13	2.41	4.09	2.65	3.69
GSS	Mean	145.80	153.51	105.05	15.15	28.91	28.37	1.89	5.75	14.22	5.72
	SD	63.29	71.87	9.51	14.32	7.24	13.00	2.09	4.43	7.71	5.34
VMT	Mean	86.84	92.81	108.03	32.03	8.86	28.53	2.81	14.14	1.77	11.86
	SD	25.82	23.79	9.05	17.96	5.79	11.65	3.43	12.10	2.83	11.32
OVERALL	Mean	139.68	144.87	105.48	14.43	21.57	16.50	8.21	14.52	8.27	16.50
	SD	65.09	63.30	8.58	14.74	18.17	13.69	16.33	9.19	7.09	11.91
	CV	0.47	0.44	0.08	1.02	0.84	0.83	1.99	0.63	0.86	0.72
	MAX	316.13	323.86	122.30	53.83	68.65	55.22	71.78	34.26	23.95	46.04
	MIN	51.12	54.17	87.40	0.00	0.00	1.19	0.00	1.28	0.00	0.00

5.4 Interpretations and Inferences

Based on the PMF modeling results (Figures 5.14 and 5.15) and their critical analyses, the following inferences and insights are drawn to establish quantified source-receptor impacts and to pave the path for the preparation of an action plan. Tables 5.1 to 5.2, show site-specific average source contribution to PM₁₀ and PM_{2.5}, and these tables are frequently referred to bring the important inferences to the fore.

- The relative sources contributions of PM₁₀ and PM_{2.5} in ambient air quality are generally the same. The sources (% contribution given in parenthesis for PM₁₀ - PM_{2.5} to the ambient air levels) include secondary inorganic aerosol (SIA) (13 – 14%), industrial and combustion (21 – 22%), soil and road dust (24 – 17%), MSW burning (8 – 8%), vehicles (12 – 15%), and biomass burning (14 – 17%).
- The most consistent sources for PM₁₀ and PM_{2.5} are vehicles, soil and road dust and industrial emissions. On average, the other sources may contribute more (or less), but their contributions vary from day to day. The most variable source was MSW burning, followed by SIA. Biomass burning was consistent in PM_{2.5}, but it was not true for PM₁₀.
- Soil and road dust contribute 24% in PM₁₀ and 17% in PM_{2.5}, showing high variability in the city, which infers that the road condition in the city is not up to the mark. It indicates that most parts of roads and kerb-sides were poorly maintained.
- The contribution of biomass burning is relatively high at 14% (for PM₁₀) and 17% (for PM_{2.5}). Sizeable biomass is consistent in PM, indicating local sources present in Baddi and nearby areas. Biomass burning is because of arboriculture activities, agricultural residue burning, high energy crop burning for fuel, etc.
- From the uncollected solid waste, the major part would be burned. It is seen that MSW burning is a major source that contributes to both PM₁₀ and PM_{2.5} (8%). This emission is expected to be large in the regions of economically lower strata of the society, which do not have proper infrastructure for collection and disposal of MSW.
- MHJ site was surrounded by several industries. Therefore, it has the movement of large trucks ferrying raw material and finished products. Poor road conditions were spotted and dumping and burning of MSW and plastic waste along the roadsides was a routine practice. The MSW/plastic burning contribution is exceptionally high at

31% both in PM₁₀ and PM_{2.5} that indicating improper management of waste generated from industries.

- Industrial contribution (22%) in the city is high for both PM₁₀ and PM_{2.5}, which are in conformance with the fact that the city has a large number of industries. Industrial emission affirms that the fuels used both in domestic and industries are not of the clean category. Most of the industrial emissions are from combustion and process emissions. It may be noted that industrial emissions are only 5% of PM₁₀, but their contribution is much higher at the breathing level.
- Secondary inorganic aerosol is significant in both PM₁₀ (13%) and PM_{2.5} (14%).
- Vehicles' contribution is consistent in PM₁₀ (12%) and PM_{2.5} (15%) in the city.

Directions for PM control

- Industrial and combustion sources

The industrial units in the Baddi must comply with the norms notified by the HPSPCB. There might be some unauthorized industries in Baddi that must be closed. The industries must shift to bag filters (or equivalent control devices) and in the next two years coal must be phased out from all industries.

- Soil and road dust

This source contributes about 24% to PM₁₀. The silt load on some of the road is very high and silt can become airborne with the movement of vehicles. The estimated PM₁₀ emission from road dust is over 45 tons per day. Similarly, soil from the open fields gets airborne due to agricultural operations. The potential control options can be sweeping and watering roads, better construction and maintenance, growing plants, grass, etc. to prevent the resuspension of dust.

- Biomass burning

Biomass burning should be minimized if not completely stopped. Possibly it could be switched to cleaner fuel for domestic fuel, local bakery and hotels industries and other local thermal energy-consuming industries in industries. All biomass burning should be stopped and strictly implemented.

- MSW burning

One of the reasons for burning MSW is lack of infrastructure for timely collection of MSW and people conveniently burn or it may smolder slowly for a long time. In this regard, infrastructure for collection and disposal of MSW has to improve and the burning of MSW should be completely banned.

- Coal combustion

Coal combustion contribute about 10% of PM_{10} and unless sources contributing to flyash are controlled, one cannot expect improvement in air quality. It appears these sources are more of fugitive in nature than regular point sources. Flyash emission from hotels, restaurants and tandoors also cause large emissions and requires better housekeeping and flyash disposal.

- Secondary particles

What are the sources of secondary particles, the major contributors to Baddi's PM? These particles are expected to source from precursor gases (SO_2 , and NO_x) which are chemically transformed into particles in the atmosphere. Mostly the precursor gases are emitted from far distances from large sources. For sulfates, the major contribution can be attributed to large power plants and refineries. However, contribution of NO_x from local sources, especially vehicles and power plants can also contribute to nitrates. Behera and Sharma (2010) for Kanpur have concluded that secondary inorganic aerosol accounted for significant mass of $PM_{2.5}$ (about 34%) and any particulate control strategy should also include control of primary precursor gases.

The effectiveness of the pollution control options and selection of optimal mix of control options are analyzed in Chapter 6.

6 Control options, Analyses and Prioritization for Actions

6.1 Air Pollution Scenario in the City of Baddi

The city of Baddi has a complex urban environment concerning air pollution sources and faces severe air pollution of PM_{10} and $PM_{2.5}$. There are several prominent sources within and outside the city contributing to PM_{10} and $PM_{2.5}$ in ambient air. Chapter 4 presents the emission inventory and Chapter 5 describes the contributions of sources to the ambient air concentrations. Based on the comprehensive source apportionment study, the sources of PM_{10} and $PM_{2.5}$ contribute to ambient air quality in the winter season. The highlights of the source apportionment study are presented below.

The relative sources contributions of PM_{10} and $PM_{2.5}$ in ambient air quality in winter months are generally the same. The sources (% contribution given in parenthesis for PM_{10} - $PM_{2.5}$ to the ambient air levels) include: SIA particles (13 – 14%), industrial and combustion (21 – 22%), soil and road dust (24 – 17%), MSW burning (8 – 8%), vehicles (12 – 15%), and biomass burning (14 – 17%).

Although sources contributing to air pollution are different from season to season, the overall action plan should include control of all sources regardless of the season. This chapter presents various air pollution control options and their effectiveness in improving air quality. At the end of the chapter, a time-sensitive action plan is presented (Table 6.2).

6.2 Controlling of sources within the city

6.2.1 Hotels/Restaurants/Banquet Halls

The total number of big hotels and restaurants was approximately 50, mainly situated in the central part of the city and along with the National Highway-105. It was observed that coal/wood is being used as fuel in the tandoor, the common fuel other than wood is LPG. The PM emission in the form of flyash contributes to air pollution from this source.

The banquet halls (BHs) also use diesel generator sets at the time of power failure and coal, especially in tandoor and other cooking. Figure 6.1 was shown the locations of hotels, restaurants, guest houses (GHs) and BHs in Baddi City.

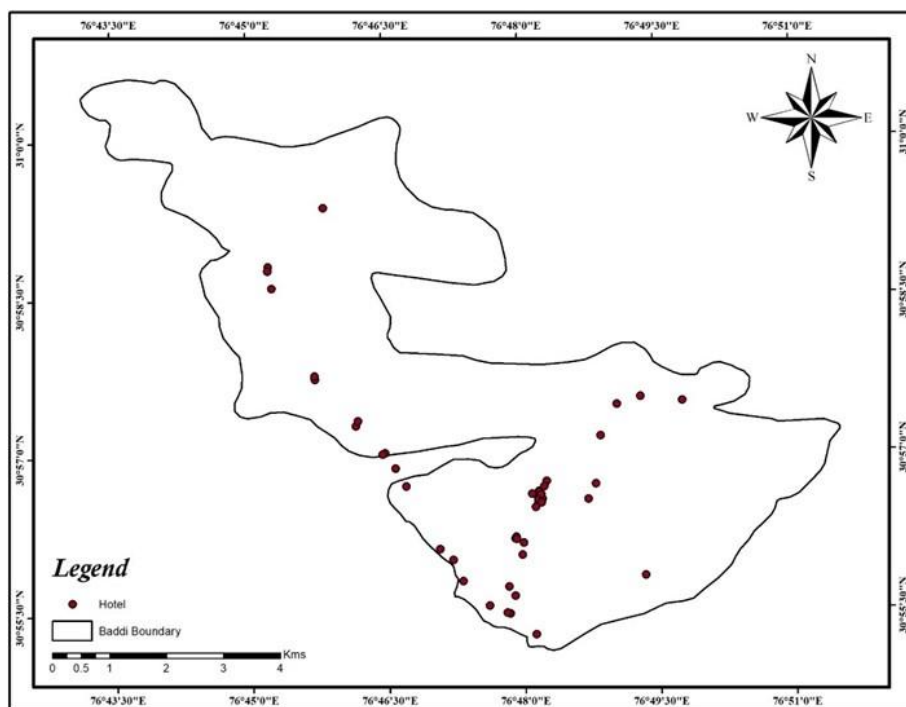


Figure 6.1: Location of Hotels, Restaurants, GHs and BHs in Baddi City

It is also seen that the ash/residue from the tandoor and other activities are indiscriminately disposed of near the roadside. This contributes to road dust emissions. The Municipal Council Baddi should enforce coal-free cooking in the hotels and restaurants, BHs and marriage places. The ash must be stored in hole-free bags and disposed of. One may consider linking the commercial license to clean fuel, which may be enforced by Municipal Council Baddi, Department of Food, Civil Supplies and Consumer Affairs, and oil companies (Indian Oil, HP, etc.). A 70% reduction of PM₁₀ (34 kg/d) and PM_{2.5} (18 kg/d) emissions from the sources can be achieved by stopping the use of coal/wood, and dung cakes.

It is proposed that (i) all restaurants with a sitting capacity of more than 10 should not use coal/wood in any form and shift fully to electric or gas-based appliances (ii) DG sets should be under the designated norms, meet stack height requirements and use only BS-VI fuel with DPF. (iii) DG sets of 2KVA and smaller (operating at ground level) should be banned and one can use an inverter or solar-based generators, and in the long-term, DG sets of 10 KVA and bigger should shift to PNG.

6.2.2 Municipal Solid Waste (MSW) Burning

MSW and other residue burning are rampant in Baddi (Figures 6.2 – 6.3). In winter, the overall PM_{10} and $PM_{2.5}$ contribution from MSW burning is 8% (Figure 5.15, Chapter 5) and stopping this burning is the simplest way to reduce PM_{10} and $PM_{2.5}$ levels. Any form of garbage burning should be strictly stopped and strictly monitored for its compliance. The Municipal Council Baddi should have the provision of penalties and fines to deter the people from burning any residue and improve the collection and disposal of the MSW.

Proper disposal of MSW will require the development of infrastructure (including access to remote and congested areas) for effective collection of MSW and disposal at the scientific landfill site. The Municipal Council Baddi should prioritize the MSW collection mechanism starting systematically in each ward with an emphasis on public awareness. Special attention is required for fruits and vegetable markets, commercial areas, mandis and high-rise residential buildings. Industrial waste burning is dealt with separately.



Figure 6.2: MSW Burning in several parts in Baddi City



Figure 6.3: Solid waste burning in the area

A mechanism should be developed to carry out a mass balance of MSW generation, collection and disposal on a weekly and monthly basis. Major commercial areas identified for this issue were Sai Road, Rotary Chowk, Labour Chowk, and NRI Chowk. Major residential areas (having high density) were Housing Board Colony, Haripur Sandoli, Jhar Majri and Barotiwala.

Desilting and cleaning of municipal drains by Municipal Council Baddi should be undertaken on a regular interval, as the silt with biological activities can cause emission of air pollutants like H_2S , NH_3 , VOCs, etc.

The official MSW dumping sites are located in Kainduwal, having undisposed of waste. The MSW treatment and disposal sites should be developed and operated in complying with MSW waste management rules. The treatment and rightful disposal of fresh waste should not take more than 7 days i.e., as storage becomes a major source of VOCs.

Sensitize people and media through workshops and literature distribution to prevent waste burning and its unauthorized disposal; this activity may be undertaken by Municipal Council Baddi, HPSPCB, NGOs and municipal corporators.

The banning of MSW waste burning can reduce the emissions by 100% of PM₁₀ (43 kg/d) and PM_{2.5} (29 kg/d).

A helpline Number (For reporting complaints about air pollution viz., open burning, fugitive emission due to construction activities, etc.) should be created and advertised.

6.2.3 Brick Kilns

Brick kilns are one of the major contributors to air pollution from the surrounding areas of Baddi. It is important to cover this sector in terms of emissions, although the majority of brick kilns lie outside the city boundary. These brick kiln (outside the city boundary) affects the local air quality of the city. A detailed survey was conducted by the IITK team and activity data were collected. There are approximately 12 brick kilns present in Baddi (Figure 6.4). Some brick kilns were present just at the border of the city, it is important to consider these brick kilns, as they contribute to the city's air pollution. These kilns used wood and coal as prominent fuels.

It has been found that most of the brick kilns were on conventional (Bull-trench) technology and only few on Zig Zag technology (emissions vary for two technologies).

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 with modern pollution control equipment.

The conversion of all brick kilns to Zig-Zag technology can reduce emissions by 60% to 295 kg/d for PM₁₀ and 206 kg/d for PM_{2.5}.

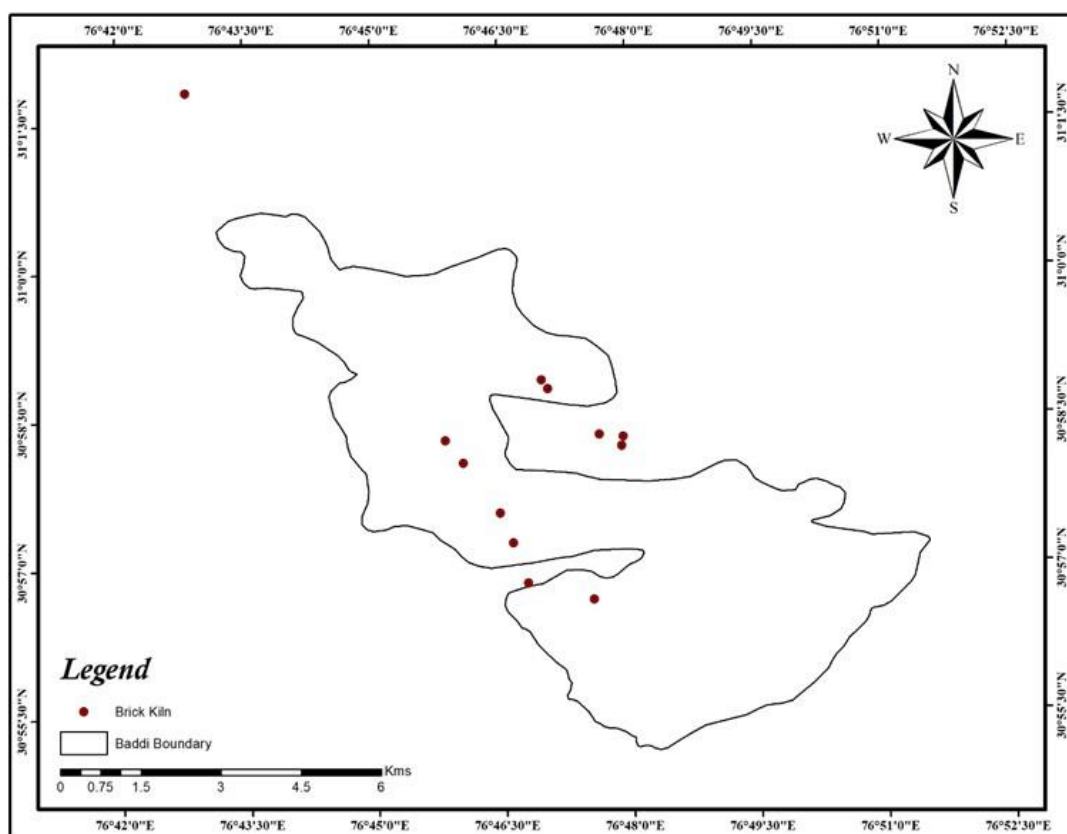


Figure 6.4: Location of Brick Kilns in Baddi City

6.2.4 Construction and Demolition

The construction and demolition (C&D) emission can be classified as temporary or short-term. In a developing urban area, these temporary or short-term construction activities are frequent. This source is one of the significant ground-level emission sources. Nearly at all the construction sites, the construction material and their debris (lying open, without cover) are being stored outside the construction premises, near the road (Figure 6.5).

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

- Wet suppression
- wind speed reduction (for large construction sites)
- Waste should be properly disposed of and not stored on the premises or on the roadside.
- Proper handling and storage of raw material: covered 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 is covered by a fine screen.
- No storage (no matter how small) of construction material near the roadside (up to 10 m from the edge of the road).

The above control measures should be coordinated and supervised by Baddi Barotiwala Nalagarh Development Authority (BBNDA), Himachal Pradesh Housing Board, Municipal Council Baddi, Urban Development Department, PWD, and HPSPCB.

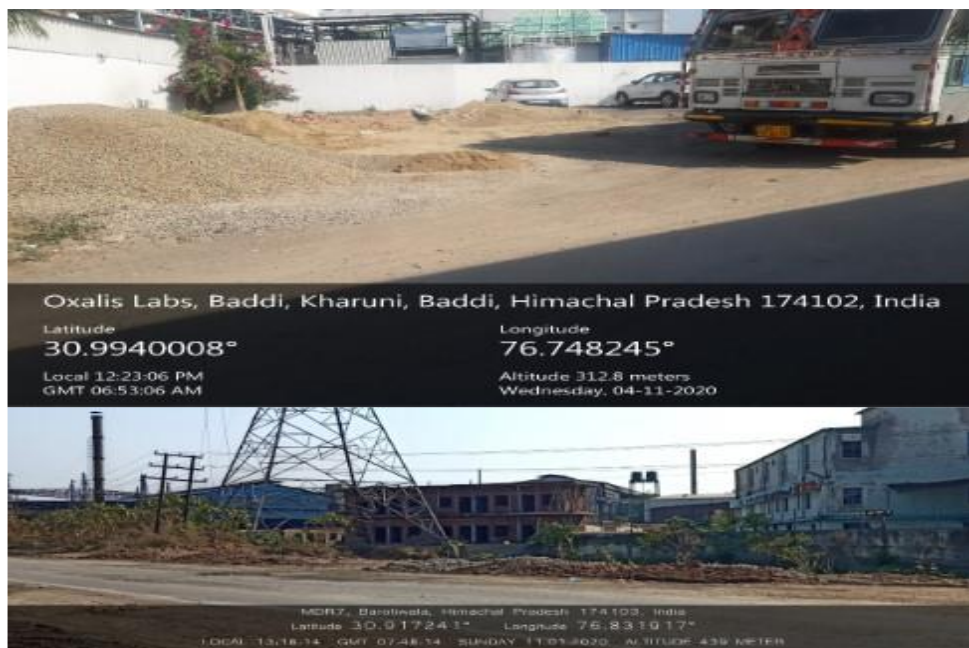


Figure 6.5: Construction material and debris near construction sites

The suggested control measures will reduce the emission by 50% in PM₁₀ (99 kg/day) and 72% in PM_{2.5} (32 kg/day). This will also reduce the road dust and fly ash contribution to ambient air concentration.

6.2.5 Domestic sector

The projected population of Baddi city for the year 2020 is approximately 40,000 and the emission from the domestic sector for the same is calculated. The emission could be high due to significant floating population employed in industries. The fuel consumption pattern shows LPG (79%) consumption (CRISIL report, 2015), wood (12%), dung (2%), coal (2%), kerosene (4%) and crop residue (1%). 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 to have LPG.

The LPG should be made available to the remaining 21% of households to make the city 100% LPG-fuelled. By 2030, planning should be done that as many households as a possible shift to electric cooking. For new societies, buildings should have a good infrastructure for PNG.

This action is expected to reduce 82% of PM₁₀ (34 kg/day) and 81% of PM_{2.5} (25 kg/d) emissions from domestic sector.

6.2.6 Soil and Road Dust

It has been observed that the soil and road dust emissions and their contribution to ambient air concentration are consistent and it is one of the largest sources of PM₁₀ and PM_{2.5} emissions. The silt load, an important factor in PM emissions from the road varied from 8.2 to 62.7 g/m² which is very high. The industrial area, where heavy vehicle movement is seen, also shows the high road dust emission. It is suggested that high traffic density roads should be properly maintained, paved from one end to another, have sidewalks through interlocking blocks for the pedestrians, proper drainage from the road, shrubs should be planted on-road dividers. Out of the total road network, about 60% of surface quality is poor.

The following control measures are suggested to reduce the dust emissions from the major roads:

1. Convert all unpaved, partially paved roads to fully paved roads. PWD (Public Works Department) and 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 should be 90% (Amato et al., 2010) and this should be part of the specification with no leakages of collected dust vacuum trucks. If the sweeping is done twice a month, the road dust emission will be reduced by 42% (PM₁₀= 19168 kg/day and PM_{2.5}= 4409 kg/day).
3. If the silt road is greater than 3 gm/m², the vacuum-assisted sweeping should be carried out along with washing by the municipal council and the HPSPCB should have the surveillance of this action.
4. NHAI should ensure that the silt load on highways maintained by them should

have a silt load of less than 3 gm/m².

5. The condition of the roads must be maintained properly with no potholes and shoulders paved by interlocking concrete to have a proper sidewalk.
6. The truck carrying construction material, or any airborne material should be covered.
7. Vacuum sweeping of roads with high silt load locations (Sai Road, Baddi-Barotiwalla Road, Haripur-Sandoli Road and other major roads) should be carried out at least four times a month also carpeting of shoulders, maintenance of the road, dividers, and kerbs should be carried out at regular intervals. This activity should have proper documentation including the quantity of dust collected from the roads.
8. Shrubs and perennial forages, or grass covers should be planted on the medians wherever possible.

The road dust deposition can be seen on the roads. It can be seen the roads are broken in patches causing higher road dust emissions (Figures 6.6).

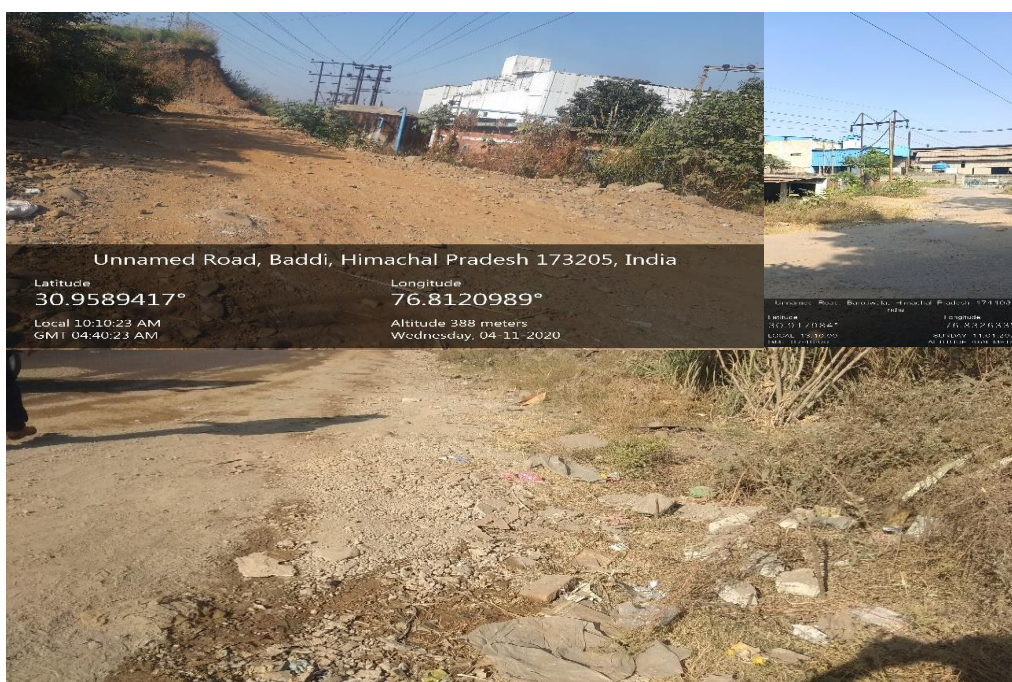


Figure 6.6: Road Dust is prominent on various roads

The above control measures should be coordinated and supervised by BBNDA, Himachal Pradesh Housing Board, Municipal Council Baddi, NHAI, PWD, and State Forest Department (for increasing green cover and plantation) as per their jurisdictions.

For example, the quality of roads, silt load with less than 3.0 gm/m³ and interlocked concrete shoulder undertaken at Hyderabad can be seen and employed in Baddi (Figure 6.7).

❑ Construction of Foot Paths



❑ End to End Development of Roads



Figure 6.7: Quality of dust-free Roads, footpaths and dividers with dust control
(Courtesy Greater Hyderabad Municipal Corporation)

6.1.1 Vehicle Emission Control, Congestion and Traffic Management

The vehicle emission contribution is significant for CO, NO_x, PM₁₀, and PM_{2.5}. There is a relatively large contribution of diesel vehicles (trucks, buses, LCVs, cars, etc.) to PM₁₀, PM_{2.5} and NO_x. The source apportionment results show that ARF and MHJ and have very large vehicle contributions (17 – 20% in PM_{2.5}; Figure 5.14, Chapter 5) with an overall contribution of vehicles in the city is 15% of PM_{2.5} in winter months. Out of about 1.5 tonnes/d emission of PM_{2.5} from vehicles, about 70% is from diesel vehicles, especially trucks and buses. Therefore, control measures must focus on advanced technological intervention for diesel vehicles like Diesel Particulate Filter (DPF). The general recommendations for vehicular emission control are enumerated below (specific recommendations are discussed later).

1. Retro-fitment of DPF: These filters have a PM emission reduction efficiency of 60-90%. If the diesel vehicles entering and those in the city are equipped with DPF, there is a possible reduction of 40% of PM_{2.5} emissions. This option must be explored as Bharat stage VI fuel is available and this technology can be adopted.
2. Industries should encourage employing trucks and heavy-duty vehicles of Bharat

stage-VI or IV with DPF for transportation of the raw and finished products at and from the industry.

3. By the end of 2024, a target of 50% of the total registration of vehicles in the city should be EVs in the sector of 2Ws, 3Ws and passenger cars. A suitable subsidy or tax break may be considered for the individuals opting for EVs. Charging infrastructure should come up quickly at multiple places (As per Ministry of Petroleum guidelines, Charging infrastructure for EV- Revised guidelines and standards, Oct 1, 2019, MoP), including public buildings and parking lots and battery swapping facilities should be planned to avoid long charging periods, especially for two-wheelers.
4. Emissions from in-use vehicles also depend on the maintenance and upkeep of vehicles. In this regard, it is suggested that each vehicle manufacturing company should have its authorized service centres in sufficient numbers to cater to the need of their vehicles in the city. The automobile manufacturing company-owned service centres (AMCOSC) should be fully equipped for complete inspection and maintenance of vehicles ensuring vehicles conform to emission norms and fuel economy after servicing. Every vehicle at least once a year should undergo a thorough check-up and compliance with pollution control devices and their proper functioning from an authorized centre.
5. The current official PUC centres in Baddi are 21 (*Refer: Transport Department, Government of India*). 4 - 8 PUC Centres are required per 1,00,000 vehicles (5mins/vehicle and 12 hrs/day). Maintenance and calibration of equipment must be ensured by regular surveillance.
6. Restriction on plying and phasing out of 10 years old commercial diesel-driven vehicles.
7. Check the overload vehicles: Expedite installation of weigh-in-motion bridges and machines at all entry points to Baddi to ensure that vehicles are not overloaded. There should be random checks on suspicious heavily loaded vehicles and a severe penalty is levied if they are found overloaded.
8. Himachal Road Transport Corporation (HRTC) should plan and install multiple electric charging facilities in its depots (in Baddi and other destinations) to quickly move towards electric buses.
9. The local public transport in the city should also move to electric buses. It is suggested that buses should be medium size of 30 seating capacity and provide better

frequency for easy maneuvering in the city to avoid difficult turning and congestion.

10. Route rationalization: Improvement of availability by rationalizing routes and fleet enhancement with requisite modifications. Ensure integration of the existing metro system with bus service.
11. IT systems in buses, bus stops, and control centre and passenger information systems should be introduced for the reliability of bus services and monitoring.
12. The public transport system is inadequate. The large intracity passenger demand is met mostly by tempos and autorickshaws. The tempo movements are undisciplined, and they form multiple lanes, stop as per their will in the middle of the road and hardly follow any traffic rules; this leads to congestion and safety hazard. There should be designated places where tempos can stop to drop and take passengers/commuters. There is no tempo terminal facility thus these mushroomed up in one place completely blocking the road at the terminus.
13. The intersections are poorly designed. There is a need to improve the intersections of roads at many places in Baddi city. The traffic signal, wherever installed, does not function properly which leads to slow traffic movement and reduced road safety. Steps shall be taken to install traffic signals on all the major intersections and traffic police shall enforce smooth traffic.
14. Other than a few roads, there is a lack of footpath availability and marking of zebra crossing for the pedestrian movements and people are forced to walk on the road. Proper footpaths and ease of crossing should be available for the pedestrians.

Decongestion of Roads

The city is Asia's biggest pharmaceuticals hub and is home to some of the largest pharmaceutical companies, the 6th most densely populated city in the Himachal Pradesh. It is the main centre of commercial and industrial activities in the state. A chaotic, undisciplined, and poorly managed traffic is normal on Sai Road. Driving in the opposite direction of main traffic, a culture of me first, parking in no-parking areas and on-street parking are the major causes of traffic congestion and pose a safety hazard. The slow movement of vehicles results in much higher emissions than vehicles at smooth cruising speed. The large vehicles (Trailers and Trucks) majorly operate in the areas of Pinjore-Baddi-Nalarah Highway, Haripur-Sandoli Bypass, Malpur road and Baddi-Barotiwala Road require specific attention including installation of DPF.

To increase the average speed and get full advantage of BS-VI, decongestion, removing encroachments from the roads, stopping unauthorized and improper parking is essential. The off-street parking is inadequate in the city causing jams and permanent congestion because of on-street haphazard parking.

The specific points that will help in decongestion are elaborated below.

- Heavy encroachment by shopkeepers and street vendors is observed in the commercial area and residential areas, and vehicles are parked on the road. The parked vehicles take up to 40% of the road width, although one-third of the roads are more than 30 m wide. This reduces road utilization by about 50%.
- The unauthorized vehicle service centres located near the road make things worse as the vehicle is parked on-road while servicing and repairing and oil and grease spillage can be seen, some of the areas where these unorganized shops can be seen are Baddi-Sitalpur and Haripur-Sandoli.
- Heavy-duty vehicles and buses which are destined for other cities pass through major roads within Baddi city and create heavy congestion. The important points of congestions are Hotel Legend, Maluk Majara, Vardhman Chowk, Samsung Plaza, Gol Market Chauraha, Nagar Nigam and Sikka Hotel Chowk. The city main road is Sai Road and this is also Haripur-Sandoli Bypass road; As a result, these routes within the city will also be congested.
- Areas that are adjacent to the market centers like Gol Market, Samsung Plaza, Nagar Nigam, Sikka Hotel Chowk experience heavy traffic congestion due to the unregulated parking and encroachment by local shop owners. The on-street parking has to be removed and if required multistorey parking is developed (discussed later).

During the traffic recording and survey done by IIT Kanpur, the following major intersections are identified as traffic bottlenecks (Table 6.1 and Figure 6.8).

Table 6.1: Major Traffic Bottleneck at Baddi City

Hotel Legend	Maluk Majara
Vardhman Chowk	Samsung Plaza
Gol Market Chauraha	Nagar Nigam
Sikka Hotel Chowk	

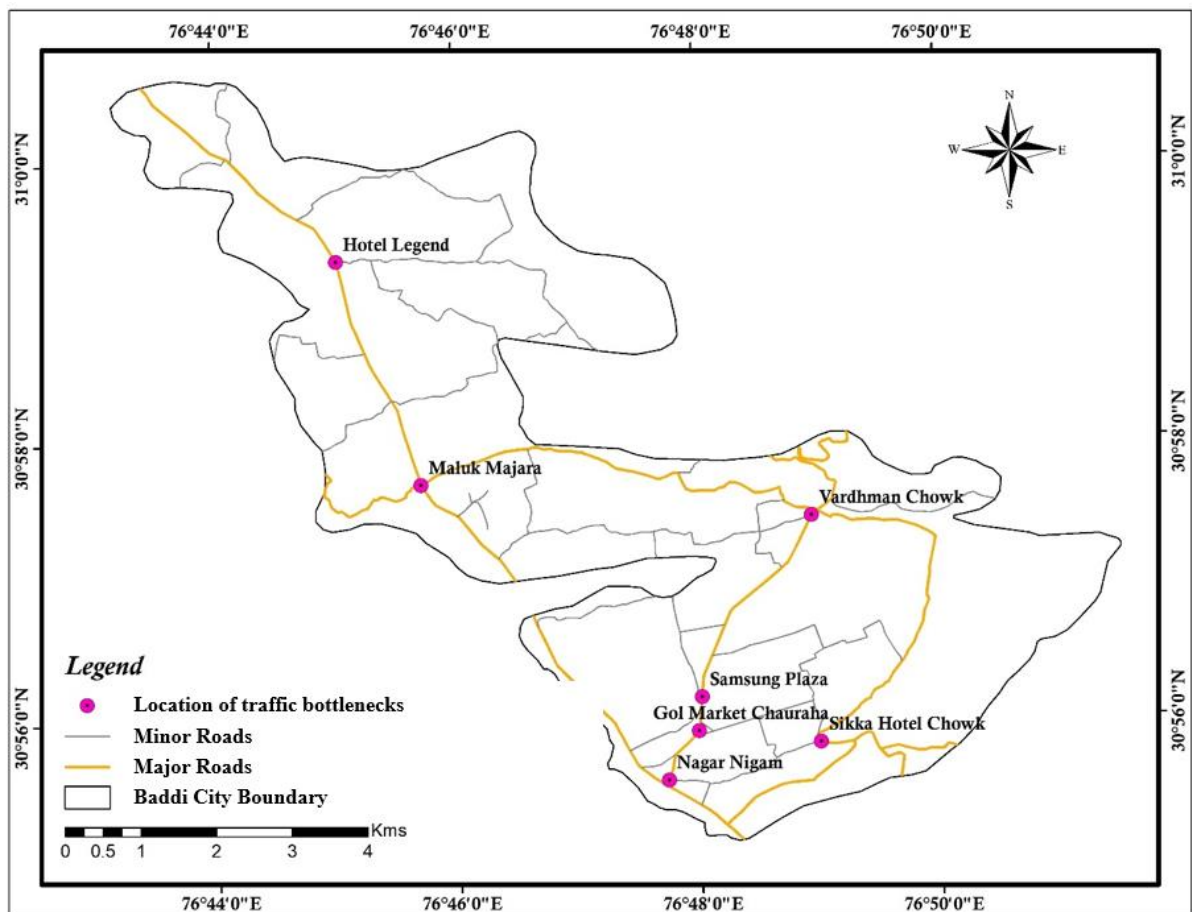


Figure 6.8: Location of traffic bottlenecks

Parking spaces

The off-street parking is inadequate in the city. There must be no parking zone (up to 50 m including auto, electric and hand-pulled rickshaw) near the intersections (Figure 6.9) it will help the smooth traffic flow. Certain parking policies in congestion areas (high parking costs, at city centers, only parking should be limited for physically challenged people.

The city should strictly follow Recommendations from IRC 12-2015 of prohibiting on-street parking as detailed below:

- Near Intersections: the capacity of an intersection is greatly reduced if vehicles are allowed to park on the approaches. Visibility is also adversely affected & safety is reduced. It is the general practice to prohibit parking for a distance of about 50 m on the approaches to a major intersection.
- Narrow Streets: Narrow streets with heavy traffic require that all possible measures should be taken to remove obstacles to traffic flow. Prohibition of parking can have a

salutary effect on traffic flow & congestion. In the busy street of the central area, it is generally desirable to prohibit parking on two-way streets with less than 5.75 m in width & one-way streets less than 4 m in width.

- Pedestrian Crossings: Desirable to prohibit parking within about 8.0 m from the pedestrian crossings.
- Structures: Structures such as bridges, tunnels and underpasses generally have a roadway width less than the highway and for this reason, it is desirable to prohibit parking on them.

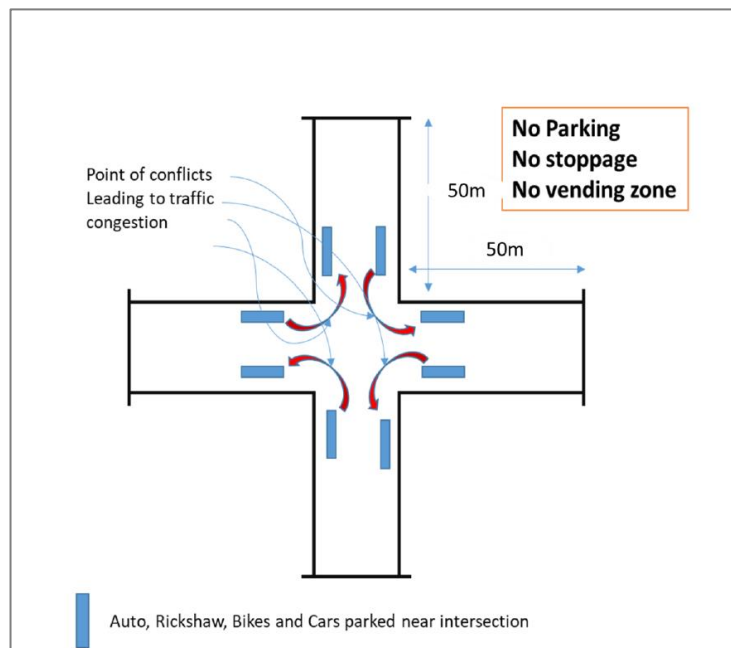


Figure 6.9: Conflicts due to on-street parking near intersections

There are modern technologies to facilitate multilevel car parking systems and the city should consider multilevel car parking systems in near future.

Automated Multilevel Car Parking Systems

Automated car parking Systems are much in vogue - a method of automatically parking and retrieving cars that typically use a system of pallets and lifts and signaling devices for retrieval. They serve advantages like safety, saving of space, time and fuel (since one does not have to drive around for locating space) but also need to have an extra and a very detailed assessment of the parking required, space availability and traffic flow. These can be further categorized into fully automatic or semi-automatic systems.

Dependent/Stack System: This allows two passenger cars to be parked one above the other (Figure 6.10). Its single post saves space and offers flexibility. Besides a platform (curved at the ends to allow the car to roll on/roll off conveniently) there is an operating control pendant that can be located anywhere in the garage, basement, and outdoor structure for operation from a safe distance.

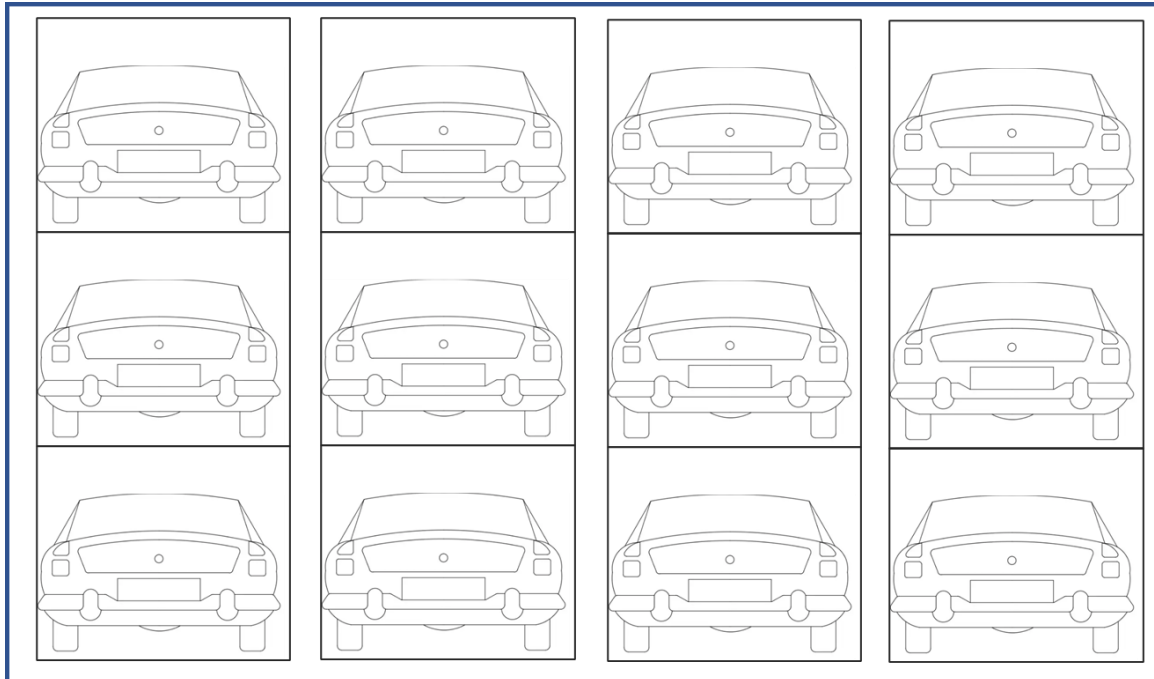


Figure 6.10: Multi-level car parking (example)

Parking prices

Since on-street parking has been a major concern within the region, strict guidelines need to be adopted to discourage private vehicles in the settlements. In some areas, parking charges of Rs. 20 per hour needs to be introduced in the city. Also, the building norms must have the mandatory provision of parking at everyone's house. Unauthorized on-street parking must be penalized and strict monitoring of compliance with defined rules to be enforced. "No parking zone" and no-vending zones signs should be placed at required locations exhibiting parking issues and they should also be painted on roads with clear markings.

Mostly, the parking is done on the walkways, and there is insufficient street space for pedestrians, cyclists, and public transport. In some places, there do exist parking places but still, people prefer to park on-street because of lower convenience and high prices at designated parking.

Promoting Public Transport Travel

Increasing the efficiency of public transport can deliver benefits of enhanced road capacities, accessibility and safety, and security. Thus, it is proposed to improve the efficiency of the existing public transport system and bring in a new fleet of low-floor electric buses. The size of these buses (e.g. 30-seater minibusses) should be decided to keep in mind the limited road width available at several locations in the city. Since the oversized buses tend to occupy most of the carriageway and further lead to congestion at bottlenecks while turning.

6.2.7 Industries

Besides PM pollution (discussed later), ambient air samples collected in the industrial area during the winter months show high levels of PM₁₀ and PM_{2.5}; these levels are not acceptable. There are more than 300 polluting units that are claimed to have control devices installed. The devices are inadequate or poorly operated with very low collection efficiency. It is suggested that these industries must control PM with highly efficient capture devices and suitable disposal of collected particles.

It is also observed that the majority of industries use coal, wood, pet coke, rice husk and HSD as fossil fuels, in the industries. Since the residential areas are surrounded by many industrial clusters within the city, the industry should shift to PNG or LDO or other cleaner fuels in a time-bound manner possibly in one year.

A coordinated effort under the supervision of HPSPCB and Industries Departments (i.e., BBNDA) is suggested to implement the following control measures:

- The majority of industries use multi-cyclones as air pollution control devices. It is recommended that these cyclones should be replaced by baghouses for effective control of particulate emissions.
- Ensuring compliance with emission standards in industries: All industries causing Air, Water, and Noise pollution shall be made compliant w.r.t environmental regulations.
- Strict action to stop unscientific disposal of industrial waste in the surrounding area.
- Industrial waste burning should be stopped immediately which is seen in the industrial area especially packing materials.
- The area and road in front of the industry should be free from any storage or disposal of any waste or raw material.

- The industry should follow best practices to minimize fugitive emission within the industry premises; all leakages, transfer points, loading and unloading, material handling within the industry should be controlled.
- Adequate and quality electric supply should be available to the industries for an effective industrial operation and avoidance of the DG sets.
- It is seen that industrial waste (hazardous) is mixed with MSW and burnt in several parts of Baddi. It is recommended that no industrial waste should be mixed with MSW rather disposed of at TSDF for hazardous waste disposal.
- There are industries with induction furnaces, which is a very pollution process, 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.
- To address the pollution caused by fugitive emissions using induction furnaces a fume gas capturing device has been developed and is commercially available. A side-based suction (Figures 6.11 – 6.13) is far more effective than top suction, which interferes with the movement of the crane.

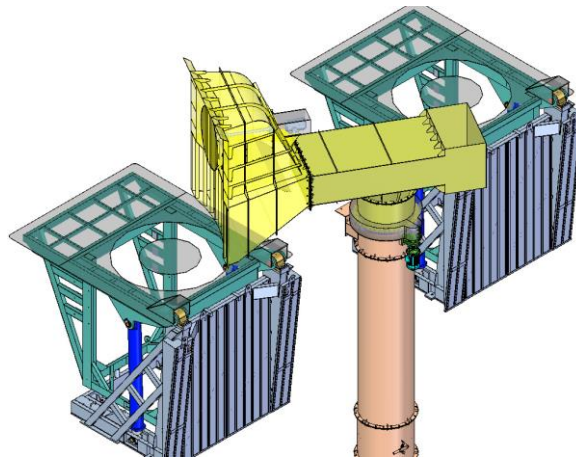


Figure 6.11: Proposed Suction Hood (Pic courtesy: Electrotherm)

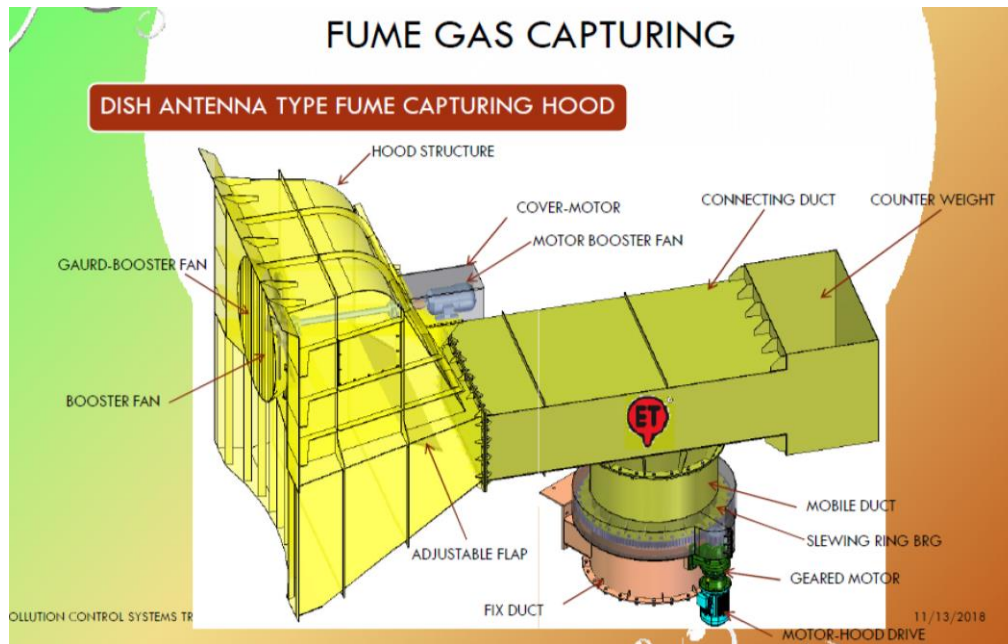


Figure 6.12: Side-based Suction Hood (Pic courtesy: Electrotherm)



Figure 6.13: Working on side-based Suction Hood (Sharma, 2020)

- It is recommended that a fume gas capturing hood followed by baghouse should be used to control air pollution.

The economics of the side-based suction hood for an induction furnace:

Assume a capacity of 8 tons per batch

Running time = 8 hrs.

Capital Cost of Suction Hood= Rs. 40 lakhs

Electricity cost for Running for one year = Rs. 26.5 lakhs

Running + Capital Cost for ten years = Rs. 3.0 crore

Per year operational cost (including maintenance) = Rs. 30 lakhs

Turnover of the company per year = Rs. 3 crore

Pollution control cost is 10% of turnover. Which is somewhat high and may raise the question of the economic viability of the industry, especially when other such industries in the country do not do such a level of investment. The industry will need some support in terms of soft loans or even some subsidies.

It is seen that waste is burnt in industrial areas (Barotiwala, Jharmajri, Lodhimajra, Davni). Hazardous waste (oil, grease, and paint, packaging material) is dumped and burned on the roads in the areas like Haripur-Sandoli where the trucks are being repaired. Industrial waste burning must be stopped under the supervision of HPSPCB. It is also seen that solid waste (all types) is dumped and stored just outside the premises of the industry; this is not acceptable and it looks unpleasant and at times spills over the road. It is recommended that all the hazardous waste should send to an industrial non-hazardous TSDF for industrial waste. They should not be allowed to dispose of the waste on roads or in front of the industry. Strict compliance and surveillance are required that hazardous waste goes to TSDF under the supervision of Municipal Council Baddi and HPSPCB.

6.3 Summary of Actions and Control Options

It may be noted that air polluting sources are plenty and efforts are required for every sector/source. In addition, there is a need to explore and implement various options for controlling air pollutants. A list of potential control options (technical, administrative and management) based on the above discussion that includes interventions is presented in Table 6.2 for PM_{2.5} and PM₁₀.

6.4 Strengthening of HPSPCB Baddi, Regional Office

- New manpower recruitment for sampling, analysis, assessment, and surveillance
- Automated stack testing kit
- The surveillance team should work in two shifts (day and night)
- Strict action against visible emission and reporting mechanism
- Proper documentation of violation of emission norms
- Capacity-building should be done through regular training of personals
- Laboratory upgradation

Table 6.2: A Glance of Control Options and Action Plan for City of Baddi (for details read section 6.2)

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
Hotels/ Restaurants/ Banquet Halls	All Restaurants small or large should not use coal and shift to gas-based or electric (for sitting capacity of more than 10 persons) appliances.	Municipal Council Baddi	1 year
	Link Commercial license to clean fuel	Municipal Council Baddi, Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian Oil/HP, etc.)	1 year
	Ash/residue from the tandoor and other activities should not be disposed of near the roadside. Requires ward-level surveillance.	Municipal Council Baddi	1 year
Domestic Sector	LPG to all. Slums and about 21% of the population are still using wood, biomass and dung as cooking fuel.	Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian Oil/HP, etc.)	1 year
	No new building complex or society be allowed without a PNG supply distribution network	Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian Oil/HP, etc.)	1 year
	By 2030, the city may plan to shift to electric	Department of Food, Civil Supplies and	10 years

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
	cooking (common in western countries) or PNG at the minimum	Consumer Affairs and Oil Companies (Indian Oil/HP, etc.)	
Municipal Solid Waste (MSW) Burning	Any type of garbage burning should be strictly stopped. Current waste collection and surveillance are poor.	Municipal Council Baddi	Immediate
	Surveillance is required that hazardous waste goes to TSDF.	Municipal Council Baddi, HPSPCB, BBNDA	
	Desilting and cleaning of municipal drains	Municipal Council Baddi	
	Waste burning in Industrial areas should be stopped.	HPSIDC, HPSPCB	
	Daily, Monthly mass balance of MSW generation and disposal	Municipal Council Baddi	
	Sensitize people and media through workshops and literature distribution so as not to burn the waste.	Municipal Council Baddi, HPSPCB, and NGO	
Construction and Demolition	Wet suppression	Baddi, Barotiwala, Nalagarh Development Authority (BBNDA), Municipal Council Baddi, Urban Development Department, PWD	Immediate
	Wind speed reduction (for large construction sites)	BBNDA, Municipal Council Baddi, Urban Development Department, PWD	

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
	Enforcement of C&D Waste Management Rules. The waste should be sent to a construction and demolition processing facility	BBNDA, Municipal Council Baddi, Urban Development Department, PWD	Immediate
	Proper handling and storage of raw material: covered the storage and provide the windbreakers.	BBNDA, Municipal Council Baddi, Urban Development Department, PWD	
	Vehicle cleaning and specific fixed wheel washing on leaving the site and damping down of haul routes.	BBNDA, Municipal Council Baddi, Urban Development Department, PWD	
	The actual construction area should be covered by a fine screen.	BBNDA, Municipal Council Baddi, Urban Development Department, PWD	
	No storage (no matter how small) of construction material near the roadside (up to 10 m from the edge of the road)	BBNDA, Municipal Council Baddi, Urban Development Department, PWD	
	Builders should leave 25% area for green belt in residential colonies to be made mandatory.	BBNDA, Municipal Council Baddi, Urban Development Department, PWD	
	Sensitize construction workers and contract agencies through workshops.	BBNDA, Municipal Council Baddi, Urban Development Department, PWD, HPSPCB, and	

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
		NGO	
Road Dust	The silt load in Baddi varies from 8.2 to 62.7 g/m ² . The silt load on each road should be reduced to under 3 gm/m ² . Regular vacuum sweeping should be done on the road having a silt load above 3 gm/m ² .	BBNDA, Municipal Council Baddi, National Highway Authority, PWD, HPSPCB (for silt load compliance)	Immediate
	Convert unpaved roads to paved roads. Maintain pothole-free roads.	BBNDA, Municipal Council Baddi, National Highway Authority, PWD, HPSPCB to carry out surveillance	
	Implementation of truck loading guidelines; use appropriate enclosures for haul trucks and gravel paving for all haul routes.	BBNDA, Municipal Council Baddi, National Highway Authority, PWD	
	Increase green cover and plantation. Undertake the green of open areas, community places, schools, and housing societies.	BBNDA, Municipal Council Baddi, National Highway Authority, State Forest Department, PWD	
	vacuum-assisted sweeping is carried out four times a month on major roads with road washing.	BBNDA, Municipal Council Baddi, National Highway Authority, PWD	
Vehicles	Diesel vehicles entering the city should be equipped	State Transportation Department	3 years

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
	with DPF which will bring a reduction of 40% in emissions (This option can be implemented with vehicles of the BS-IV category as well)		
	Industries must be encouraged to use BS-VI or BS-IV (with DPF) vehicles for the transportation of raw and finished products	Industrial Associations and State transport Department	Immediate
	Restriction on plying and phasing out of 10 years old commercial diesel-driven vehicles.	Transport Department	2 years
	Introduction of cleaner fuels (CNG/ LPG) for all vehicles (other than 2-W).	Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian Oil/HP, etc.)	2 years
	Check to overload: Expedited installation of weigh-in-motion bridges and machines at all entry points to Baddi.	Transport Department, Traffic Police, Baddi, NHAI, Toll agencies	Six-months
	Electric/Hybrid Vehicles should be encouraged; New residential and commercial buildings to have charging facilities. All new city buses should be electric.	Transport Department, ARTO Baddi	1 year

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
	Bus stop and their parking should be rationalized to ensure more efficient utilization. The depots should include well-equipped maintenance workshops. Adequate charging stations.	Transport Department, ARTO Baddi	1year
	Enforcement of bus lanes and keeping them free from obstruction and encroachment.	Municipal Council Baddi, ARTO Baddi	1 year
	Route rationalization: Improvement of availability by rationalizing routes and fleet enhancement with requisite modification.	BBNDA, ARTO Baddi, Traffic Police, Baddi	1 year
	IT systems in buses, bus stops, control centers, and passenger information systems for the reliability of bus services and monitoring.	Baddi Barotiwala Nalagarh Development Authority, ARTO Baddi, Traffic Police, Baddi	1 year
	Movement of materials (raw and product) within the city should be allowed between 10 PM to 5 AM.	Transport Department, Baddi, BBNDA, ARTO Baddi, Traffic Police, Baddi	1 year
Industries and DG Sets	Ensuring emission standards in industries. Shifting of polluting industries.	HPSPCB, Industries Department	1 year
	Strict action to stop unscientific disposal of hazardous waste in the surrounding area	Municipal council and HPSPCB	

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
	There should be separate Treatment, Storage, and Disposal Facilities (TSDFs) for hazardous waste.	Industrial Associations, BBND, HPSIDC, Industries Department, HPSPCB	2 years
	Industrial waste burning should be stopped immediately	Industrial Associations, HPSIDC, HPSPCB	Immediate
	Following best practices to minimize fugitive emissions within the industry premises, all leakages within the industry should be controlled	Industrial Associations, HPSIDC, HPSPCB	Immediate
	Area and road in front of the industry should be the responsibility of the industry	Industrial Associations, HPSIDC, HPSPCB	
	Category A Industries (using coal and other dirty fuels)		
	About 299 boilers, Heater and furnaces in Baddi are running over coal, wood, and other dirty solid fuels which should be shifted to natural gas and electricity	Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian Oil/HP, etc.), Industrial Associations, HPSPCB	2 years
	Almost all rotary furnaces having significant emissions are running on coal that needs to be shifted to natural gas and electricity	Industrial Associations, HPSPCB	2 years
	Multi-cyclones should be replaced by baghouses.	Industrial Associations, HPSPCB	2 years

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
	Ensure installation and operation of air pollution control devices in industries.		
	Category B Industries (Induction Furnace)		
	Recommended Fume gas capturing hood followed by Baghouse should be used to control air pollution	Industrial Associations, HPSPCB	2 years
	Diesel Generator Sets		
	Strengthening of grid power supply, uninterrupted power supply to the industries	State Energy Department, HPSEBL	2 years
	Renewable energy should be used to cater to the need of office requirements in the absence of power failure to stop the use of DG Set	Industrial Associations	2 years
Decongestion of Roads in high traffic areas	Strict action on roadside encroachment. Disciplined movement of tempos to stop only at designated spots. Action on driving in the wrong lane	BBNDA, Municipal Council Baddis, ARTO Baddi, Traffic Police, Baddi	6 months
	Disciplined Public transport (designate one lane stop).	ARTO Baddi., Traffic Police, Baddi	
	Removal of the free parking zone. No parking within 50 m of any major crossing and or chaurahs,	BBNDA, Municipal Council Baddi, ARTO Baddi, Traffic Police, Baddi	

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
	rotaries. Strictly follow Indian Road Congress guidelines		
	Examine the existing framework for removing broken vehicles from roads and create a system for speedy removal and ensure minimal disruption to traffic.	BBNDA, ARTO Baddi, NHAI, Traffic Police, Baddi	
	Synchronize traffic movements or introduce intelligent traffic systems for lane-driving.	BBNDA, ARTO Baddi, NHAI, Traffic Police, Baddi	
	Mechanized multi-story parking at bus stands, and big commercial areas. Remove at least 50 percent of on-street parking in the city.	BBNDA, ARTO Baddi, Municipal Council Baddi, NHAI, Traffic Police, Baddi	
	Identify traffic bottleneck intersections and develop a smooth traffic plan. For example, Hotel Legend, Maluk Majara, Vardhman Chowk, Samsung Plaza, Gol Market Chauraha, Nagar Nigam and Sikka Hotel Chowk are the main bottlenecks for traffic.	BBNDA, ARTO Baddi, Municipal Council Baddi, Traffic Police, Baddi	
	Parking policy in congestion areas (high parking	BBNDA, ARTO Baddi, Municipal Council	

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
	cost, at city centers, only parking is limited for physically challenged people, etc).	Baddi, NHAI, Traffic Police, Baddi	
	The important point of congestion is Gol market Chaburah. Parking on the Sai Road should be strictly prohibited.	ARTO Baddi, Traffic Police	2 years
*The above steps should not only be implemented in Baddi municipal limits rather these should be extended up to at least 10 km beyond the boundary. This will need support from the central government.			

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Annexure 1

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

Source		Units of Emission factor	PM ₁₀	PM _{2.5}	SO ₂	NO _x	CO
Domestic	Wood	g/kg	5.04	4.54	0.48	1.4	31
	Crop residue	g/kg	11	9.90	0.12	0.49	58
	Dung	g/kg	5.04	4.54	0.48	1.4	31
	Coal	g/kg	20	18	13.3	3.99	24.92
	Kerosene	g/lit	0.61	0.55	4	2.5	62
	LPG	g/lit and kg/10 ⁶ M ³	2.1	1.89	0.4	1.8	0.25
DG Set		g/kwh	1.33	1.2	1.24	18.8	4.06
MSW Burning		g/kg	8	5.44	0.5	3	42
Brick Kiln	wood	g/kg	15.3	13.7	0.2	1.4	115.4
	coal	g/kg	10.15	7.10	13.3	3.99	24.92
Industrial	LDO	g/lit	2.37	2.13	18.84S	6.6	0.6
	HSD	g/lit	1.49	1.34	18.84S	6.6	0.6
	Rice Husk	g/kg	11	9.9	0.12	0.49	58
	Wood	g/kg	17.3	15.57	0.2	1.3	126.3
	Natural gas	kg/(10) ⁶ m ³ (SCM)	121.6	109.4	9.6	2240	1344
	Coal	g/kg	10.15	1.05	19S	11	0.25
	Diesel	g/lit	1.49	1.34	18.84	6.6	0.6
Vehicle	2 wheelers	g/vkt	0.035	0.03	0	0.29	2.12
	3 wheelers	g/vkt	0.27	0.24	*	0.5	0.54
	4 wheelers	g/vkt	0.06	0.05	*	0.25	1
	LCV	g/vkt	0.64	0.58	*	3.1	1.86
	Bus	g/vkt	1.24	0.74	*	9.46	8.4
	Truck	g/vkt	1.24	0.74	*	9.46	8.4
Construction		kg/day/m ²	0.0025	0.0006	-	-	-

* Average kilometre run per litre of diesel is taken as: 10 km (for 3W); 15km (for 4W); 7 km (for LCV and 5 km (for Buses/Trucks). Sulfur content in diesel is taken as =10 ppm (wt/wt).

Annexure 2

Gridded Emissions for Baddi city are represented below.

GRID	PM₁₀	PM_{2.5}	SO₂	NO_x	CO
HB1	0	0	0	0	0
HB2	0	0	0	0	0
HB3	0	0	0	0	0
HB4	0	0	0	0	0
HB5	0	0	0	0	0
HB6	0	0	0	0	0
HB7	21.93	5.83	17.32	10.84	10.41
HB8	1435.02	394.83	26.44	889.26	899.02
HB9	179.87	65.09	127.25	237.08	270.56
HB10	8.32	2.98	0.39	3.40	11.22
HB11	21.09	10.43	17.74	111.47	30.98
HB12	0	0	0	0	0
HB13	0	0	0	0	0
HB14	0	0	0	0	0
HB15	0	0	0	0	0
HB16	0	0	0	0	0
HB17	0	0	0	0	0
HB18	0	0	0	0	0
HB19	0	0	0	0	0
HB20	0	0	0	0	0
HB21	147.66	51.59	18.92	247.98	701.59
HB22	1828.76	871.79	444.74	1578.21	2729.91
HB23	538.85	262.69	211.22	947.07	2151.92
HB24	2346.70	910.48	261.06	1521.35	2532.09
HB25	899.77	293.83	153.17	696.25	1126.70
HB26	28.24	21.51	142.97	267.40	328.47
HB27	0	0	0	0	0
HB28	0	0	0	0	0
HB29	0	0	0	0	0
HB30	0	0	0	0	0
HB31	0	0	0	0	0
HB32	0	0	0	0	0
HB33	0	0	0	0	0
HB34	1766.52	427.59	44.41	371.51	249.71
HB35	407.60	164.03	208.45	902.56	4818.92
HB36	836.74	271.61	148.68	689.25	3236.20

GRID	PM₁₀	PM_{2.5}	SO₂	NO_x	CO
HB37	359.92	163.28	120.80	1282.38	1207.76
HB38	409.20	347.26	554.75	988.15	3004.70
HB39	129.00	69.17	46.14	548.84	1392.79
HB40	33.48	29.84	42.02	231.17	2090.12
HB41	6.93	6.39	4.86	48.20	220.60
HB42	0	0	0	0	0
HB43	0	0	0	0	0
HB44	0	0	0	0	0
HB45	0	0	0	0	0
HB46	0	0	0	0	0
HB47	648.12	156.43	31.14	117.88	86.13
HB48	1789.49	463.03	117.51	557.14	547.37
HB49	20.85	16.97	336.86	65.97	38.10
HB50	9.58	4.00	3.12	14.98	24.58
HB51	174.77	91.10	49.86	119.70	364.31
HB52	136.15	105.73	228.43	1328.63	2100.16
HB53	703.06	541.89	337.20	1179.24	1122.93
HB54	175.53	117.26	830.01	835.11	1390.78
HB55	4.69	3.34	0.66	2.11	22.36
HB56	0.74	0.53	0.10	0.33	3.52
HB57	0	0	0	0	0
HB58	0	0	0	0	0
HB59	2251.75	541.80	229.96	408.67	287.26
HB60	4361.58	1051.15	99.18	795.50	571.45
HB61	20529.92	4947.67	66.14	3752.39	2925.62
HB62	74.87	58.41	170.85	150.00	1605.92
HB63	113.78	61.87	126.81	388.69	166.92
HB64	157.87	58.50	49.22	249.46	686.93
HB65	204.95	103.22	66.65	161.91	1447.25
HB66	999.82	294.21	73.79	698.99	1232.64
HB67	130.73	59.73	39.64	236.19	109.33
HB68	2.97	1.21	0.15	0.49	5.16
HB69	0.25	0.17	0.03	0.11	1.17
HB70	0.06	0.04	0.01	0.03	0.29
HB71	0	0	0	0	0
HB72	0	0	0	0	0
HB73	1.02	0.73	0.14	0.46	4.86
HB74	1292.27	345.54	151.04	642.97	699.43
HB75	117.06	77.55	138.03	120.63	652.38
HB76	105.59	35.54	11.94	126.54	339.11
HB77	70.86	29.95	14.60	150.11	1140.66
HB78	8.33	6.85	31.34	78.56	33.74
HB79	0.04	0.03	18.02	0.02	0.18

GRID	PM₁₀	PM_{2.5}	SO₂	NO_x	CO
HB80	575.18	162.21	77.25	312.42	330.56
HB81	0.01	0.01	0.00	0.00	0.05
HB82	0.01	0.01	0.00	0.01	0.06
HB83	0	0	0	0	0
HB84	0	0	0	0	0
HB85	0	0	0	0	0
HB86	0	0	0	0	0
HB87	1.57	1.12	0.22	0.71	7.50
HB88	1325.25	395.82	101.02	629.75	2328.29
HB89	122.06	52.48	109.19	139.58	179.82
HB90	45.27	21.92	23.59	92.44	247.38
HB91	144.67	78.61	124.12	114.66	332.76
HB92	0.41	0.35	0.29	4.28	1.46
HB93	0	0	0	0	0
HB94	0	0	0	0	0
HB95	0	0	0	0	0
HB96	0	0	0	0	0
HB97	0	0	0	0	0
HB98	0	0	0	0	0
HB99	0	0	0	0	0
HB100	0.38	0.27	0.05	0.17	1.81
HB101	506.17	136.89	56.08	269.91	302.95
HB102	931.26	260.95	275.48	652.73	737.24
HB103	121.62	88.01	101.56	389.11	4894.78
HB104	38.68	20.03	14.50	81.74	245.28
HB105	10.09	10.30	5.05	41.29	660.04
HB106	0.09	0.06	0.01	0.04	0.42
HB107	0	0	0	0	0
HB108	0	0	0	0	0
HB109	0	0	0	0	0
HB110	0	0	0	0	0
HB111	0	0	0	0	0
HB112	0	0	0	0	0
HB113	0.25	0.18	0.03	0.11	1.17
HB114	509.17	137.19	60.97	268.02	296.47
HB115	340.37	100.30	46.86	210.34	1563.76
HB116	27.88	18.98	23.26	108.68	927.03
HB117	20.16	10.59	8.60	55.49	111.08
HB118	15.43	7.74	15.61	37.45	56.75
HB119	0	0	0	0	0
HB120	0	0	0	0	0
HB121	0	0	0	0	0
HB122	0	0	0	0	0

GRID	PM₁₀	PM_{2.5}	SO₂	NO_x	CO
HB123	0	0	0	0	0
HB124	0	0	0	0	0
HB125	0	0	0	0	0
HB126	0	0	0	0	0
HB127	622.17	184.91	32.86	336.69	1995.49
HB128	426.09	114.86	78.11	223.68	248.41
HB129	0.09	0.06	0.01	0.04	0.42
HB130	0	0	0	0	0
HB131	0.04	0.03	0.01	0.02	0.20
HB132	0.11	0.08	0.01	0.05	0.50
HB133	0	0	0	0	0
HB134	0	0	0	0	0
HB135	0	0	0	0	0
HB136	0	0	0	0	0
HB137	0	0	0	0	0
HB138	0	0	0	0	0
HB139	0	0	0	0	0
HB140	0	0	0	0	0
HB141	0	0	0	0	0.02
HB142	0	0	0	0	0
HB143	0	0	0	0	0
HB144	0	0	0	0	0
HB145	0	0	0	0	0
HB146	0	0	0	0	0
HB147	0	0	0	0	0
HB148	0	0	0	0	0
HB149	0	0	0	0	0
HB150	0	0	0	0	0
HB151	0	0	0	0	0
HB152	0	0	0	0	0
HB153	0	0	0	0	0
HB154	0	0	0	0	0