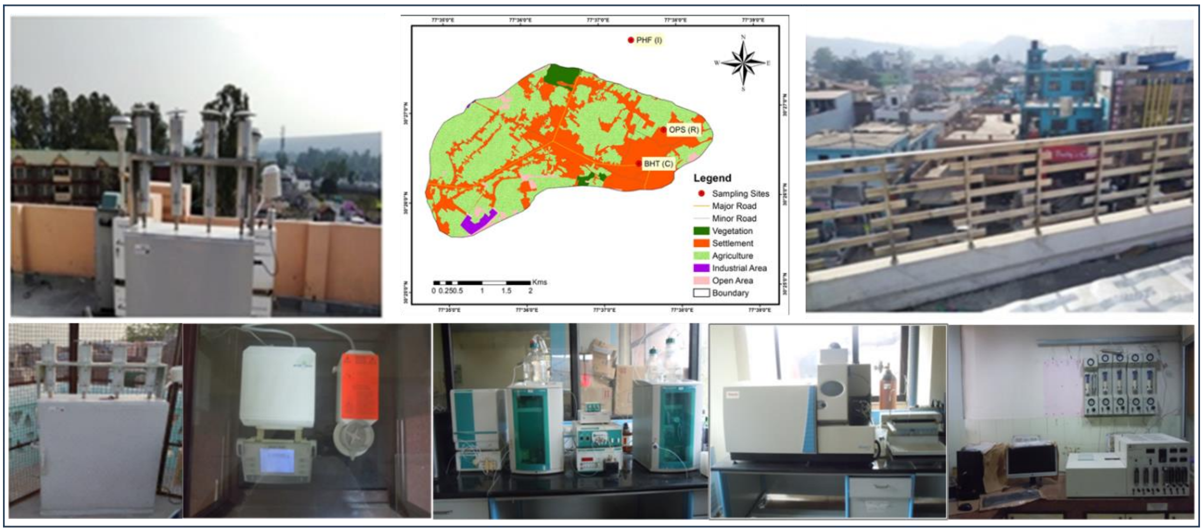
Source Apportion-based Action Plans for Restoring Air Quality in Non- Attainment Cities in the State of Himachal Pradesh in respect of PM_{10}, $PM_{2.5}$ and other Notified Pollutants

City: Paonta Sahib

(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 Paonta Sahib 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 PM_{10} (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 Paonta Sahib.
- 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 three air quality sites were categorized based on the predominant land-use pattern (Table 1) to cover varying land-use prevailing in the city. PM_{10}, $PM_{2.5}$, SO_2, NO_2, 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 (November 29 - December 07, 2019).

Table 1: Description of sampling sites in Paonta Sahib

S. No.	Sampling Site	Site Code	Description of the site	Type of sources
1.	HPPCB Office	OPS	Residential	Domestic cooking, vehicles, road dust, garbage/MSW burning, biomass
2.	Brighten Hotel	BHT	Commercial	DG sets, vehicles, road dust, garbage/waste burning, hotels, restaurants, coal uses
3.	Pharma Force	PHF	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 PM_{10}, $PM_{2.5}$ and their compositions have been referred to bring important inferences to the fore.

- The mean PM_{10} levels were 113 – 136 µg/m^3 and the mean $PM_{2.5}$ levels were 73 – 86 µg/m^3.

- Particulate pollution is the main concern in the city, where PM_{10} levels are 1.1 – 1.4 times higher than the national air quality standards and $PM_{2.5}$ levels are 1.2 – 1.4 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 very poor 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 122±10 µg/m^3 against the acceptable level of 100 µg/m^3. The highest levels were observed at BHT and the lowest at OPS.

The important components are the secondary particles (NO_3^- + SO_4^{2-} + NH_4^+), which account for about 21% of total PM_{10}, and combustion-related total carbon (TC = EC + OC) accounts for about 25%; both fractions of secondary particles and combustion-related carbons account for 46% of PM_{10} in winter months.

The crustal component (Si + Al + Fe + Ca) accounts for about six percent in PM_{10}. This suggests soil and road dust have less significant contributions. The coefficient of variation (CV) is about 0.22 (of the fraction of crustal component), which suggests the crustal source contributes consistently in the winter months.

The Cl^- content in PM_{10} is consistent and varies between 7 – 10%, 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 BHT at 12 µg/m^3 compared to the overall city level of 10.6 µg/m^3. The high level at BHT signifies some local burning of waste as a means of disposal of solid waste.

$PM_{2.5}$

The overall average concentration of $PM_{2.5}$ in winter is 79±5 µg/m^3 against the acceptable level of 60 µg/m^3. The highest levels are observed at PHF and the lowest at OPS.

The important components are the secondary particles (NO_3^- + SO_4^{2-} + NH_4^+), which account for about 23% of total $PM_{2.5}$ and combustion-related total carbon (TC = EC + OC) accounts for about 29%; both fractions of secondary particles and combustion-related carbons account for 52% of $PM_{2.5}$ in winter months. The highest levels of secondary particles were observed at OPS (24%) and TC at BHT (33%).

The Cl^- content in $PM_{2.5}$ is consistent and varies between 8 – 11%, which is an indicator of the burning of MSW and plastic waste.

Gaseous pollutant levels

NO_2 and SO_2 levels meet the national air quality standard of 80 µg/m^3. The highest NO_2 and SO_2 levels were at BHT with some high peaks. BHT was a commercial site having uses of coal in restaurants and nearby areas. In addition, high levels of NO_2 and SO_2 are expected to undergo chemical transformation to form fine secondary particles in the form of nitrates and sulfates, adding to high levels of existing PM_{10} and $PM_{2.5}$. NH_3 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 BHT. The annual benzene levels are expected to be well below the NAQS of 5 µg/m^3 and in the safe limit in the city.

General inferences

It is to be noted that OC3/TC ratio is about 0.30 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 Paonta Sahib.

Total PAH levels (17 compounds; particulate phase) had high variability in the range of 5.5 to 13.4 and B(a)P at 0.60 ng/m^3 (annual standard is one ng/m^3); the comparison with the annual standard is not advisable due to different averaging times. The highest PAH levels were observed at BHT.

The concentrations of molecular markers in $PM_{2.5}$ (a total of 6 compounds) vary in the range of 37 to 44 ng/m^{3,} 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. Combustion sources (vehicles, soil and road dust, coal, and MSW burning) are consistent and require a strategy to control these sources.

Trend analysis

The long-term (2010-2019) temporal PM_{10} and NO_2 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 PM_{10} in Paonta Sahib as few months show a decreasing trend and most of months indicate no trend. However, NO_x shows decreasing trend in most of months and no trend in few months at both sites. The annual levels of PM_{10} and NO_x show decreasing trend at Station I and no trend at Station II.

Emission Inventory

Emission inventory (EI) is a basic necessity for planning air pollution control activities. The overall baseline EI for Paonta Sahib 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 PM_{10}, NO_x, SO_2 and CO) from all sources is presented in Figure 6.

The total PM_{10} emission load in the city is estimated to be 9206 kg/day. The top four contributors to PM_{10} emissions are Road Dust (72%), Vehicles (13%), Industries (10%), and Brick Kilns (4%); 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 3659 kg/day. The top four contributors to $PM_{2.5}$ emissions are Road Dust (41%), Vehicular (30 %), Industries (20%), and Brick Kilns (6 %); these are based on annual emissions. Seasonal and daily emissions could be highly variable.

SO_2 emission load in the city is estimated to be 2312 kg/day. Industrial (79%), Brick Kiln (18%), and Hotels, restaurants, GHs & BHs (2%) are the top three contributors to SO_2 emissions.

NOx emissions load in the city is estimated to be 10360 kg/day. The majority of total emissions are attributed to Vehicular (79%), Industries (19%), and Brick Kilns (1%). Vehicular emissions that occur at ground level, probably making it the most important emission. NOx apart from being a pollutant itself is an important component in the formation of secondary particles (nitrates) and ozone. NOx from vehicles and industry are potential sources for controlling NOx emissions.

The estimated CO emission is about 8730 kg/day. The major contributors to CO emissions are Vehicular (81%), Brick Kilns (9%), and Industries (5%). Vehicular emissions could be the main target for controlling CO for improving air quality with respect to CO.

The estimated emissions are for benzene: 311 g/d, Pb: 1265 g/d, As: 53 g/d, Ni: 384 g/d and BaP: 26 g/d from all sources.

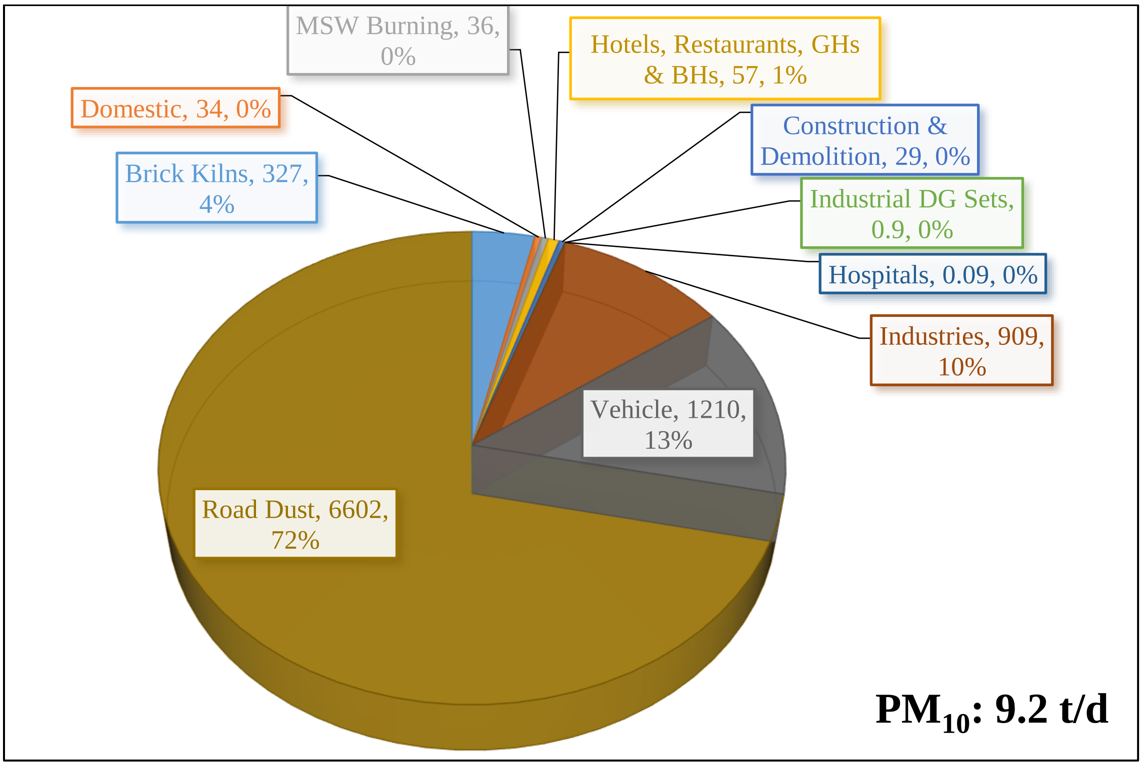


Figure 1: PM_{10} emission Inventory of different sources in Paonta Sahib (kg/d)

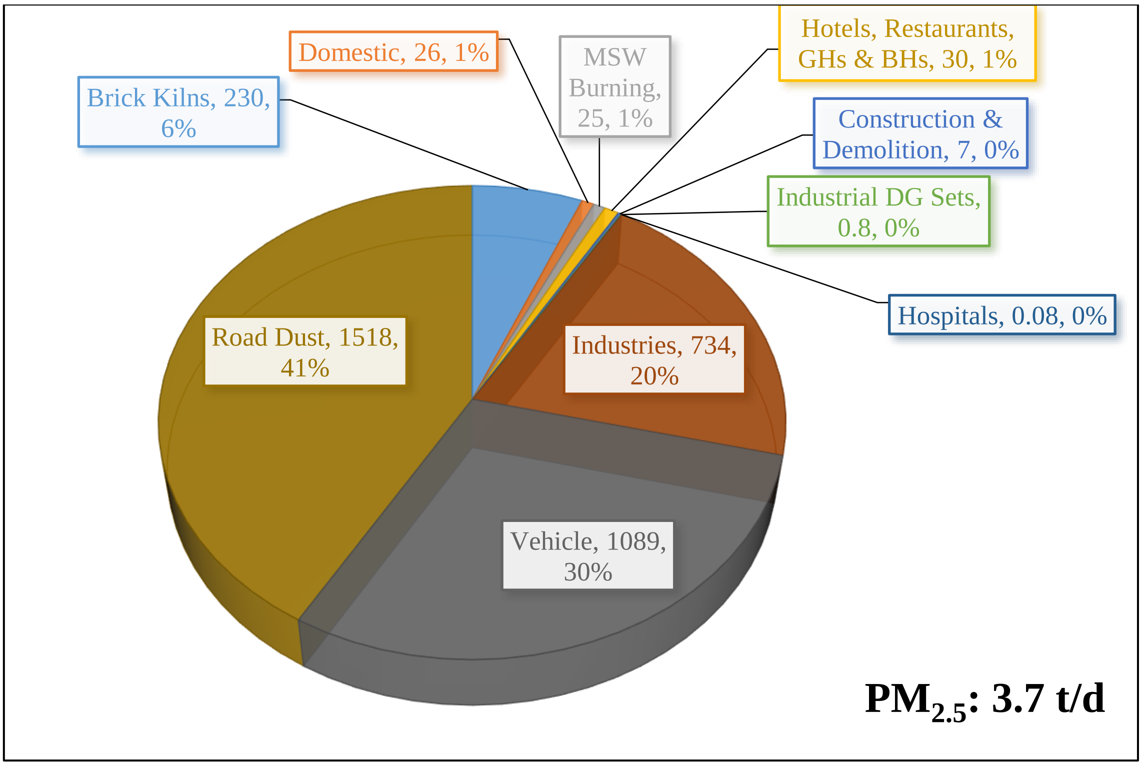


Figure 2: $PM_{2.5}$ emission load of different sources in Paonta Sahib (kg/d)

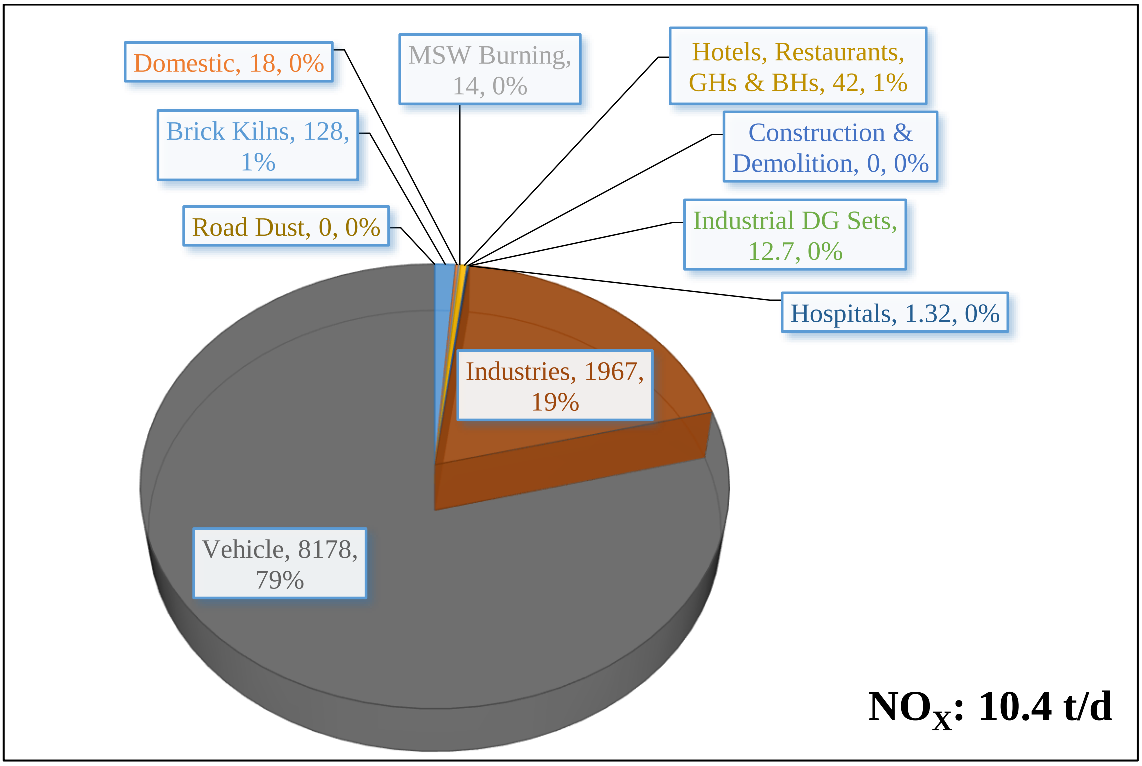


Figure 3: NO_x emission load of different sources in Paonta Sahib (Kg/d)

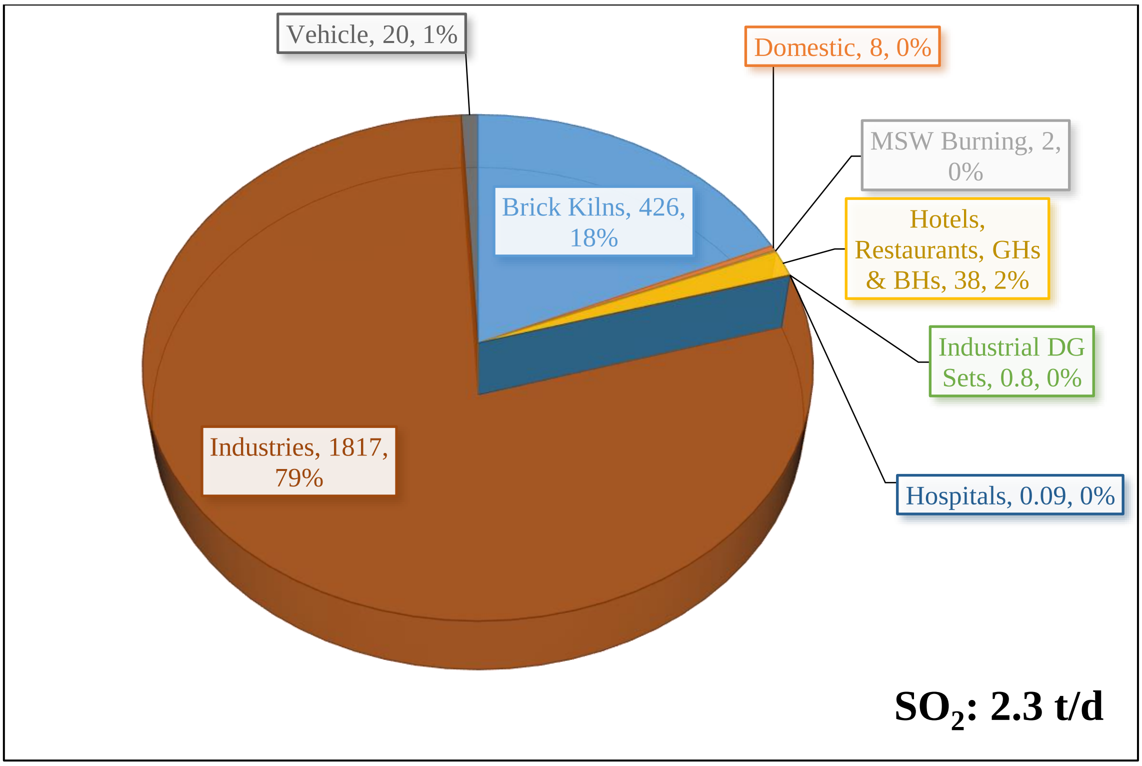


Figure 4: SO_2 emission load of different sources in Paonta Sahib (kg/d)

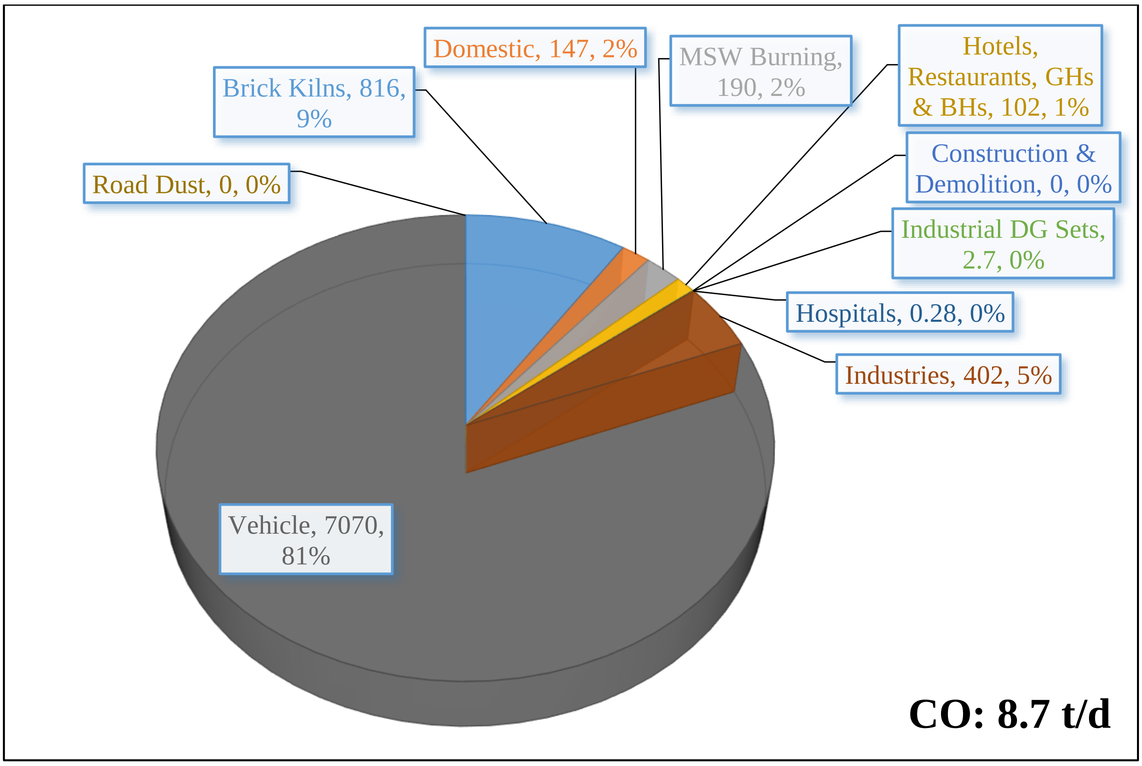


Figure 5: CO emission load of different sources in Paonta Sahib (kg/d)

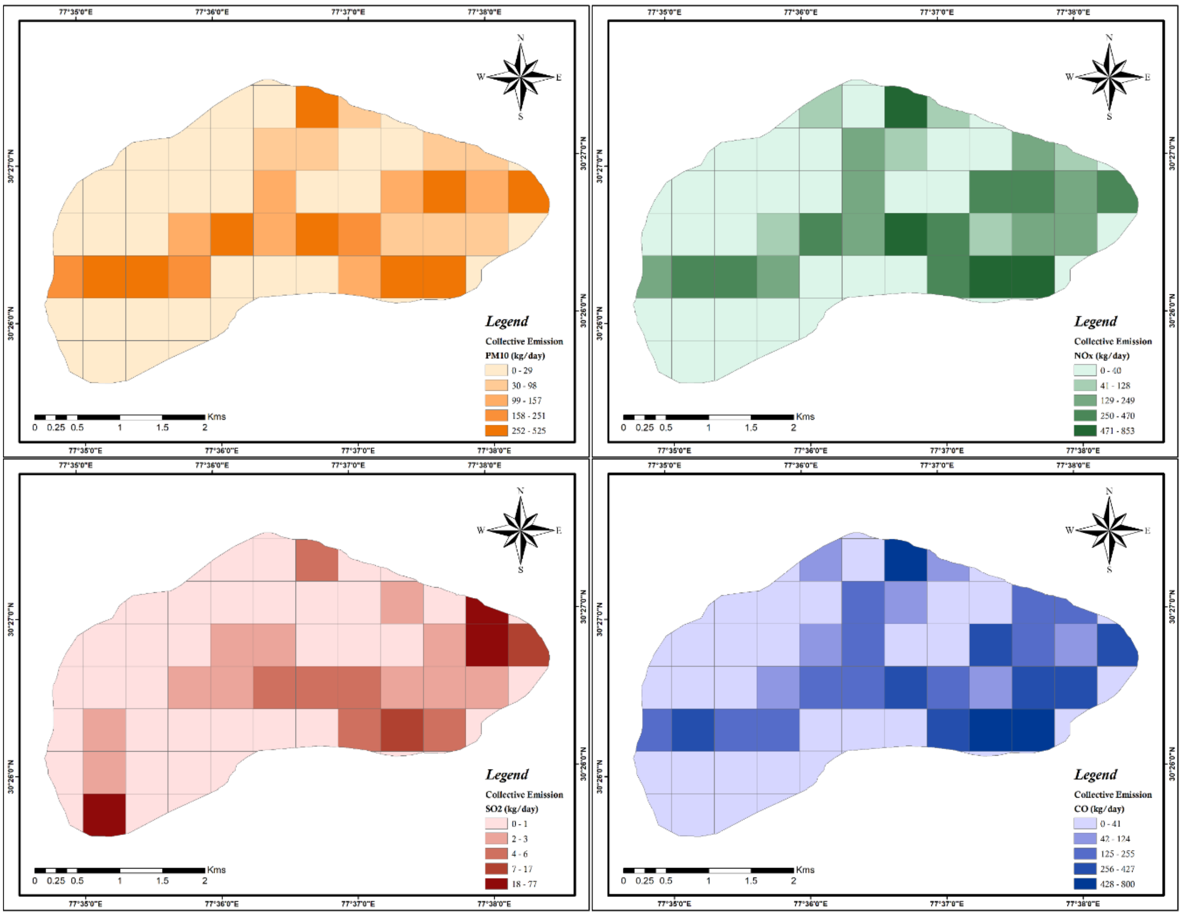


Figure 6: Spatial distribution of PM_{10}, NOx, SO_2 and CO emissions in the city

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 vehicles (21 – 22%), soil and road dust (19 – 16%), secondary inorganic aerosol (SIA) (12 – 15%), construction activities (14 – 13%), biomass burning (10 – 9%), MSW burning (8 – 9%), coal combustion and flyash (10 – 9%) and industrial emission (6 – 6%).

- The most consistent sources for PM_{10} and $PM_{2.5}$ are vehicles and soil and road dust. On average, the other sources may contribute more (or less), but their contributions vary from day to day. The most variable source was construction activities followed by biomass burning and coal combustion.
- Vehicles' contribution is most significant and consistent in PM_{10} (21%) and $PM_{2.5}$ (22%) in the city.
- Soil and road dust is the second most contributor in PM_{10} (19%) and $PM_{2.5}$ (16%), showing high variability, 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.
- Coal and flyash contribute 10% in PM_{10} and 9% in $PM_{2.5}$. It could be due to uses in industries, hotels and restaurants and as a part of cement used for construction activities.
- Secondary inorganic aerosol is significantly high contribution in both PM_{10} (12%) and $PM_{2.5}$ (15%).
- 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} (8%) and $PM_{2.5}$ (9%). This emission is expected to be large in the regions of economically lower strata of the society and commercial places, which do not have proper infrastructure for collection and disposal of MSW.
- PHF site was in the industrial area having major polluting industries. Therefore, it has the movement of large trucks ferrying raw material and finished products. The dumping and burning of MSW and plastic waste along the roadsides were a routine practice. The MSW/plastic burning contribution is high both in PM_{10} (9%) and $PM_{2.5}$ (13%) that indicating improper management of waste generated in the industrial area.
- Industrial contribution in the city is reasonable for both PM_{10} (6%) and $PM_{2.5}$ (6%) 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 6% of PM_{10} and 6% of $PM_{2.5}$, and their contribution is significant at the breathing level.
- The contribution of biomass burning is significant among all sources at 10% (for PM_{10}) and 11% (for $PM_{2.5}$). Sizeable biomass is consistent in PM, indicating local

sources present in Paonta Sahib city and nearby areas. Biomass burning is because of arboriculture activities, agricultural residue burning, high energy crop burning for fuel, etc.

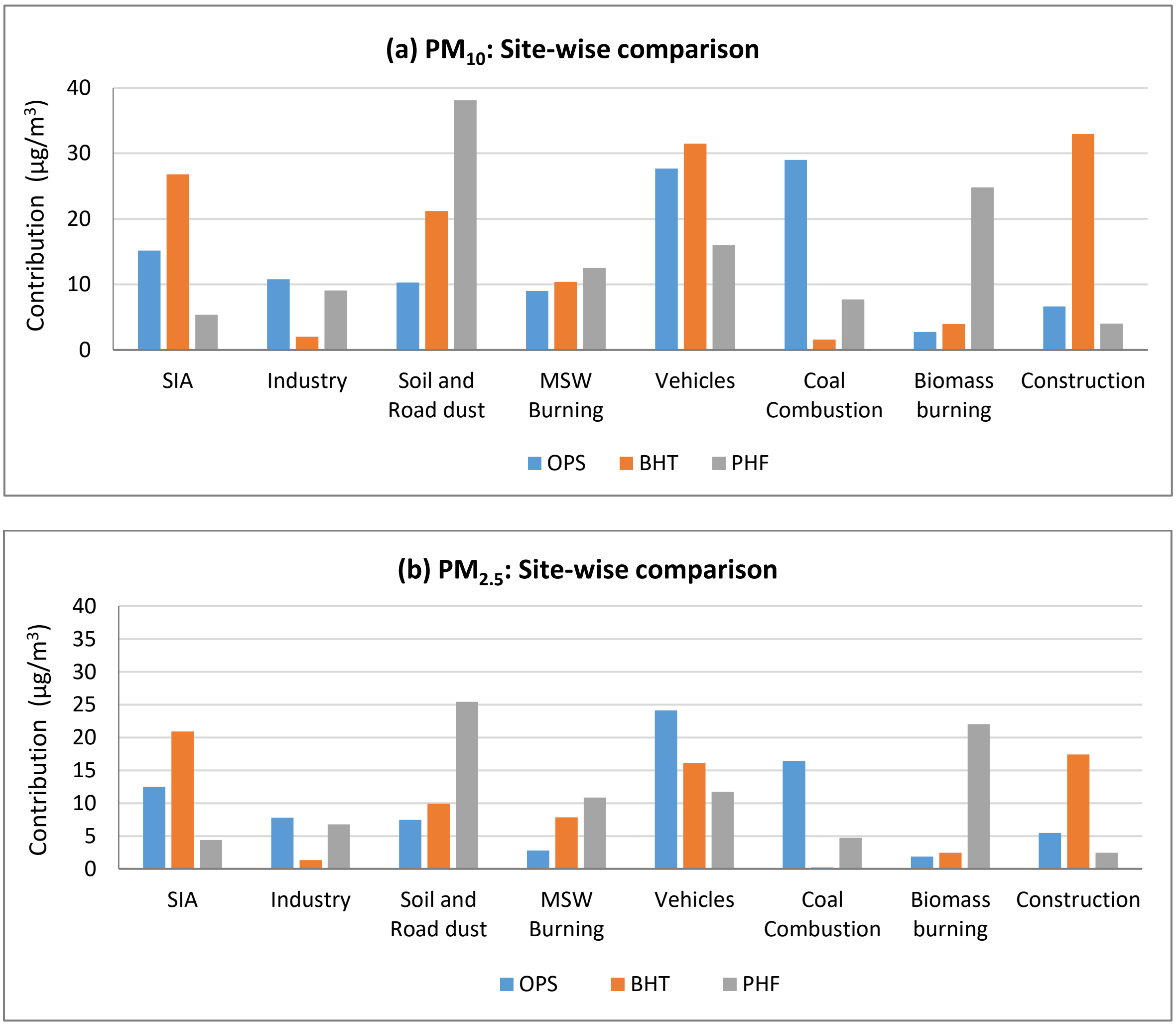
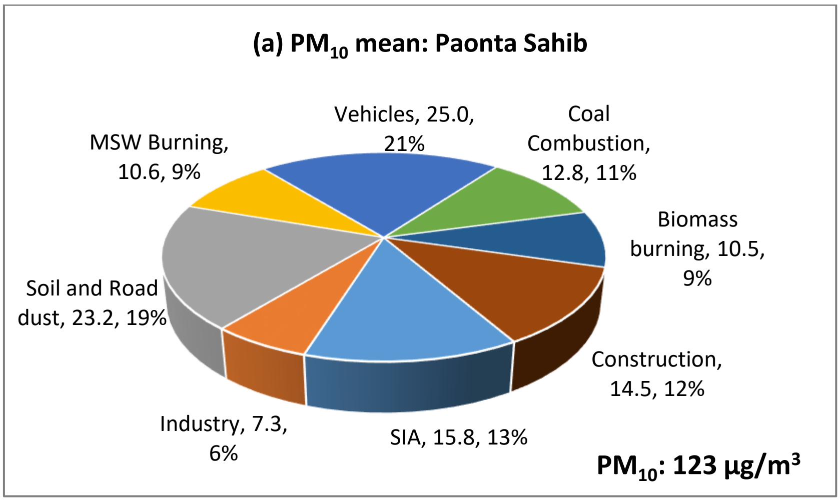


Figure 7: Site-specific source-wise contribution to PM_{10} and $PM_{2.5}$



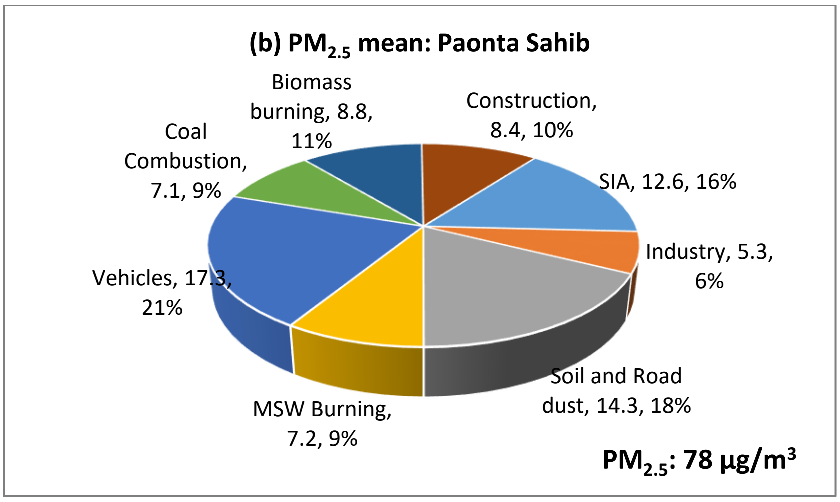


Figure 8: City level source contributions to PM_{10} and $PM_{2.5}$ levels

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 (sitting capacity of more than 15) and restaurants was approximately 58, mainly situated in the central part of the city and along with the National Highways 7 and 707. 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 during power failure and coal, especially in tandoor and other cooking.

  The Municipal Council, Paonta Sahib may enforce coal-free cooking in hotels, restaurants, BHs and marriage places as far as possible. The ash must be stored in leak-free bags and adequately disposed of. One may consider linking the commercial license to clean fuel, which may be enforced by the Municipal Council, Paonta Sahib, Department of Food, Civil Supplies and Consumer Affairs, and oil companies (Indian Oil, HP, etc.).

- **MSW burning and management**

  MSW and others residue burning are rampant in Paonta Sahib. In winter, the overall source contribution from MSW burning is 8% in PM_{10} and 9% in $PM_{2.5}$ 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, Paonta Sahib 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.

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 Main Market, Shamsherpur near ITI college, Badripur Chowk. Major residential areas (having high density) were Shanti colony, Badripur Chowk, Subh Khera, Nav Vihar Colony, Taruwala and Yamuna Vihar Colony.

Desilting and cleaning of municipal drains by Municipal Council, Paonta Sahib 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.

In Paonta Sahib, 'treatment, storage, and disposal facility (TSDF)' is not available for MSW management. A 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, Paonta Sahib 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.

It is recommended to develop an Integrated TSDF along with provision of electricity connection and necessary water connection. 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, Paonta Sahib, 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.

- **Construction and Demolition**

The construction and demolition (C&D) emission can be classified as temporary or short-term. These temporary or short-term construction activities are frequent in a developing urban area. 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 may be created in cooperation with Paonta Sahib authorities, a common practice in large cities. The control measures for emission at a construction site 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 while leaving the site and damping down 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 Paonta Sahib Development Authority (PSDA), Himachal Pradesh Housing Board, Municipal Council, Paonta Sahib, Urban Development Department, PWD, and HPSPCB.

- **Domestic sector**

The fuel consumption pattern shows LPG (79%) consumption (PPAC, MoPNG, 2016), 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-fueled. 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. A sizable floating population working in industries must also have an LPG supply.

- **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 PM_{10} and $PM_{2.5}$ emissions. The silt load, an important factor in PM emissions from the road varied from 1.5 to 4 g/m^2 which is high (typical load in developed countries is less than 1 g/m^2). 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 50% 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. PWD (Public Works Department) and city administration should act immediately to reduce the pollution load from road dust.
- Municipal Council should carry out vacuum-assisted sweeping.
- If the silt road is greater than 2 gm/m^2, 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.
- NHAI should ensure that the silt load on highways maintained by them should have a silt load of less than 2 gm/m^2.
- 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 (Kishanpura-Jamniwala Road, Main Market Road, Badripur Chowk, Vishwakarma Chowk, Bangran Chowk, Main Market 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 PSDA, Himachal Pradesh Housing Board, Municipal Council, Paonta Sahib, 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, NOx, PM_{10}, and $PM_{2.5}$. There is a relatively large contribution of diesel vehicles (trucks, buses, LCVs, cars, etc.) to PM_{10}, $PM_{2.5}$ and NOx. Out of about 1089 kg/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).

  - 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 2030, 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, MoPG), 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 (5 mins/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 may be considered.
- Check the overload vehicles: Expedite installation of weigh-in-motion bridges and machines at all entry points to Paonta Sahib to ensure that vehicles are not overloaded.
- Himachal Road Transport Corporation (HRTC) should plan and install multiple electric charging facilities in its depots (in Paonta Sahib 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 maundering in the city to avoid difficult turning and congestion.
- Route rationalization: Improve availability by rationalizing routes and fleet enhancement with requisite modifications. Ensure integration of the existing bus stops on the national highway.
- Information Transmission (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 Paonta Sahib city. Wherever installed, the traffic signal does not function properly, leading 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 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 take full advantage of BS-VI, decongestion, removing road encroachments, 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 removed and ensure that service centres have adequate space for workshop activities and that servicing is not done on the roadside.
- Heavy-duty vehicles and buses which are destined for other cities pass through major roads within Paonta Sahib city and create heavy congestion. The important points of congestions are Kishanpura-Jamniwala Road, Main Market Road, Badripur Chowk, Vishwakarma Chowk, Bangran Chowk, Main Market; As a result, these routes within the city will also be congested.
- Areas that are adjacent to the market centers like Main Market, Court Road, Vishwakarma Chowk, Badripur Chowk, Shamsherpur experience heavy traffic congestion due to the unregulated parking and encroachment by local shop owners.
- 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.
- 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: 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 must be adopted to discourage private vehicles in the city centre and congested settlements and increase parking costs within the city centre.

- 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**

  More than 9 polluting units 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, and HSD as fossil fuels, in the industries. Since many industrial clusters surround the residential areas 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., PSDA) 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 at 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) for industries dealing with solvents and petroleum uses or manufacturing.

- Adequate and quality electric supply should be available to the industries for an effective industrial operation and avoidance of the DG sets.
- 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, Paonta Sahib and HPSPCB.

- **Brick Kilns**

Brick kilns are one of the major contributors to air pollution from the surrounding areas of Paonta Sahib. It is important to cover this sector in terms of emissions, although the majority of brick kilns lie outside the city boundary.

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.

Strengthening of HPSPCB Paonta Sahib, 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 their personnel

- 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 Paonta Sahib

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 15 persons) appliances.	Municipal Council, Paonta Sahib	1 year
	Link Commercial license to clean fuel	Municipal Council, Paonta Sahib, 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, Paonta Sahib	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 cooking (common in western countries) or PNG at the	Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian	10 years

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
	minimum	Oil/HP, etc.)	
Municipal Solid Waste (MSW) Burning	Develop an integrated treatment, storage and disposal facility (TSDF)	Municipal Council, Paonta Sahib, HPSPCB, PSDA	One year
	Any type of garbage burning should be strictly stopped. Current waste collection and surveillance are poor.	Municipal Council, Paonta Sahib	Immediate
	Surveillance is required that hazardous waste goes to TSDF.	Municipal Council, Paonta Sahib, HPSPCB, Paonta Sahib Development Authority (PSDA)	
	Desilting and cleaning of municipal drains	Municipal Council, Paonta Sahib	
	Waste burning in Industrial areas should be stopped.	HPSIDC, HPSPCB	
	Daily, Monthly mass balance of MSW generation and disposal	Municipal Council, Paonta Sahib	
	Sensitize people and media through workshops and literature distribution so as not to burn the waste.	Municipal Council, Paonta Sahib, HPSPCB, and NGO	
Construction and Demolition	Wet suppression	PSDA, Municipal Council, Paonta Sahib, Urban Development Department, PWD	Immediate
	Wind speed reduction (for large construction sites)	PSDA, Municipal Council, Paonta Sahib, Urban Development Department, PWD	
	Enforcement of C&D Waste Management Rules. The	PSDA, Municipal Council, Paonta Sahib,	Immediate

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
	waste should be sent to a construction and demolition processing facility	Urban Development Department, PWD	
	Proper handling and storage of raw material: covered the storage and provide the windbreakers.	PSDA, Municipal Council, Paonta Sahib, Urban Development Department, PWD	
	Vehicle cleaning and specific fixed wheel washing on leaving the site and damping down of haul routes.	PSDA, Municipal Council, Paonta Sahib, Urban Development Department, PWD	
	The actual construction area should be covered by a fine screen.	PSDA, Municipal Council, Paonta Sahib, 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)	PSDA, Municipal Council, Paonta Sahib, Urban Development Department, PWD	
	Builders should leave 25% area for green belt in residential colonies to be made mandatory.	PSDA, Municipal Council, Paonta Sahib, Urban Development Department, PWD	
	Sensitize construction workers and contract agencies through workshops.	PSDA, Municipal Council, Paonta Sahib, Urban Development Department, PWD, HPSPCB, and NGO	
Road Dust	The silt load in Paonta Sahib varies from 1.5 to 4 g/m^2. The silt load on each road should be reduced to	PSDA, Municipal Council, Paonta Sahib, National Highway Authority, PWD, HPSPCB	Immediate

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
	under 2 gm/m^2. Regular vacuum sweeping should be done on the road having a silt load above 2 gm/m^2.	(for silt load compliance)	
	Convert unpaved roads to paved roads. Maintain pothole-free roads.	PSDA, Municipal Council, Paonta Sahib, 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.	PSDA, Municipal Council, Paonta Sahib, National Highway Authority, PWD	
	Increase green cover and plantation. Undertake the green of open areas, community places, schools, and housing societies.	PSDA, Municipal Council, Paonta Sahib, National Highway Authority, State Forest Department, PWD	
	vacuum-assisted sweeping is carried out four times a month on major roads with road washing.	PSDA, Municipal Council, Paonta Sahib, 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	Industrial Associations and State transport Department	Immediate

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
	finished products		
	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 Paonta Sahib.	Transport Department, Traffic Police, Paonta Sahib, 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 Paonta Sahib	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 Paonta Sahib	1year
	Enforcement of bus lanes and keeping them free from obstruction and encroachment.	Municipal Council, Paonta Sahib, ARTO Paonta Sahib	1 year

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
	Route rationalization: Improvement of availability by rationalizing routes and fleet enhancement with requisite modification.	PSDA, ARTO Paonta Sahib, Traffic Police, Paonta Sahib	1 year
	IT systems in buses, bus stops, control centers, and passenger information systems for the reliability of bus services and monitoring.	PSDA, ARTO Paonta Sahib, Traffic Police, Paonta Sahib	1 year
	Movement of materials (raw and product) within the city should be allowed between 10 PM to 5 AM.	PSDA, ARTO Paonta Sahib, Traffic Police, Paonta Sahib	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	
	There should be separate Treatment, Storage, and Disposal Facilities (TSDFs) for hazardous waste.	Industrial Associations, PSDA, 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

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
	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 5 boilers, Heater and furnaces in Paonta Sahib 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. 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	State Energy Department, HPSEBL	2 years

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
	power supply to the industries.		
	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.	PSDA, Municipal Council, Paonta Sahibs, ARTO Paonta Sahib, Traffic Police, Paonta Sahib	6 months
	Disciplined Public transport (designate one lane stop).	ARTO Paonta Sahib., Traffic Police, Paonta Sahib	
	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.	PSDA, Municipal Council, Paonta Sahib, ARTO Paonta Sahib, Traffic Police, Paonta Sahib	
	Examine the existing framework for removing broken vehicles from roads and create a system for speedy removal and ensure minimal disruption to traffic.	PSDA, ARTO Paonta Sahib, NHAI, Traffic Police, Paonta Sahib	
	Synchronize traffic movements or introduce intelligent traffic systems for lane-driving.	PSDA, ARTO Paonta Sahib, NHAI, Traffic Police, Paonta Sahib	
	Mechanized multi-story parking at bus stands, and big commercial areas.	PSDA, ARTO Paonta Sahib, Municipal Council, Paonta Sahib, NHAI, Traffic Police,	

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
	Remove at least 50 percent of on-street parking in the city.	Paonta Sahib	
	Identify traffic bottleneck intersections and develop a smooth traffic plan. For example, Kishanpura-Jamniwala Road, Main Market Road, Badripur Chowk, Vishwakarma Chowk, Bangran Chowk and Main Market are the main bottlenecks for traffic.	PSDA, ARTO Paonta Sahib, Municipal Council, Paonta Sahib, Traffic Police, Paonta Sahib	
	Parking policy in congestion areas (high parking cost, at city centers, only parking is limited for physically challenged people, etc).	PSDA, ARTO Paonta Sahib, Municipal Council, Paonta Sahib, NHAI, Traffic Police, Paonta Sahib	
	The important point of congestion is Main Market. Parking in Main Market parking should be strictly prohibited.	ARTO Paonta Sahib, Traffic Police	2 years
*The above steps should not only be implemented in Paonta Sahib municipal limits rather these should be extended up to at least 10 km beyond the boundary. This will need support from the central government and adjacent city administration.			

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Acknowledgments

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1 Introduction

1.1 Background

Air pollution has emerged as a major challenge, particularly in urban areas. The problem becomes more complex due to the multiplicity and complexity of 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 PM_{10} (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 PM_{10} 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 Paonta Sahib, a city in Himachal Pradesh having a large number of industries in different sectors, i.e., textile, fast-moving consumer goods, pharmaceuticals, pesticides, food processing, electroplating, metal finishing, metal refining and engineering industries.

1.2 General Description of Paonta Sahib

1.2.1 Geography and Demography

Paonta Sahib is an industrial cum commercial town and municipal council in Sirmour district of Himachal Pradesh situated at 30.438°N 77.624°E with the elevation of 389 m. The city lies in the lap of Shiwalik foothills and near the border of Himachal Pradesh and Uttarakhand states. It is situated on National Highway 72 that is about 45 Kms away from Nahan near to the right bank of the river Yamuna. It has immense potential for future growth for establishing an export market for fruits, vegetables, timbers, and other forest produces.

In Paonta Sahib, the key business activities are trade, commerce, industries and agriculture. The industry sectors are categorized as Major industries are cement, power, aviation, pharmaceutical, textiles, chemicals, limestone, beverages and engineering industries. Paonta Sahib houses more than 75 industries in different sectors. The air polluting (red category) industries are comprising bulk drugs, metal finishing, electroplating and pesticides formulations. The major industries are located in the industrial sector in Gondpur area of Paonta Sahib.

As per the 2011 census, the population of Paonta Sahib city is 25,183; of which males and females are 13,265 and 11,918 respectively (Census-India, 2012) with the population density of 4062 persons per km^2. The city is governed by Municipal Council, which has 11 wards.

1.2.2 Climate

The climate of Paonta Sahib features humid sub-tropical (warm and temperate) nature and the temperature varies from 8°C to 39°C with an annual average of 23.8°C. The city features mild winters, hot and dry summers and a monsoon season. The total average rainfall in Paonta Sahib area is about 1600 – 1700 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 SO_2 and NO_x were observed well below the permissible limit at stations of the national air quality monitoring programme (NAMP) (CPCB, 2019). PM_{10} concentrations varied seasonally with atmospheric processes and anthropogenic activities. The annual average of PM_{10} at two NAMP stations were observed above the permissible limit by a factor of 1.2 to 2.8 for the period of 2010 to 2020 shown in Figure 1.1 (Naveen et al., 2020).

A report (CPCB, 2019) on air quality status and trend showed the annual average levels of PM_{10} (83 µg/m^3), NO_2 and SO_2 for the year 2019. The CPCB (CBCB, 2019) has reported the levels of in the range 17 - 188 µg/m^3 for PM_{10}, 9 - 21 µg/m^3 for NO_2 and 2 - 8 µg/m^3 for SO_2 for Paonta Sahib.

Although Paonta Sahib city faces air pollution problems due to the number of sources, no detailed study of the chemical composition of PM_{10} and $PM_{2.5}$ in recent years has been undertaken to identify the sources and their contributions to air pollution.

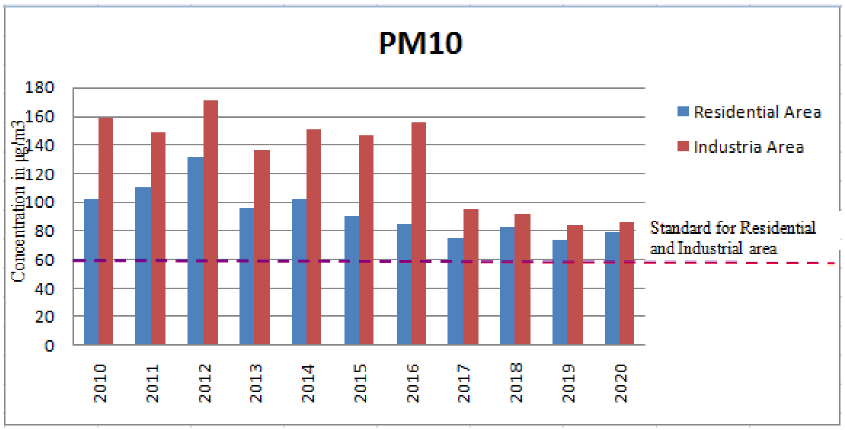


Figure 1.1: Annual average levels of PM_{10} from 2010 to 2020 (Naveen et al., 2020)

1.4 Objectives and Scope of Work

Objectively the project aims to achieve the following:

- Development of GIS-based gridded (0.5 km × 0.5 km resolution) emission inventory for air pollutants PM_{10}, $PM_{2.5}$, SO_2, NO_2, NH_3, CO, O_3, 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 PM_{10}, $PM_{2.5}$, SO_2, NO_2 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 PM_{10}, $PM_{2.5}$, SO_2, NO_2, NH_3, and VOCs. Analyze collected PM_{10} 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 PM_{10}, 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.

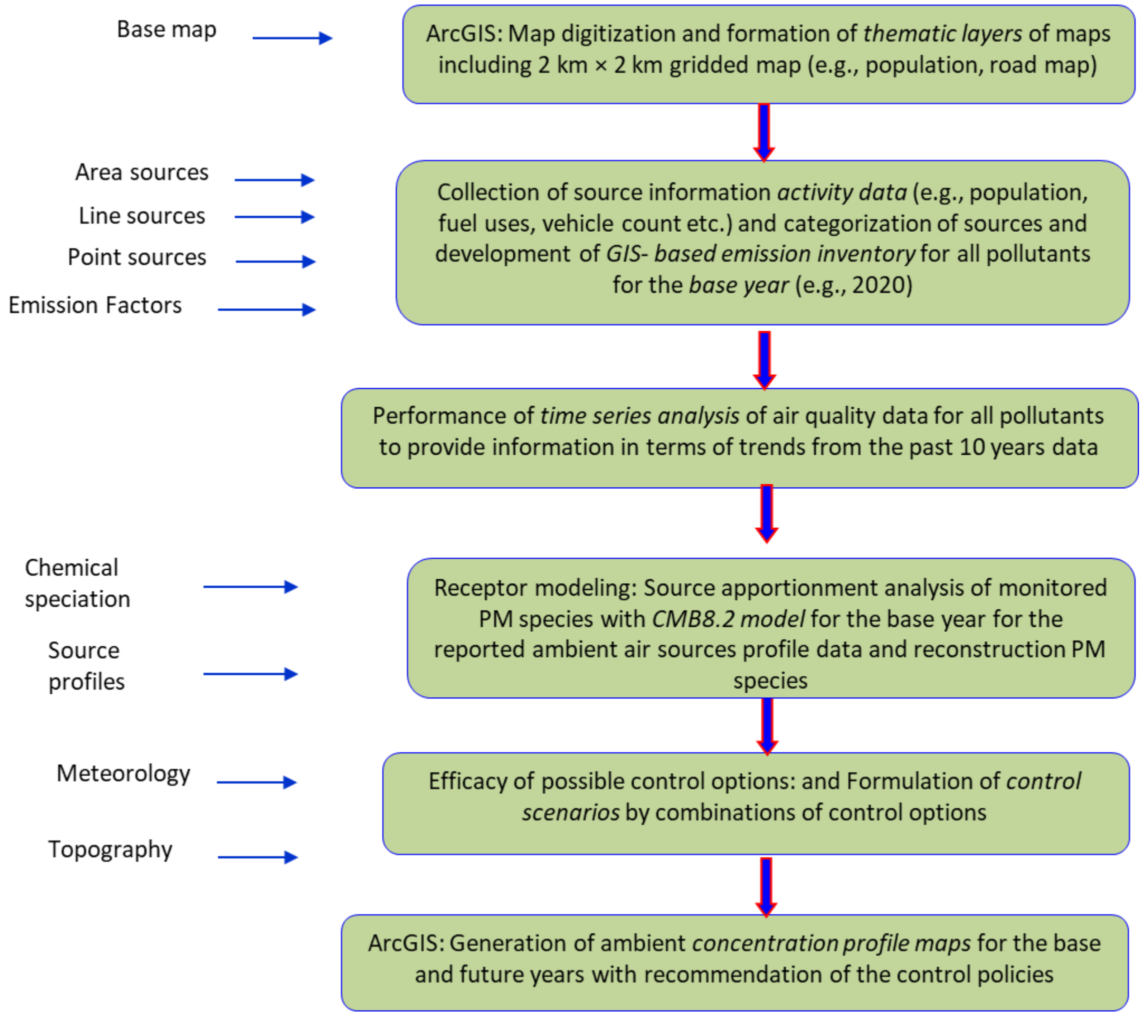


Figure 1.2: Approach to the Study and Major Tasks

1.5.1 Selection of sampling sites

It was considered appropriate that three sites in a city like Paonta Sahib 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, Paonta Sahib.

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: SO_2, NO_x, CO, PM_{10}, $PM_{2.5}$ on a GIS platform and other pollutants NH_3, 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) and updated version 5.1 of SPECIATE (USEPA, 2020). 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 and fingerprints for their applicability in the local environment of Paonta Sahib city. For the sake of uniformity, source profiles for non-vehicular sources for PM_{10} and $PM_{2.5}$ were adopted from USEPA (2006). These profiles were used to verify profiles derived from ambient PM levels and its chemical compositions by positive matrix factorization (PMF) model.

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 PM_{10} 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) (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 Paonta Sahib city in Himachal Pradesh for the winter season from the sampling and chemical analysis results carried out in the present study.

2.1 Methodology

2.1.1 Site Selection and details

A total of three 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 Paonta Sahib

S. No.	Sampling Site	Site Code	Description of the site	Type of sources
1.	HPPCB Office	OPS	Residential	Domestic cooking, vehicles, road dust, garbage/MSW burning, biomass
2.	Brighten Hotel	BHT	Commercial	DG sets, vehicles, road dust, garbage/waste burning, hotels, restaurants, coal uses
3.	Pharma Force	PHF	Industrial	Industries, DG sets, vehicles, road dust, garbage/industrial waste burning, coal

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.

Paonta Sahib: 1. OPS 2. BHT 3. PHF

Figure 2.1: Photographs of Sampling Sites

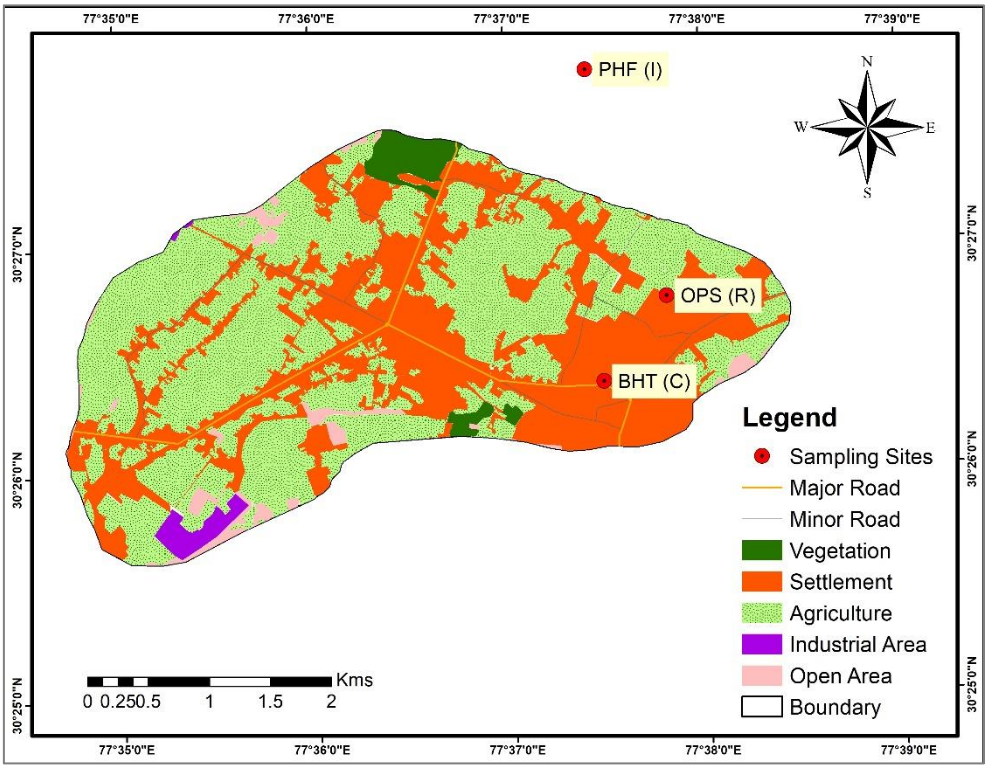


Figure 2.2: Land-use Pattern and Locations of Sampling Sites

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 (NO_2), Sulphur dioxide (SO_2), carbon monoxide (CO), ozone (O_3), ammonia (NH_3) and volatile organic compounds (VOCs) and (ii) particulate matter sampling (PM_{10} 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 600ºC)	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 PM_{10}, 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 (SO_2, NO_2

and NH_3), Continuous online gaseous analyzer (Airshed planning professional Pvt Ltd, India, Figure 2.3(i)) used for CO and O_3, 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.

PM_{10} 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±2ºC 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 SO_2, NO_2, NH_3, CO, O_3, PM_{10}, $PM_{2.5}$, 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 (November 29 – December 07, 2019). The analysis of SO_2, NO_2 and NH_3 was carried out daily at the laboratory in Paonta Sahib 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 2.6 present the details of sampling days for all pollutants at all monitoring sites.

Table 2.4: Sampling Days of Various Pollutants at OPS

OPS - Paonta Sahib, Winter								
	29-Nov-19	30-Nov-19	1-Dec-19	2-Dec-19	3-Dec-19	4-Dec-19	5-Dec-19	6-Dec-19
PM10								
PM2.5								
OC								
EC								
VOC								
NO2								
NH3								
SO2								

Table 2.5: Sampling Days of Various Pollutants at BHT

BHT - Paonta Sahib, Winter									
	29-Nov-19	30-Nov-19	01-Dec-19	02-Dec-19	03-Dec-19	04-Dec-19	05-Dec-19	06-Dec-19	07-Dec-19
PM10									
PM2.5									
OC									
EC									
VOC									
NO2									
NH3									
SO2									

Table 2.6: Sampling Days of Various Pollutants at PHF

BHT - Paonta Sahib, Winter									
	29-Nov-19	30-Nov-19	01-Dec-19	02-Dec-19	03-Dec-19	04-Dec-19	05-Dec-19	06-Dec-19	07-Dec-19
PM10									
PM2.5									
OC									
EC									
VOC									
NO2									
NH3									
SO2									

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 2.7. The air quality for twelve notified parameters is discussed in the next section.

Table 2.7: 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_6H_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 minimum104 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 (PM_{10}, $PM_{2.5}$)

A statistical summary of PM levels is presented in Table 2.8 for all sites.

HPPCB Office (OPS)

The time-series of 24-hr average concentrations of PM_{10} and $PM_{2.5}$ are shown in Figure 2.4. Average levels were 73±21 µg/m^3 (for $PM_{2.5}$) and 113±28 µg/m^3 (for PM_{10}). The levels of PM_{10} and $PM_{2.5}$ are non-complying with the NAAQS. The corresponding CPCB air quality Index (AQI) was less than 277 and 150 in the category *poor*. The ratio of $PM_{2.5}$ to PM_{10} was 0.65 at OPS.

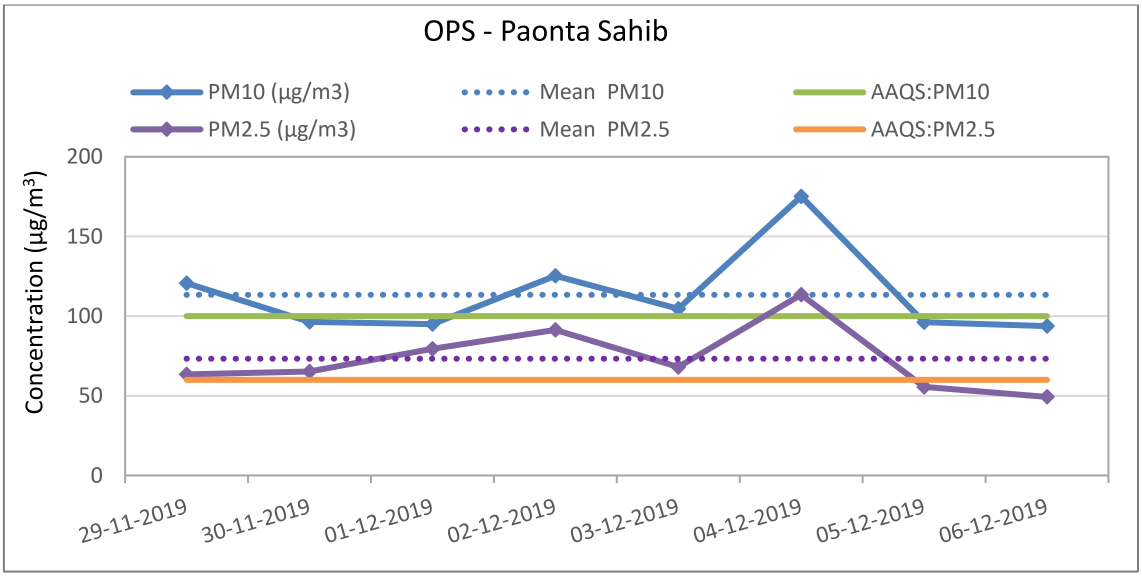


Figure 2.4: PM Concentrations at OPS

Brighten Hotel (BHT)

Time-series of 24-hr average concentrations of PM_{10} and $PM_{2.5}$ is shown in Figure 2.5. Average levels were 77±19 µg/m^3 (for $PM_{2.5}$) and 136±27 µg/m^3 (for PM_{10}). The levels of PM_{10} and $PM_{2.5}$ are non-complying with the NAQS. The corresponding CPCB air quality Index (AQI) was less than 277 and 154 in the category *poor*. The ratio of $PM_{2.5}$ to PM_{10} was 0.56 at BHT.

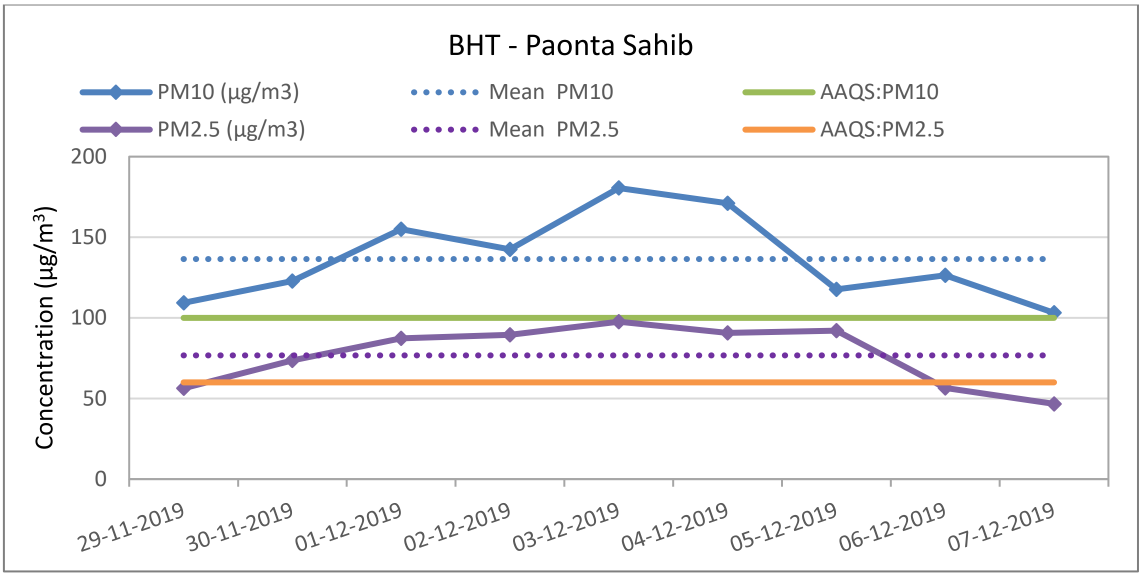


Figure 2.5: PM Concentrations at BHT

Pharma Force (PHF)

The time-series of 24-hr average concentrations of PM_{10} and $PM_{2.5}$ is shown in Figure 2.6. Average levels were 86±21 µg/m^3 (for $PM_{2.5}$) and 116±25 µg/m^3 (for PM_{10}). The levels of PM_{10} and $PM_{2.5}$ are non-complying with the NAQS. The corresponding CPCB air quality Index (AQI) was less than 306 and 147 in the category *very poor*. The ratio of $PM_{2.5}$ to PM_{10} was 0.73 at PHF.

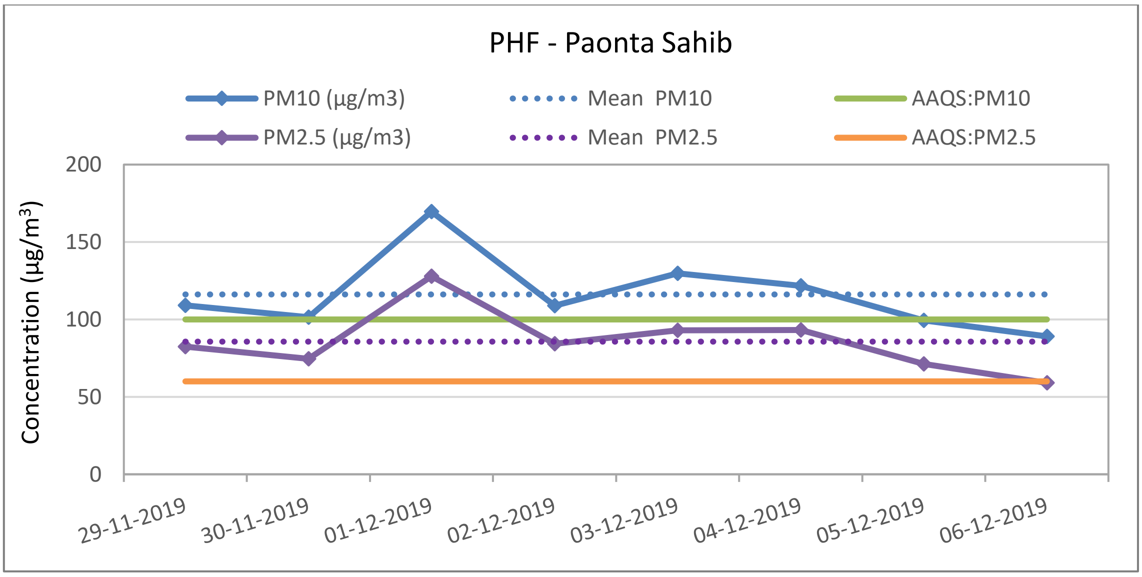


Figure 2.6: PM Concentrations at PHF

Overall PM levels

The site-wise comparison is shown for PM_{10} and $PM_{2.5}$ (Figure 2.7) and the ratio of $PM_{2.5}$ to PM_{10} (Figure 2.8) for all sites. The overall summary of experimental results for PM is shown for Paonta Sahib (Table 2.8).

The overall city mean levels in winter were 79±5 µg/m^3 (for $PM_{2.5}$) and 122±10 µg/m^3 (for PM_{10}) and the ratio ($PM_{2.5}$/PM_{10}) was 0.65±0.07. The $PM_{2.5}$ levels are about 1.3 times higher than the NAAQS (60 µg/m^3) and PM_{10} also about 1.2 times higher than the standard (100 µg/m^3). The PM_{10} levels were highest at BHT (136 µg/m^3) and lowest at OPS (113 µg/m^3). The $PM_{2.5}$ levels were highest at PHF (86 µg/m^3) and lowest at OPS (73 µg/m^3).

The ratio of $PM_{2.5}$ to PM_{10} 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 PHF (0.73) followed by OPS (0.65). The relatively high $PM_{2.5}$ at these sites could be attributed to high traffic and emissions from industrial units.

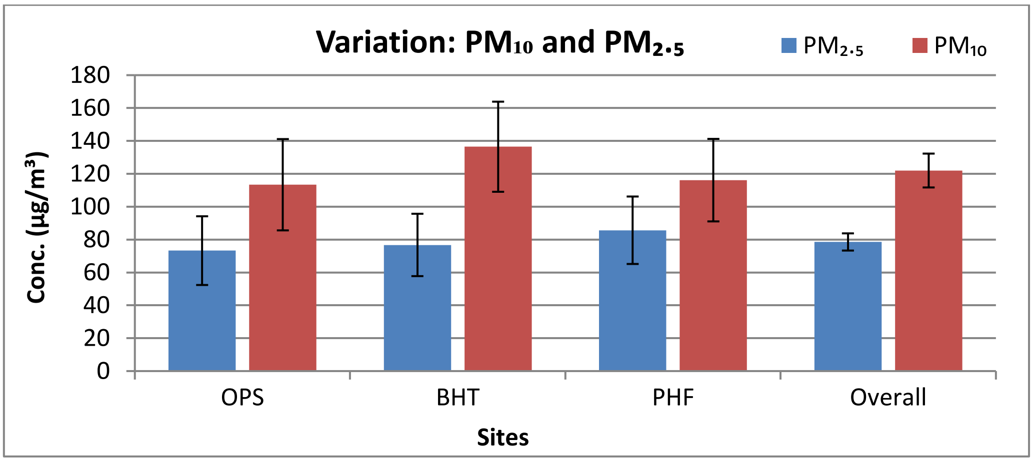


Figure 2.7: Comparison of PM levels at all sites

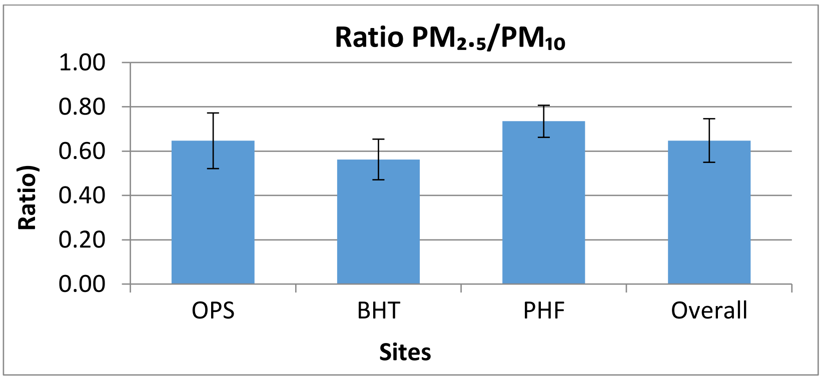


Figure 2.8: Comparison of $PM_{2.5}$/PM_{10} ratio for all sites

Table 2.8: Statistical Results of $PM_{2.5}$ and PM_{10} in ($\mu g/m^3$) at Paonta Sahib

Site		$PM_{2.5}$	PM_{10}	$PM_{2.5}/PM_{10}$
OPS	Mean±SD	73±21	113±28	0.65±0.11
	Range	49-113	94-175	0.53-0.84
BHT	Mean±SD	77±19	136±27	0.56±0.10
	Range	47-98	103-181	0.45-0.78
PHF	Mean±SD	86±21	116±25	0.73±0.04
	Range	59-128	89-170	0.66-0.77
Overall	Mean±SD	79±5	122±10	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 2.9.

OPS

The time-series of 24-hr average concentrations of SO_2, NO_2 and NH_3 are shown in Figure 2.9. It was observed that SO_2, NO_2 and NH_3 concentrations were low and meets the air quality standards.

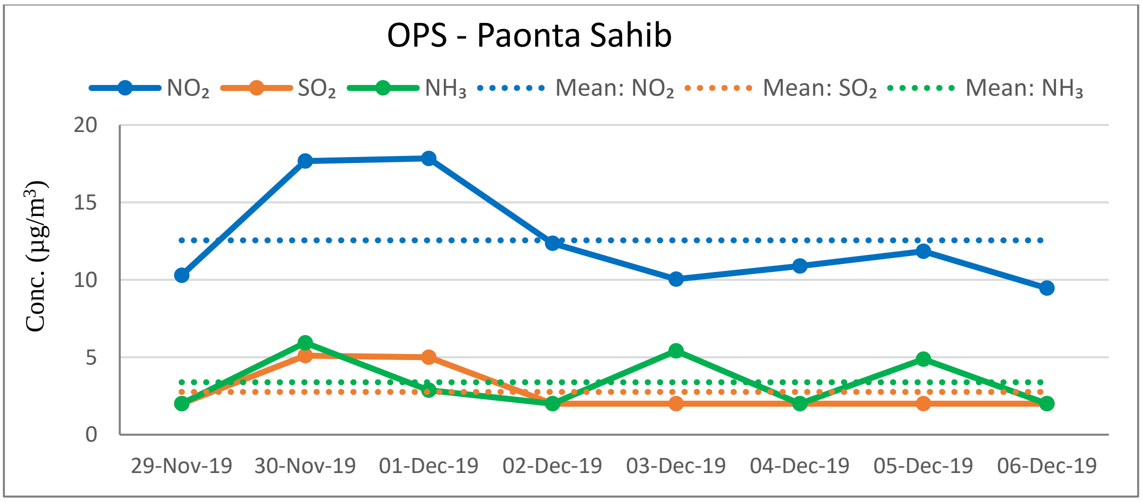


Figure 2.9: SO_2, NO_2 and NH_3 concentrations at OPS

BHT

Time-series of 24-hr average concentrations of SO_2, NO_2 and NH_3 are shown in Figure 2.10. 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 that NO_2 concentrations.

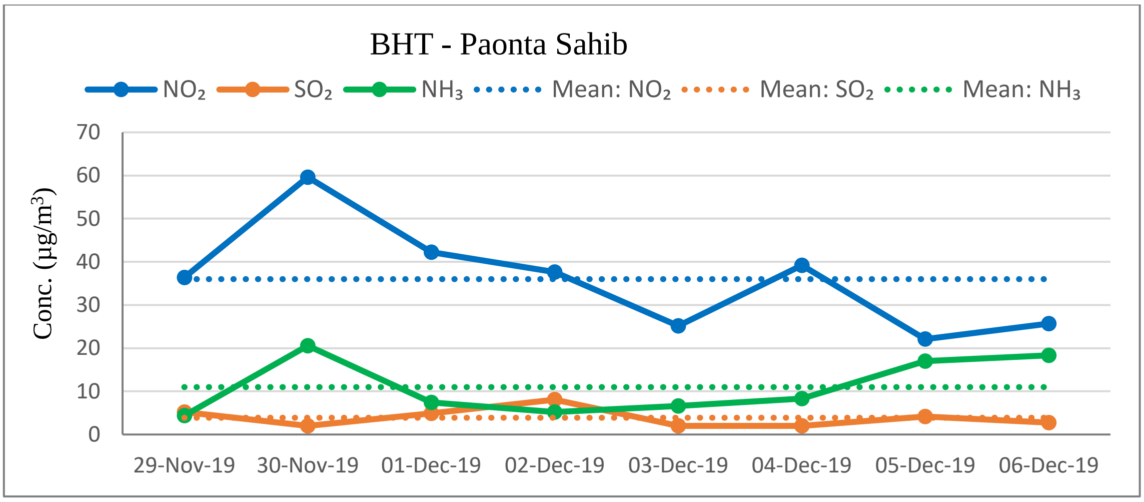


Figure 2.10: SO_2, NO_2 and NH_3 concentrations at BHT

PHF

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 SO_2, NO_2 and NH_3 concentrations were low and met the air quality standard.

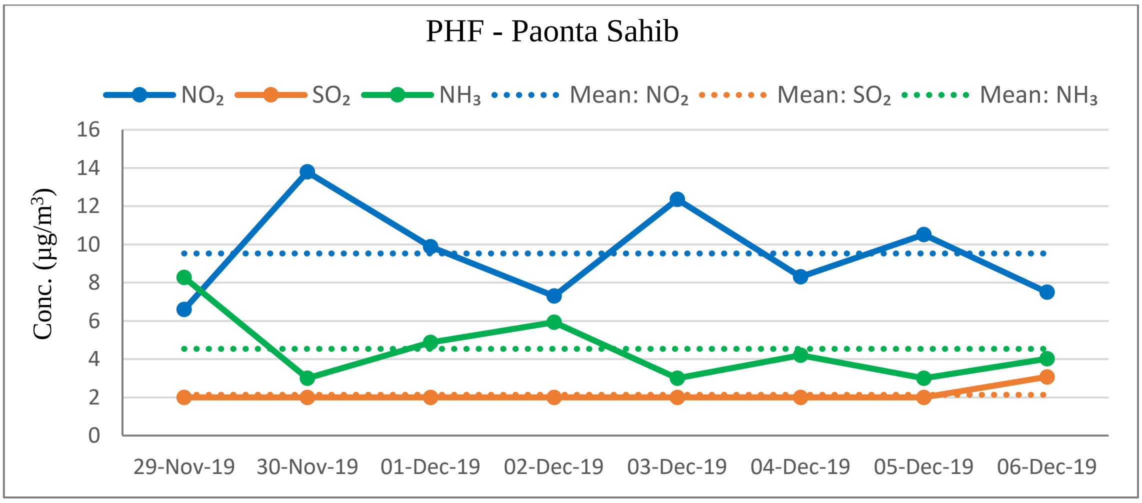


Figure 2.11: SO_2, NO_2 and NH_3 concentrations at PHF

Overall gaseous levels

The site-wise comparison is shown for NO_2, SO_2 and NH_3 (Figure 2.12) for all sites. The overall summary of experimental results for gaseous pollutants are shown for Paonta Sahib (Table 2.9). It was observed that SO_2, NO_2 and NH_3 concentrations were met the air quality standard at all sites.

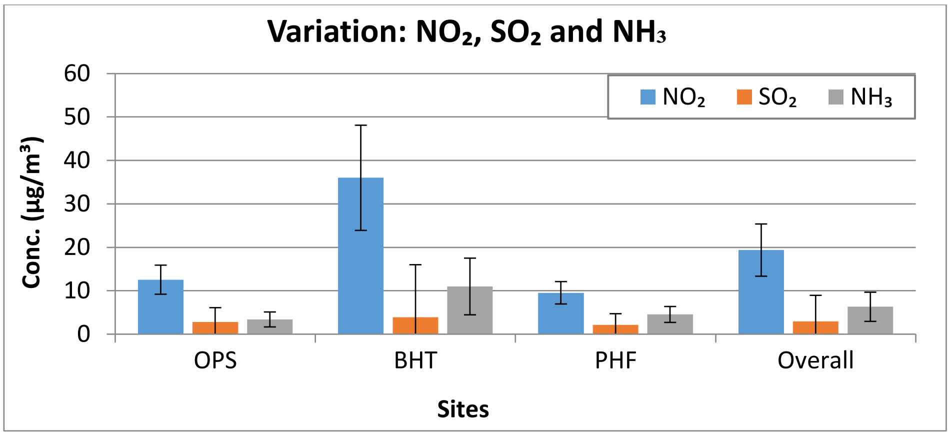


Figure 2.12: Comparison of gaseous pollutants levels at all sites

Table 2.9: Statistical results of gaseous pollutants (µg/m^3) at Paonta Sahib

Site		NO_2	SO_2	NH_3
OPS	Mean±SD	12.6±3.3	2.8±1.4	3.4±1.7
	Range	9.5-17.8	2.0-5.1	2.0-5.9
BHT	Mean±SD	36.0±12.1	3.9±2.1	11.0±6.5
	Range	22.1-59.6	2.0-8.1	4.4-20.6
PHF	Mean±SD	9.5±2.6	2.1±0.4	4.5±1.8
	Range	6.6-13.8	2.0-3.1	3.0-8.3
Overall	Mean±SD	19.4±6.0	2.9±1.3	6.3±3.4

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 2.13 and the site-wise comparison is presented in Figure 2.14 for the winter season. Statistical Results of VOC levels at Paonta Sahib are presented in Table 2.10.

The overall city-level average of BTX levels is 0.73±0.13 µg/m^3 in winter. It is observed that the BTX concentrations are highest at BHT (0.87 µg/m^3) could be due to the more commercial and traffic activities and the lowest at the OPS (0.61 µg/m^3) could be due to the less organic solvent uses and less traffic movement in residential area. The possible reason for higher concentrations in BHT 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.

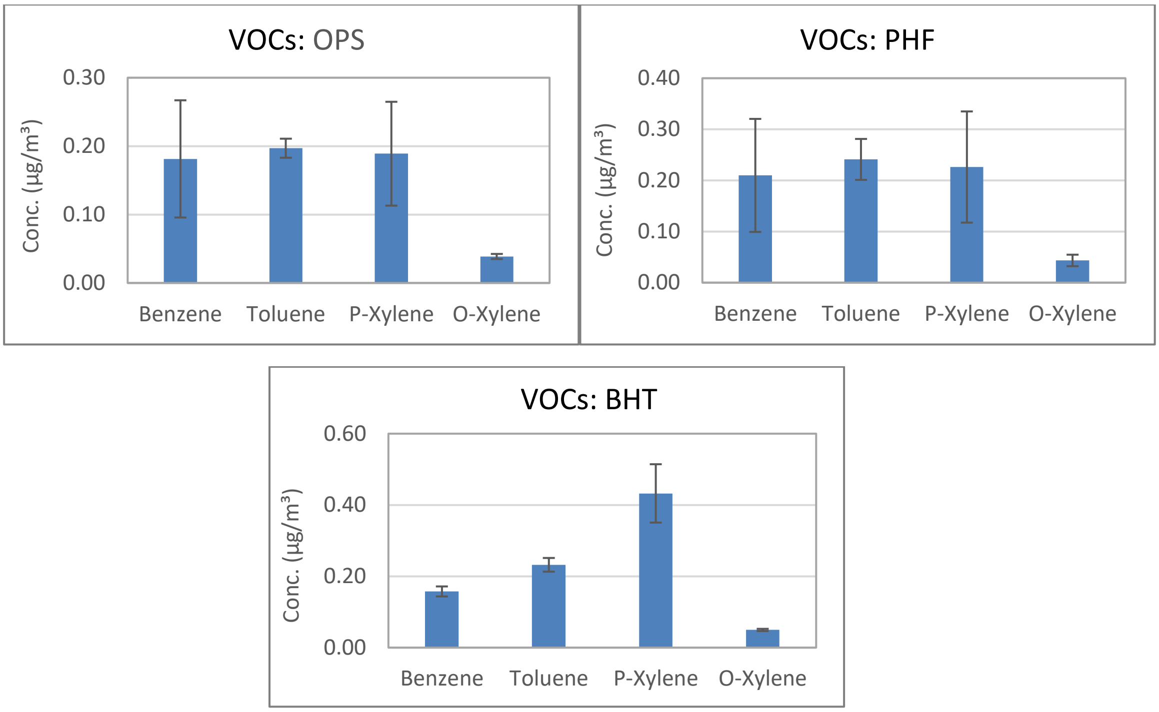


Figure 2.13: VOCs Concentrations at different sites in Paonta Sahib

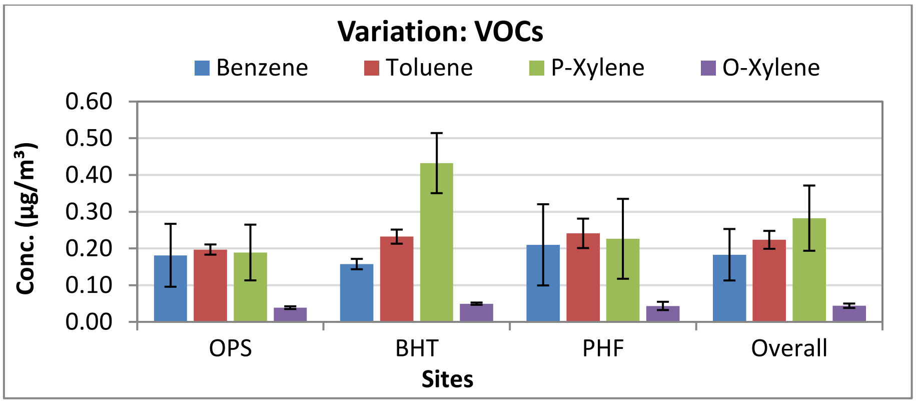


Figure 2.14: Comparison of gaseous pollutants levels at all sites

Table 2.10: Statistical Results of VOCs Contents (µg/m^3) at Paonta Sahib

Site		Benzene	Toluene	P-Xylene	O-Xylene	Total (BTX)
OPS	Mean±SD	0.18±0.09	0.20±0.01	0.19±0.08	0.04±0.00	0.61±0.11
	Range	0.14-0.33	0.18-0.21	0.06-0.25	0.03-0.04	0.46-0.76
BHT	Mean±SD	0.16±0.01	0.23±0.02	0.43±0.08	0.05±0.00	0.87±0.09
	Range	0.14-0.18	0.21-0.26	0.34-0.54	0.04-0.05	0.79-1.01
PHF	Mean±SD	0.21±0.11	0.24±0.04	0.23±0.11	0.04±0.01	0.72±0.20
	Range	0.15-0.41	0.21-0.31	0.06-0.36	0.03-0.06	0.47-1.00
Overall	Mean±SD	0.18±0.07	0.22±0.02	0.28±0.09	0.04±0.01	0.73±0.13

2.3.4 Elemental and Organic Carbon Content (EC/OC) in $PM_{2.5}$

OPS

Average concentrations of EC, OC (OC1, OC2, OC3 and OC4) and ratio of OC fraction to TC are shown in Figures 2.15 (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 OPS. Statistical results of carbon contents ($\mu g/m^3$) in $PM_{2.5}$ at OPS are presented in Table 2.11.

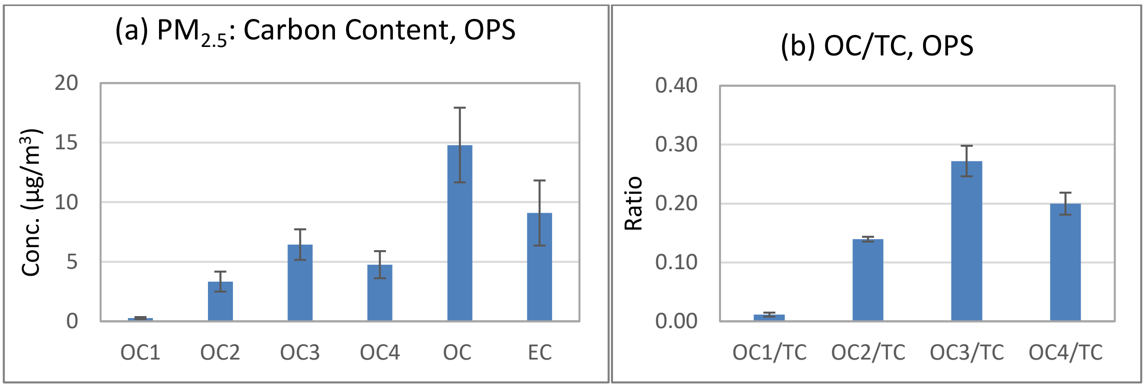


Figure 2.15: EC and OC Content in $PM_{2.5}$ at OPS

Table 2.11: Statistical Results of Carbon Contents ($\mu g/m^3$) in $PM_{2.5}$ at OPS

	OC1	OC2	OC3	OC4	OC	EC	TC	OC1/TC	OC2/TC	OC3/TC	OC4/TC
Mean	0.27	3.33	6.44	4.76	14.80	9.09	23.89	0.01	0.14	0.27	0.20
SD	0.09	0.84	1.28	1.14	3.13	2.73	5.77	0.00	0.00	0.03	0.02
CV	0.32	0.25	0.20	0.24	0.21	0.30	0.24	0.30	0.03	0.10	0.09
Max	0.39	4.99	8.31	6.56	20.26	15.11	35.37	0.02	0.14	0.31	0.22
Min	0.13	2.64	4.88	3.56	11.96	6.93	18.89	0.01	0.13	0.24	0.17

BHT

Average concentrations of EC, OC (OC1, OC2, OC3 and OC4) and ratio of OC fraction to TC are shown in Figures 2.16 (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 BHT. Statistical results of carbon contents ($\mu g/m^3$) in $PM_{2.5}$ at BHT are presented in Table 2.12.

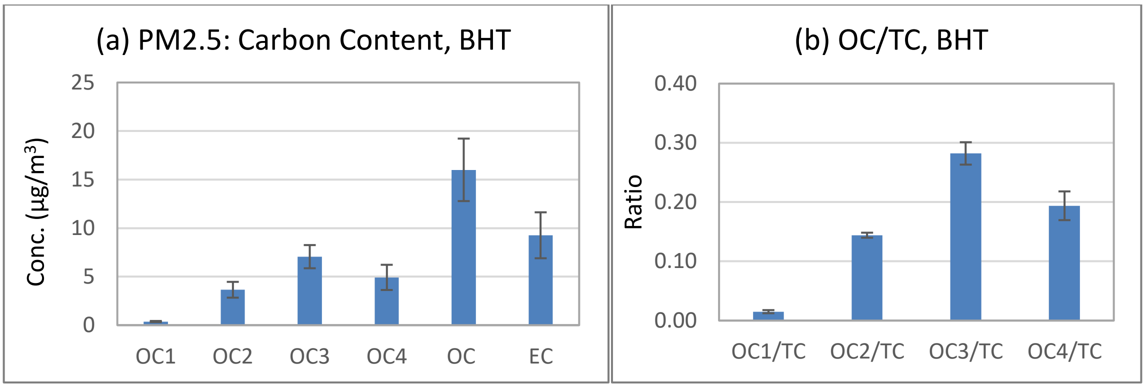


Figure 2.16: EC and OC Content in $PM_{2.5}$ at BHT

Table 2.12: Statistical Results of Carbon Contents (µg/m³) in $PM_{2.5}$ at BHT

	OC1	OC2	OC3	OC4	OC	EC	TC	OC1/TC	OC2/TC	OC3/TC	OC4/TC
Mean	0.37	3.65	7.06	4.92	16.00	9.26	25.26	0.02	0.14	0.28	0.19
SD	0.06	0.81	1.19	1.30	3.22	2.37	5.41	0.00	0.00	0.02	0.02
CV	0.17	0.22	0.17	0.26	0.20	0.26	0.21	0.18	0.03	0.07	0.13
Max	0.45	4.83	8.55	6.49	19.68	14.21	33.89	0.02	0.15	0.31	0.23
Min	0.30	2.14	4.84	2.78	10.07	5.70	15.76	0.01	0.14	0.25	0.17

PHF

Average concentrations of EC, OC (OC1, OC2, OC3 and OC4) and ratio of OC fraction to TC are shown in Figure 2.17 (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 PHF. Statistical results of carbon contents (µg/m³) in $PM_{2.5}$ at PHF are presented in Table 2.13.

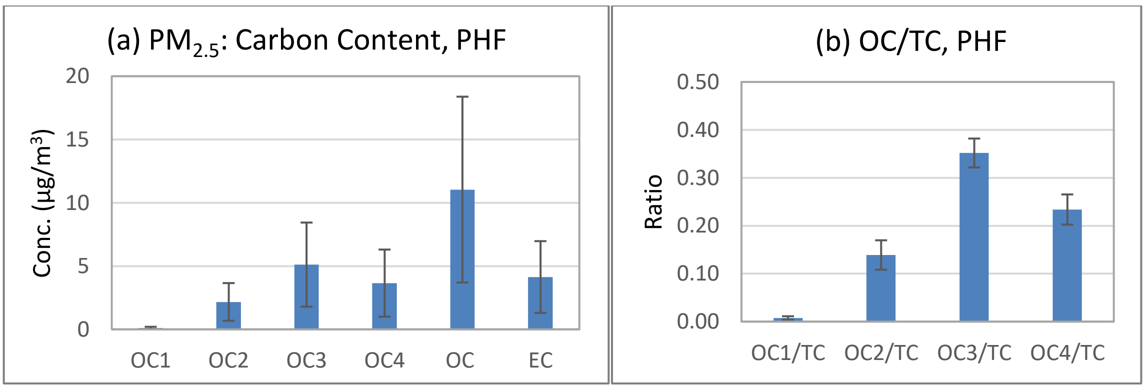


Figure 2.17: EC and OC Content in $PM_{2.5}$ at PHF

Table 2.13: Statistical Results of Carbon Contents (µg/m³) in $PM_{2.5}$ at PHF

	OC1	OC2	OC3	OC4	OC	EC	TC	OC1/TC	OC2/TC	OC3/TC	OC4/TC
Mean	0.11	2.17	5.11	3.65	11.04	4.13	15.18	0.01	0.14	0.35	0.23
SD	0.09	1.49	3.32	2.65	7.34	2.84	10.13	0.00	0.03	0.03	0.03
CV	0.85	0.69	0.65	0.73	0.66	0.69	0.67	0.47	0.22	0.09	0.13
Max	0.28	3.93	8.63	7.74	20.20	7.67	27.87	0.01	0.21	0.39	0.28
Min	0.00	0.00	0.01	0.01	0.02	0.01	0.03	0.00	0.12	0.31	0.17

Overall

The comparison for OC and EC is presented in Figure 2.18 for $PM_{2.5}$. 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 2.14.

The $PM_{2.5}$ contained a high fraction of TC (OC+EC) at 29% 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 coal, biomass and municipal solid waste (MSW) burning. It is observed that the average TC to $PM_{2.5}$ ratio was maximum at BHT (33%) and minimum at PHF (22%) in winter (Table 2.14).

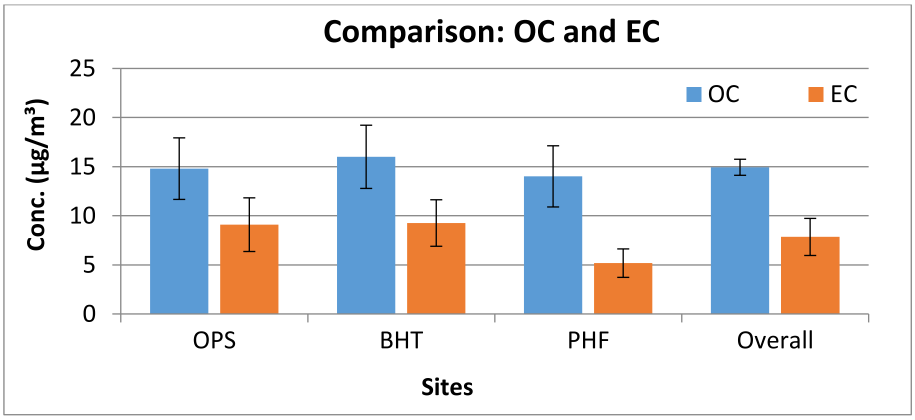


Figure 2.18: Comparison of EC and OC in $PM_{2.5}$ for all Sites

Table 2.14: Overall summary of Carbon Contents (µg/m³) in $PM_{2.5}$

Sites	$PM_{2.5}$	OC1	OC2	OC3	OC4	OC	EC	TC	OC1/TC	OC2/TC	OC3/TC	OC4/TC
OPS	73	0.27	3.33	6.44	4.76	14.80	9.09	23.89	0.01	0.14	0.27	0.20
BHT	77	0.37	3.65	7.06	4.92	16.00	9.26	25.26	0.02	0.14	0.28	0.19
PHF	86	0.14	2.66	6.67	4.54	14.01	5.17	19.19	0.01	0.14	0.35	0.23
Overall	**79**	**0.26**	**3.21**	**6.72**	**4.74**	**14.94**	**7.84**	**22.78**	**0.01**	**0.14**	**0.30**	**0.21**
SD	**5**	**0.09**	**0.41**	**0.25**	**0.16**	**0.82**	**1.89**	**2.60**	**0.00**	**0.00**	**0.04**	**0.02**

2.3.5 PAHs in $PM_{2.5}$

The concentrations of PAHs (from solid phase only) with some specific markers were analyzed. Figure 2.19 shows the average measured concentration of PAHs in Paonta Sahib for winter season. A statistical summary of PAHs is presented in Table 2.15 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 DmP (1.76 ng/m³), B(b)F (1.27 ng/m³), B(ghi)P (1.13 ng/m³), B(a)P (0.60 ng/m³), InP (0.57 ng/m³), B(k)F (0.34 ng/m³) and DEP (0.33 ng/m³) in winter.

The overall average total PAHs were 7.5±3.0 ng/m³. B(a)P, although has the annual standard of 1 ng/m³ and we cannot compare it with levels of 7 days sampling at each site, however levels of B(a)P (mean: 0.60 ng/m³) were low and annual standard may likely meet by a fair margin in the city.

Literature reported values for InP/(InP + 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 (0.33) is comparable to the reported values for diesel. It is inferred that the major source of PAHs is diesel vehicles and industrial uses of diesel.

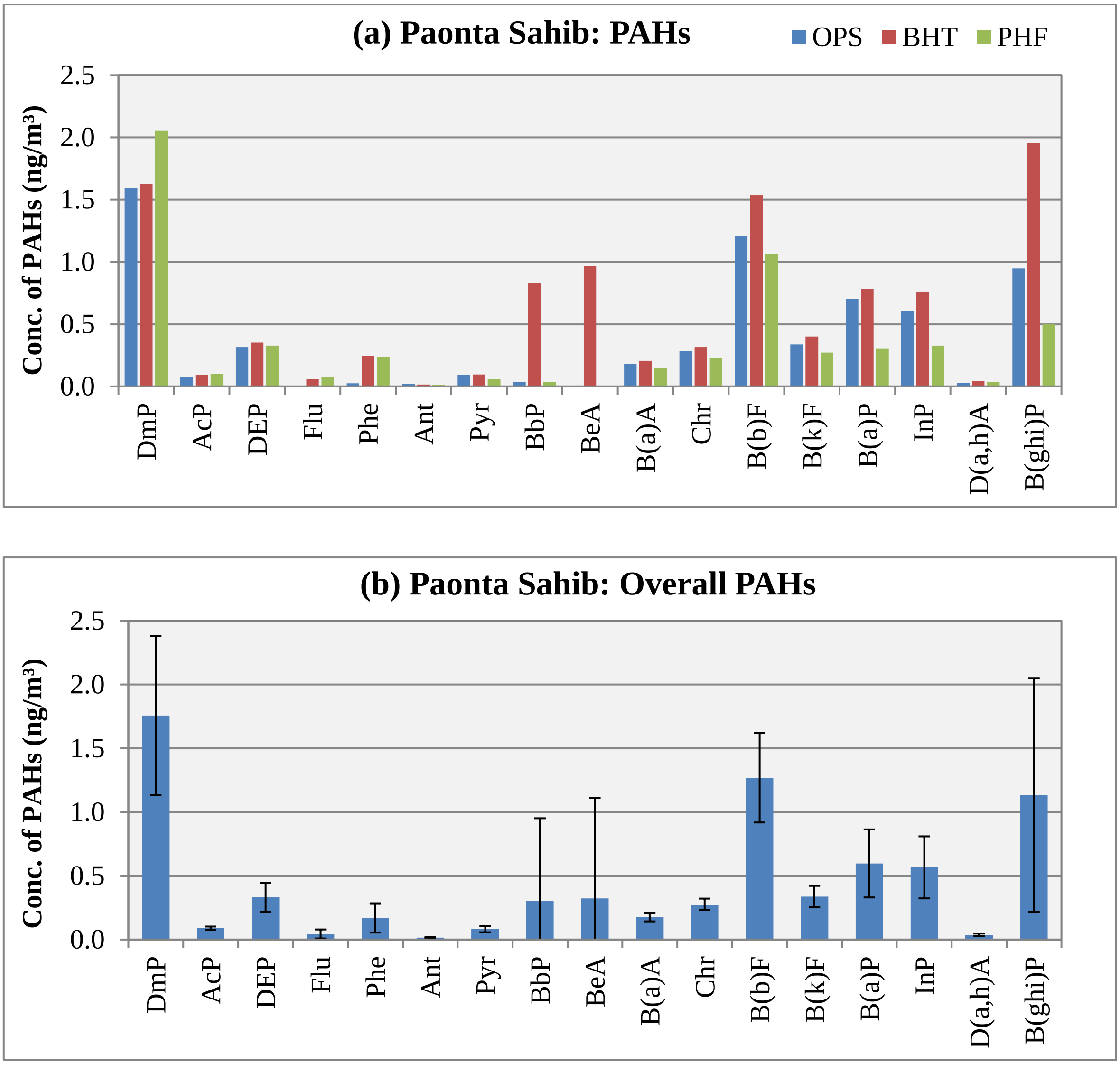


Figure 2.19: PAHs Concentrations in $PM_{2.5}$

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 2.20 and Table 2.16 show the levels of six molecular markers. Total concentration of markers was 41.3±3.6 ng/m^3 in winter. The presence of significant quantities of molecular markers, especially hopanes conclusively establishes contribution of CGD.

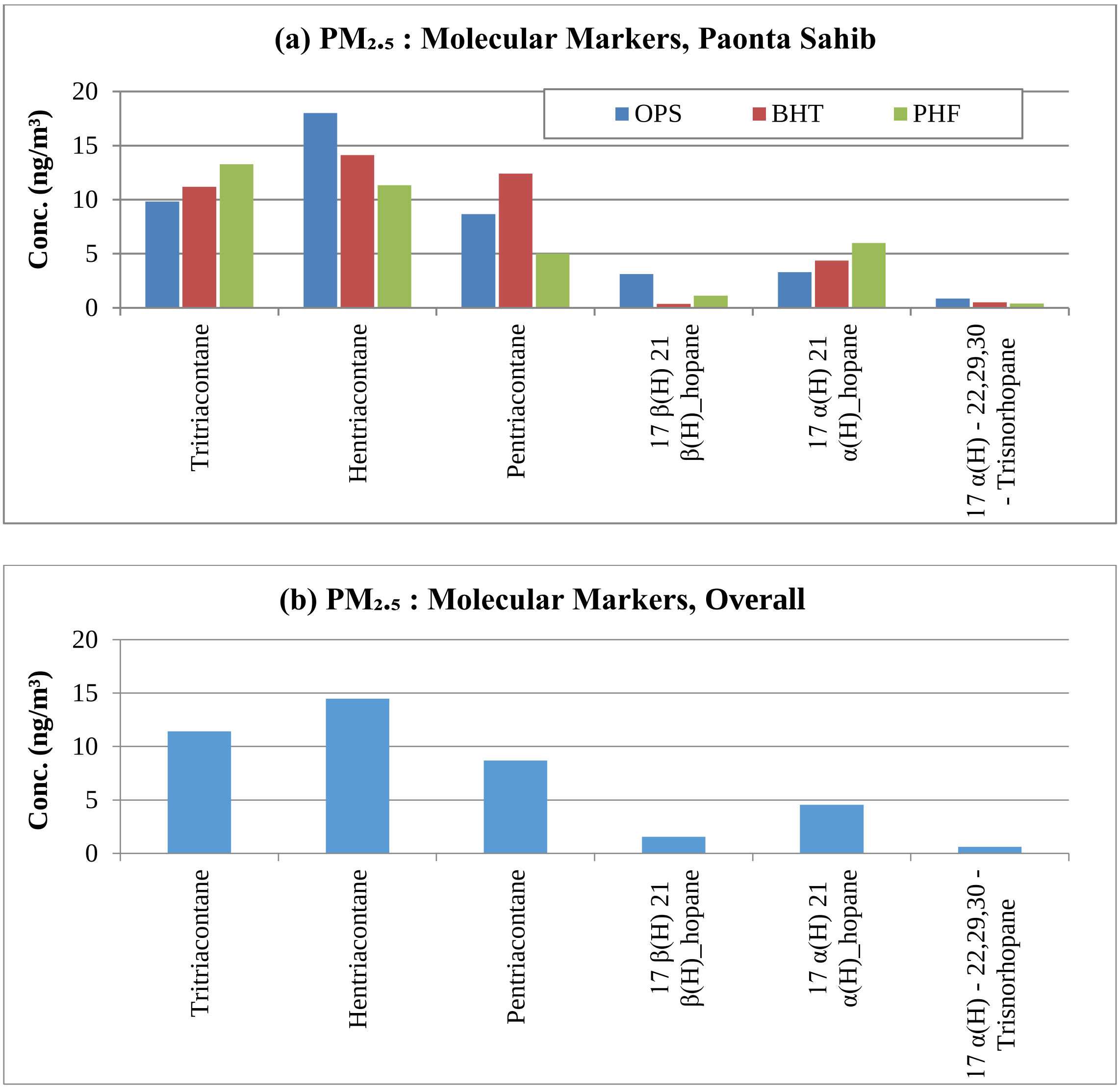


Figure 2.20: Molecular Markers in $PM_{2.5}$

2.3.7 Chemical Composition of PM_{10} and $PM_{2.5}$ and their correlation matrix

Graphical presentations of chemical species for PM_{10} and $PM_{2.5}$ for all the sites of Paonta Sahib are shown in Figure 2.21. Statistical summary for particulate matter (PM_{10} 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 2.17 – 2.20.

The correlation between different parameters (i.e., PM, OC, EC, F^-, Cl^-, NO_3^-, SO_4^{-2}, Na^+, NH_4^+, K^+, Ca^{+2}, Mg^{+2} and metals (elements) with major species (PM, OC, EC, NO_3^-, SO_4^{-2}, NH_4^+, Metals) for PM_{10} and $PM_{2.5}$ composition is presented in Table 2.21. It is seen that most of the parameters showed a good correlation (>0.30) with PM_{10} and $PM_{2.5}$. The percentage constituent of the PM_{10} and $PM_{2.5}$ are presented in Figures 2.22 and 2.23 respectively.

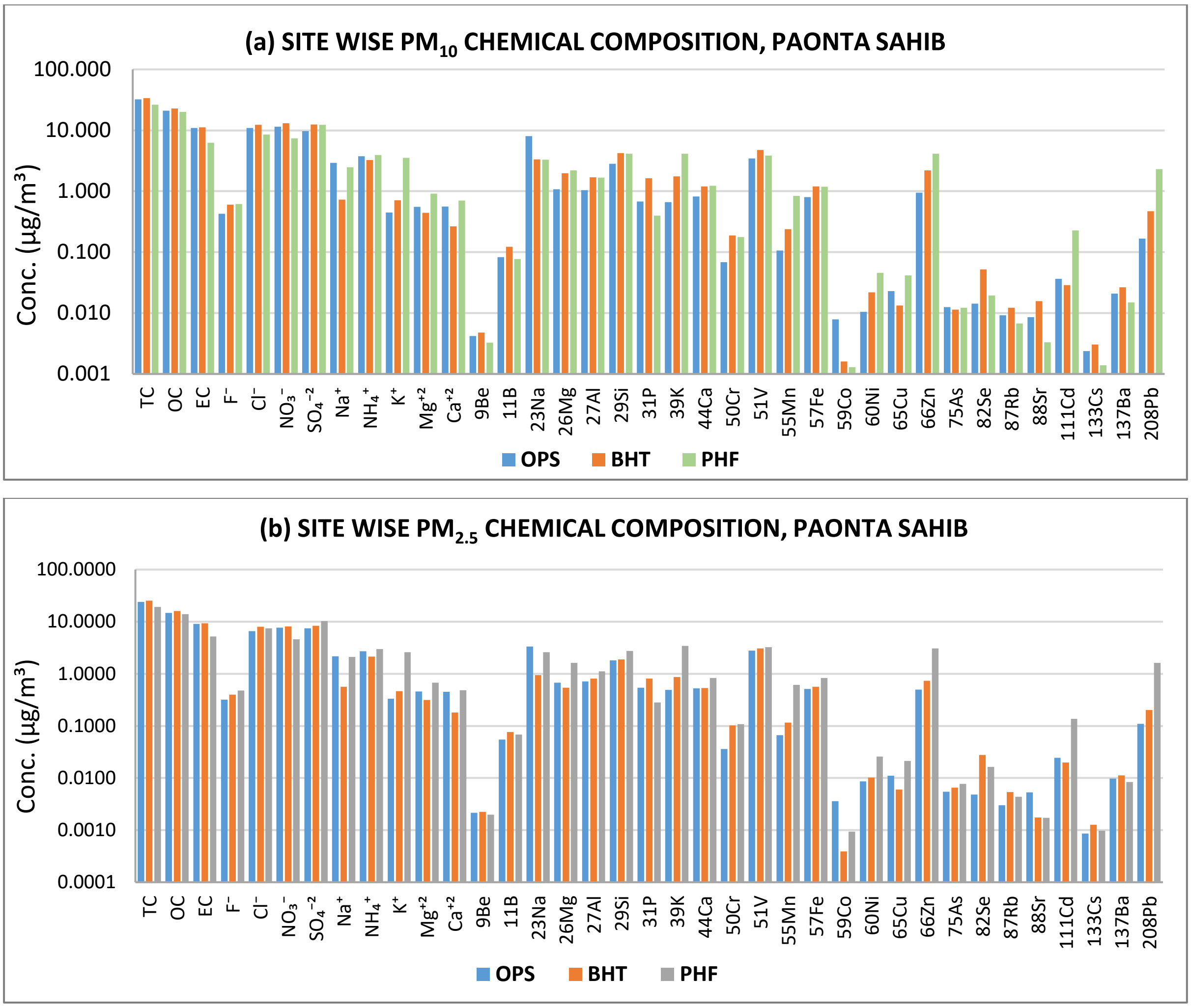
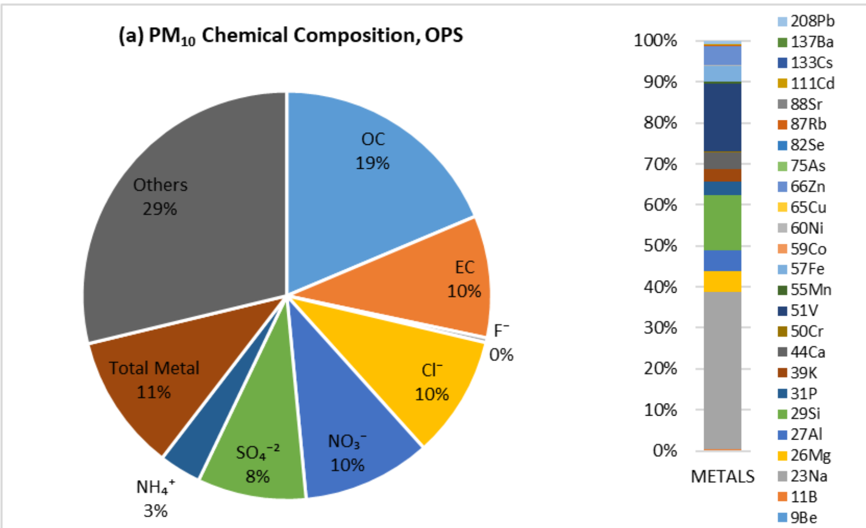


Figure 2.21: Concentrations of species in (a) PM_{10} and (b) $PM_{2.5}$



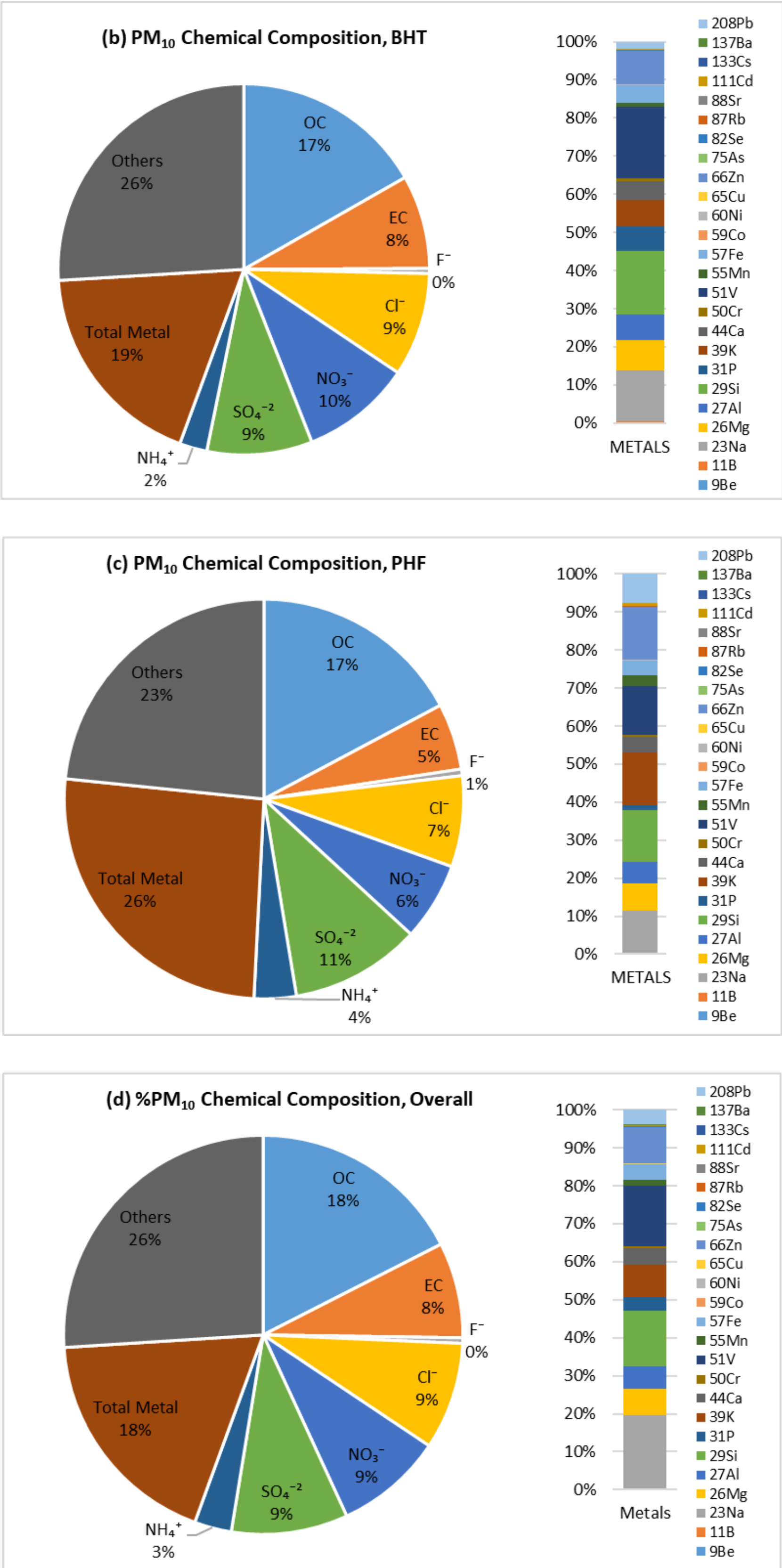
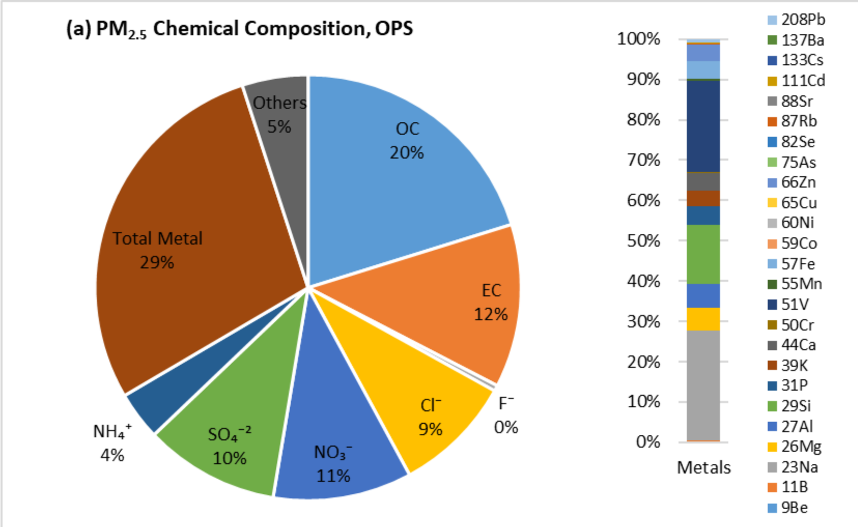
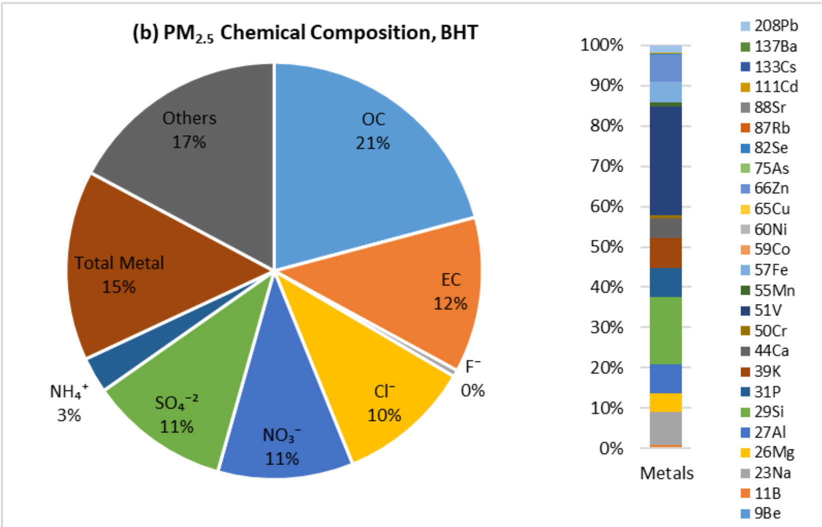
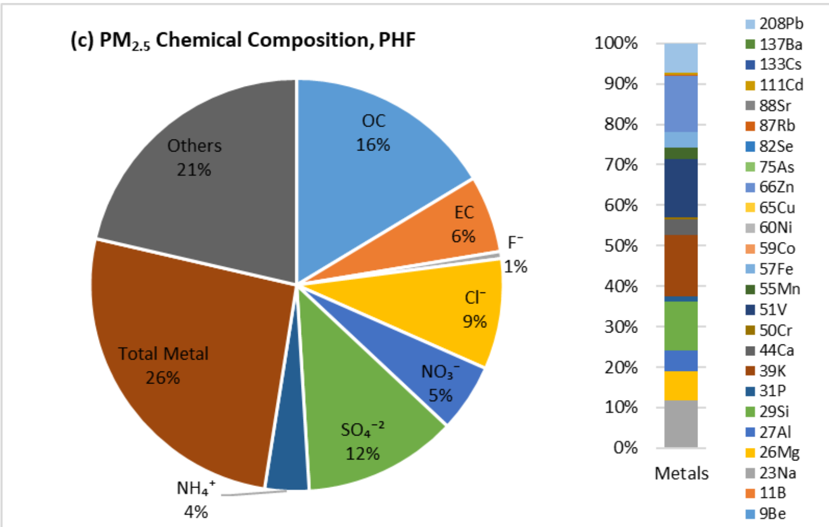


Figure 2.22: Percentage distribution of species in PM_{10}


(a) $PM_{2.5}$ Chemical Composition, OPS
OC 20%
EC 12%
F^- 0%
Cl^- 9%
NO_3^- 11%
SO_4^{-2} 10%
NH_4^+ 4%
Total Metal 29%
Others 5%
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Metals
208Pb
137Ba
133Cs
111Cd
88Sr
87Rb
82Se
75As
66Zn
65Cu
60Ni
59Co
57Fe
55Mn
51V
50Cr
44Ca
39K
31P
29Si
27Al
26Mg
23Na
11B
9Be


(b) $PM_{2.5}$ Chemical Composition, BHT
OC 21%
EC 12%
F^- 0%
Cl^- 10%
NO_3^- 11%
SO_4^{-2} 11%
NH_4^+ 3%
Total Metal 15%
Others 17%
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Metals
208Pb
137Ba
133Cs
111Cd
88Sr
87Rb
82Se
75As
66Zn
65Cu
60Ni
59Co
57Fe
55Mn
51V
50Cr
44Ca
39K
31P
29Si
27Al
26Mg
23Na
11B
9Be


(c) $PM_{2.5}$ Chemical Composition, PHF
OC 16%
EC 6%
F^- 1%
Cl^- 9%
NO_3^- 5%
SO_4^{-2} 12%
NH_4^+ 4%
Total Metal 26%
Others 21%
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Metals
208Pb
137Ba
133Cs
111Cd
88Sr
87Rb
82Se
75As
66Zn
65Cu
60Ni
59Co
57Fe
55Mn
51V
50Cr
44Ca
39K
31P
29Si
27Al
26Mg
23Na
11B
9Be

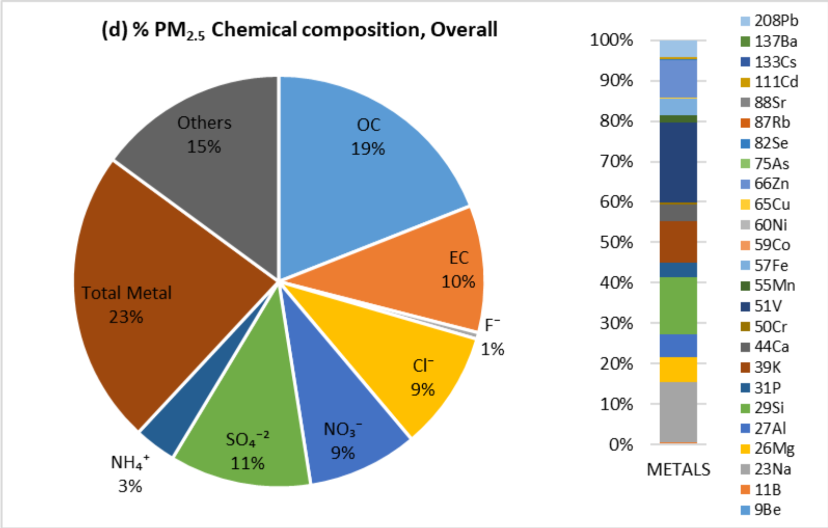


Figure 2.23: Percentage distribution of species in $PM_{2.5}$

Table 2.15: Overall summary of average concentration (ng/m^3) 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
OPS	1.59	0.08	0.31	0.00	0.02	0.02	0.09	0.04	0.00	0.18	0.28	1.21	0.34	0.70	0.61	0.03	0.95	6.45
BHT	1.62	0.09	0.35	0.06	0.25	0.01	0.10	0.83	0.97	0.21	0.32	1.54	0.40	0.78	0.76	0.04	1.95	10.29
PHF	2.06	0.10	0.33	0.07	0.24	0.01	0.06	0.04	0.00	0.14	0.23	1.06	0.27	0.31	0.33	0.04	0.50	5.78
Mean	1.76	0.09	0.33	0.04	0.17	0.02	0.08	0.30	0.32	0.18	0.28	1.27	0.34	0.60	0.57	0.04	1.13	7.51
SD	0.62	0.01	0.11	0.04	0.11	0.00	0.03	0.65	0.79	0.03	0.05	0.35	0.08	0.27	0.24	0.01	0.92	2.96
Max	2.34	0.10	0.49	0.08	0.26	0.02	0.11	1.63	1.93	0.24	0.33	1.94	0.49	0.98	0.95	0.05	2.94	13.42
Min	0.91	0.07	0.14	0.00	0.00	0.01	0.04	0.03	0.00	0.14	0.21	1.02	0.25	0.30	0.32	0.03	0.49	5.54
CV	0.36	0.14	0.34	0.81	0.68	0.28	0.31	2.16	2.45	0.19	0.16	0.28	0.25	0.45	0.43	0.28	0.81	0.39

Table 2.16: Overall summary of average concentration (ng/m^3) 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
OPS	9.83	18.01	8.67	3.12	3.31	0.86	43.80
BHT	11.20	14.11	12.40	0.38	4.36	0.52	42.97
PHF	13.28	11.33	5.03	1.13	6.00	0.41	37.18
Mean	11.43	14.49	8.70	1.54	4.56	0.60	41.32
SD	1.74	3.36	3.69	1.41	1.36	0.23	3.60
CV	0.15	0.23	0.42	0.91	0.30	0.39	0.09

Table 2.17: Statistical results of chemical characterization (µg/m^3) of PM_{10} 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
OPS	MEAN	113.36	21.14	10.95	0.43	10.94	11.50	9.76	2.93	3.77	0.45	0.55	0.56	0.00	0.08	8.00	1.07	1.04	2.81	0.68
	SD	27.76	4.48	3.29	0.14	3.26	5.88	5.59	1.58	2.34	0.18	0.26	0.15	0.00	0.04	4.99	0.22	0.22	0.56	0.17
BHT	MEAN	136.48	22.86	11.16	0.61	12.34	13.13	12.52	0.73	3.27	0.71	0.44	0.26	0.00	0.12	3.35	1.98	1.69	4.23	1.64
	SD	27.40	4.60	2.85	0.24	4.63	4.57	6.66	0.15	2.11	0.43	0.19	0.14	0.00	0.07	1.83	0.97	0.38	1.07	0.78
PHF	MEAN	116.15	20.02	6.23	0.62	8.56	7.36	12.26	2.49	3.96	3.53	0.91	0.71	0.00	0.08	3.31	2.20	1.68	4.11	0.40
	SD	25.09	4.45	1.75	0.12	0.81	4.72	5.77	0.86	1.02	0.77	0.50	0.41	0.00	0.03	0.70	0.84	0.47	0.92	0.20
		K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	%R
OPS	MEAN	0.66	0.82	0.07	3.46	0.11	0.80	0.01	0.01	0.02	0.95	0.01	0.01	0.01	0.01	0.04	0.00	0.02	0.17	79.08
	SD	0.19	0.15	0.04	0.45	0.05	0.20	0.00	0.00	0.01	0.35	0.00	0.01	0.00	0.00	0.02	0.00	0.01	0.11	6.05
BHT	MEAN	1.75	1.20	0.19	4.74	0.24	1.20	0.00	0.02	0.01	2.21	0.01	0.05	0.01	0.02	0.03	0.00	0.03	0.47	73.97
	SD	0.73	0.31	0.08	2.11	0.16	0.32	0.00	0.01	0.01	0.79	0.00	0.04	0.01	0.02	0.02	0.00	0.01	0.35	1.84
PHF	MEAN	4.11	1.23	0.18	3.85	0.84	1.18	0.00	0.05	0.04	4.13	0.01	0.02	0.01	0.00	0.23	0.00	0.01	2.31	76.51
	SD	0.44	0.24	0.09	1.04	0.28	0.26	0.00	0.04	0.03	2.11	0.01	0.00	0.00	0.00	0.14	0.00	0.01	1.19	1.36

Table 2.18: Overall statistical results of chemical characterization (µg/m^3) of PM_{10} at city level

	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	122.57	21.40	9.52	0.55	10.68	10.76	11.56	2.00	3.65	1.53	0.63	0.50	0.00	0.10	4.82	1.76	1.48	3.73	0.94
SD	27.81	4.49	3.47	0.19	3.60	5.45	5.93	1.39	1.86	1.49	0.38	0.31	0.00	0.05	3.67	0.88	0.47	1.07	0.73
MAX	180.51	28.94	18.21	1.14	19.72	21.50	24.34	5.63	9.09	4.35	1.72	1.60	0.01	0.24	19.13	4.07	2.45	5.98	3.43
MIN	89.08	14.31	4.13	0.30	5.50	2.23	3.88	0.40	0.45	0.12	0.17	0.10	0.00	0.03	1.48	0.84	0.66	1.80	0.13
CV	0.23	0.21	0.36	0.35	0.34	0.51	0.51	0.70	0.51	0.97	0.61	0.62	0.44	0.54	0.76	0.50	0.32	0.29	0.78
	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	%R
MEAN	2.16	1.08	0.15	4.05	0.39	1.06	0.00	0.03	0.03	2.42	0.01	0.03	0.01	0.01	0.09	0.00	0.02	0.96	76.42
SD	1.53	0.30	0.09	1.47	0.37	0.31	0.00	0.03	0.02	1.80	0.00	0.03	0.01	0.01	0.12	0.00	0.01	1.17	4.12
MAX	4.68	1.78	0.35	10.16	1.15	1.69	0.01	0.12	0.09	7.11	0.02	0.15	0.04	0.04	0.49	0.01	0.05	3.83	87.57
MIN	0.39	0.52	0.03	2.93	0.05	0.52	0.00	0.01	0.01	0.62	0.01	0.00	0.00	0.00	0.01	0.00	0.01	0.04	69.65
CV	0.71	0.28	0.61	0.36	0.95	0.29	0.93	1.05	0.77	0.75	0.35	0.97	0.82	1.10	1.28	1.16	0.56	1.22	0.05

Table 2.19: Statistical results of chemical characterization (µg/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
OPS	MEAN	73.26	14.80	9.09	0.32	6.63	7.72	7.50	2.17	2.69	0.33	0.46	0.45	0.00	0.05	3.35	0.68	0.71	1.81	0.54
	SD	20.91	3.13	2.73	0.07	2.24	4.30	4.14	1.33	1.58	0.16	0.29	0.17	0.00	0.02	1.24	0.24	0.20	0.52	0.08
BHT	MEAN	76.73	16.00	9.26	0.40	7.99	8.08	8.36	0.56	2.14	0.46	0.31	0.18	0.00	0.08	0.94	0.54	0.81	1.89	0.81
	SD	18.97	3.22	2.37	0.24	3.03	3.00	4.00	0.14	1.50	0.25	0.14	0.09	0.00	0.05	0.26	0.22	0.23	0.58	0.21
PHF	MEAN	85.67	14.01	5.17	0.48	7.42	4.60	10.31	2.11	2.96	2.59	0.67	0.48	0.00	0.07	2.58	1.62	1.11	2.73	0.28
	SD	20.51	3.12	1.45	0.10	1.24	2.53	6.07	0.99	1.05	0.76	0.38	0.32	0.00	0.02	0.88	0.68	0.21	0.57	0.11
		K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	%R
OPS	MEAN	0.49	0.53	0.04	2.77	0.07	0.51	0.00	0.01	0.01	0.50	0.01	0.00	0.00	0.01	0.02	0.00	0.01	0.11	83.76
	SD	0.24	0.15	0.04	0.45	0.04	0.18	0.00	0.00	0.01	0.07	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.08	3.97
BHT	MEAN	0.86	0.53	0.10	3.06	0.12	0.57	0.00	0.01	0.01	0.73	0.01	0.03	0.01	0.00	0.02	0.00	0.01	0.20	83.21
	SD	0.45	0.15	0.05	0.65	0.06	0.20	0.00	0.01	0.00	0.28	0.00	0.01	0.00	0.00	0.01	0.00	0.01	0.18	4.25
PHF	MEAN	3.41	0.83	0.11	3.27	0.61	0.84	0.00	0.03	0.02	3.08	0.01	0.02	0.00	0.00	0.14	0.00	0.01	1.62	78.93
	SD	0.62	0.19	0.05	0.73	0.22	0.21	0.00	0.03	0.02	1.71	0.00	0.00	0.00	0.00	0.07	0.00	0.01	0.89	2.15

Table 2.20: Overall statistical results of chemical characterization (µg/m^3) of $PM_{2.5}$ at city level

	$PM_{2.5}$	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	78.48	14.98	7.90	0.40	7.37	6.85	8.71	1.57	2.58	1.10	0.47	0.36	0.00	0.07	2.24	0.93	0.88	2.13	0.55
SD	19.94	3.14	2.88	0.17	2.30	3.57	4.74	1.18	1.39	1.14	0.31	0.25	0.00	0.04	1.34	0.64	0.27	0.68	0.27
MAX	127.88	20.26	15.11	1.03	12.45	16.29	23.22	4.77	6.36	3.23	1.20	1.13	0.01	0.21	5.35	2.80	1.51	4.11	1.26
MIN	46.68	10.02	3.43	0.22	2.89	1.93	2.79	0.34	0.37	0.10	0.12	0.06	0.00	0.02	0.66	0.23	0.42	0.90	0.09
CV	0.25	0.21	0.36	0.42	0.31	0.52	0.54	0.75	0.54	1.03	0.66	0.68	0.48	0.54	0.60	0.69	0.30	0.32	0.48
	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	%R
MEAN	1.56	0.63	0.08	3.03	0.26	0.64	0.00	0.01	0.01	1.41	0.01	0.02	0.00	0.00	0.06	0.00	0.01	0.63	82.02
SD	1.38	0.21	0.06	0.63	0.28	0.24	0.00	0.02	0.01	1.51	0.00	0.01	0.00	0.00	0.07	0.00	0.01	0.86	4.30
MAX	4.65	1.27	0.20	4.97	0.97	1.35	0.00	0.10	0.05	5.87	0.01	0.04	0.02	0.01	0.29	0.01	0.03	3.47	88.10
MIN	0.20	0.27	0.00	1.76	0.01	0.23	0.00	0.00	0.00	0.30	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	73.20
CV	0.88	0.34	0.70	0.21	1.07	0.37	0.95	1.27	0.95	1.07	0.36	0.64	0.70	0.98	1.16	1.09	0.83	1.37	0.05

Table 2.21: Correlation matrix for PM and its composition

	$PM_{2.5}$	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	0.75	0.76	0.39	-0.14	0.39	0.66	0.93	0.21	0.72	0.38	0.31	0.29	0.44	0.13
PM_{10}	0.75	1.00	0.88	0.71	-0.15	0.39	0.71	0.71	-0.25	0.49	-0.04	0.14	-0.03	-0.02	0.14
OC	0.76	1.00	1.00	0.78	-0.35	0.43	0.72	0.68	-0.14	0.48	-0.08	0.07	0.03	-0.08	-0.07
EC	0.39	0.71	0.78	1.00	-0.46	0.22	0.75	0.31	-0.19	0.37	-0.56	-0.20	-0.18	-0.54	-0.43
NO_3^-	0.66	0.71	0.72	0.75	-0.42	0.44	1.00	0.61	-0.03	0.52	-0.34	-0.07	-0.03	-0.32	-0.34
SO_4^{-2}	0.93	0.71	0.68	0.31	-0.12	0.31	0.61	1.00	0.17	0.55	0.36	0.29	0.33	0.42	0.14
NH_4^+	0.72	0.49	0.48	0.37	-0.22	0.22	0.52	0.55	0.22	1.00	0.23	0.25	0.10	0.28	-0.09
Metals_$PM_{2.5}$	0.44	-0.02	-0.08	-0.54	0.41	-0.11	-0.32	0.42	0.42	0.28	0.91	0.51	0.56	1.00	0.62
Metals_PM_{10}	0.44	0.14	-0.07	-0.38	0.71	-0.33	-0.34	0.14	-0.02	-0.09	0.53	0.32	0.34	0.62	1.00

2.3.8 Comparison of PM_{10} and $PM_{2.5}$ Composition

The graphical compositional comparison of $PM_{2.5}$ Vs PM_{10} for all species is shown (Figure 2.24). The chemical species considered for the comparisons are carbon content (TC, OC and EC), ionic species (F^-, Cl^-, NO_3^-, SO_4^{-2}, Na^+, NH_4^+, 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, Cl^-, NO_3^-, SO_4^{-2}, Na^+, K^+, Mg^{2+}, Ca^{2+}, B, K, Cr, V and Cd; whereas major species contributing to coarse mode are Na, Co, Cu, Rb, Cs and Ba.

The average ratio ($PM_{2.5}/PM_{10}$) 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 PM_{10}. 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 PM_{10}.

The statistical summary of the major components (i.e., crustal elements – Si, Ai, Fe, Ca; Secondary ions - NO_3^-, SO_4^{-2}, NH_4^+; TC) in PM_{10} and $PM_{2.5}$ are presented in Tables 2.22 – 2.23.

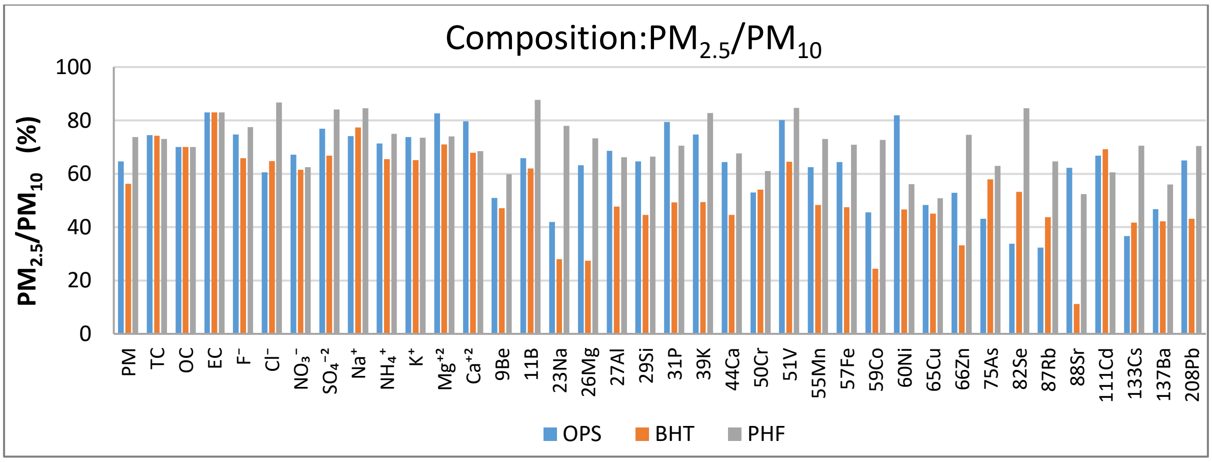


Figure 2.24: Compositional comparison of species in $PM_{2.5}$ vs PM_{10}

Table 2.22: Mean of major components: PM_{10}, winter ($\mu g/m^3$)

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}
OPS	113	5.5	0.048	25.0	0.221	32.1	0.283
BHT	136	8.3	0.061	28.9	0.212	34.0	0.249
PHF	116	8.2	0.071	23.6	0.203	26.3	0.226
Overall	122	7.3	0.060	25.8	0.212	30.8	0.253
SD	13	1.6	0.011	2.8	0.009	4.0	0.029
CV	0.103	0.220	0.188	0.107	0.042	0.131	0.114

Table 2.23: Statistical summary of major components: $PM_{2.5}$, winter ($\mu g/m^3$)

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/$PM_{2.5}$
OPS	73	3.6	0.049	17.9	0.244	23.9	0.326
BHT	77	3.8	0.049	18.6	0.242	25.3	0.329
PHF	86	5.5	0.064	17.9	0.209	19.2	0.224
Overall	79	4.3	0.054	18.1	0.232	22.8	0.293
SD	6	1.1	0.009	0.4	0.020	3.2	0.060
CV	0.081	0.248	0.163	0.022	0.086	0.140	0.204

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 PM_{10}, $PM_{2.5}$ and their compositions (Tables 2.8, 2.15-2.23) have been referred to bring the important inferences to the fore.

- The mean PM_{10} levels were 113 – 136 $\mu g/m^3$ and the mean $PM_{2.5}$ levels were 73 – 86 $\mu g/m^3$.

- Particulate pollution is the main concern in the city, where PM_{10} levels are 1.1 – 1.4 times higher than the national air quality standards and $PM_{2.5}$ levels are 1.2 – 1.4 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 very poor 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 122±10 µg/m^3 against the acceptable level of 100 µg/m^3. The highest levels were observed at BHT and the lowest at OPS.

The important components are the secondary particles ($NO_3^- + SO_4^{2-} + NH_4^+$), which account for about 21% of total PM_{10}, and combustion-related total carbon (TC = EC + OC) accounts for about 25%; both fractions of secondary particles and combustion-related carbons account for 46% of PM_{10} in winter months.

The crustal component (Si + Al + Fe + Ca) accounts for about six percent in PM_{10}. This suggests soil and road dust have less significant contributions. The coefficient of variation (CV) is about 0.22 (of the fraction of crustal component), which suggests the crustal source contributes consistently in the winter months.

The Cl^- content in PM_{10} is consistent and varies between 7 – 10%, 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 BHT at 12 µg/m^3 compared to the overall city level of 10.6 µg/m^3. The high level at BHT signifies some local burning of waste as a means of disposal of solid waste.

$PM_{2.5}$

The overall average concentration of $PM_{2.5}$ in winter is 79±5 µg/m^3 against the acceptable level of 60 µg/m^3. The highest levels are observed at PHF and the lowest at OPS.

The important components are the secondary particles ($NO_3^- + SO_4^{2-} + NH_4^+$), which account for about 23% of total $PM_{2.5}$ and combustion-related total carbon (TC = EC + OC) accounts for about 29%; both fractions of secondary particles and combustion-related carbons account for 52% of $PM_{2.5}$ in winter months. The highest levels of secondary particles were observed at OPS (24%) and TC at BHT (33%).

The Cl^- content in $PM_{2.5}$ is consistent and varies between 8 – 11%, which is an indicator of the burning of MSW and plastic waste.

Gaseous pollutant levels

NO_2 and SO_2 levels meet the national air quality standard of 80 µg/m^3. The highest NO_2 and SO_2 levels were at BHT with some high peaks. BHT was a commercial site having uses of coal in restaurants and nearby areas. In addition, high levels of NO_2 and SO_2 are expected to undergo chemical transformation to form fine secondary particles in the form of nitrates and sulfates, adding to high levels of existing PM_{10} and $PM_{2.5}$. NH_3 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 BHT. The annual benzene levels are expected to be well below the NAQS of 5 µg/m^3 and in the safe limit in the city.

General inferences

It is to be noted that OC3/TC ratio is about 0.30 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 Paonta Sahib.

Total PAH levels (17 compounds; particulate phase) had high variability in the range of 5.5 to 13.4 and B(a)P at 0.60 ng/m^3 (annual standard is one ng/m^3); the comparison with the annual standard is not advisable due to different averaging times. The highest PAH levels were observed at BHT.

The concentrations of molecular markers in $PM_{2.5}$ (a total of 6 compounds) vary in the range of 37 to 44 ng/m^{3,} 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. Combustion sources (vehicles, soil and road dust, 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 PM_{10} 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 PM_{10} 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 SO_2 levels were very low (generally less than 5 µg/m^3) and insignificant compared to NAQS levels, trend and time-series analyses were not carried out for SO_2 levels.

3.2 Methodology

The long-term (2008–2019) air quality data for two sites were considered for Paonta Sahib city. The sites were Station-I Paonta Sahib (R) and Station-II Gondpur, Paonta Sahib. The air quality data for these sites were provided by HPPCB, 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 PM_{10} 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 R^2 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 (PM_{10} 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.

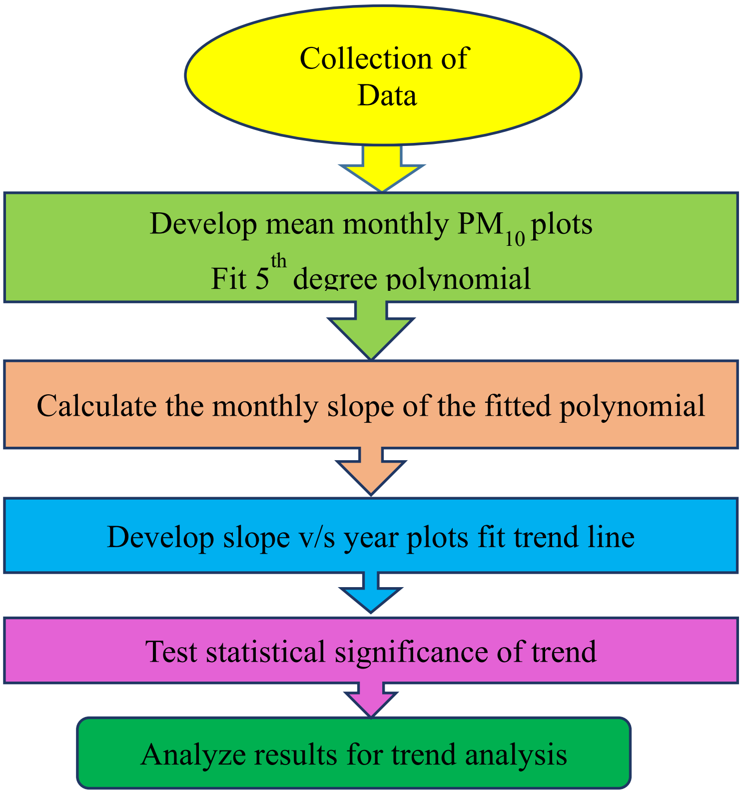


Figure 3.1: Stepwise methodology and major tasks (Nagar et al., 2019)

3.3 Results and Interpretations

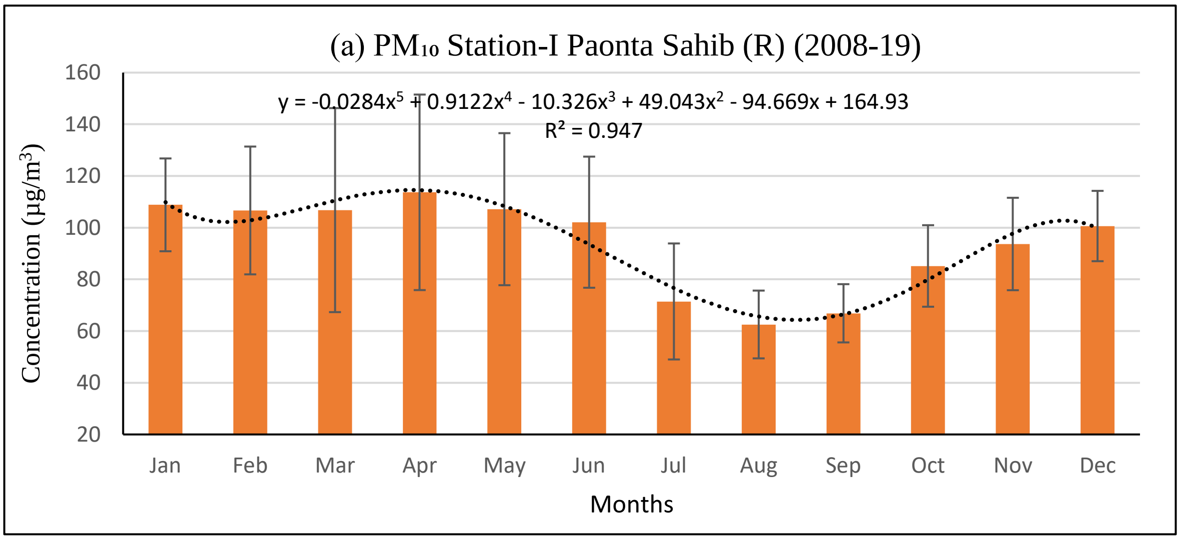
3.3.1 Annual pattern in PM_{10} and NO_2

The total number of monthly means of 24-hr PM_{10} and NO_x measurements in Paonta Sahib was about 135 (at each site). The monthly mean levels of PM_{10} and NO_x averaged over 2008 – 2019 for two sites in Figures 3.2 – 3.3.

Two peaks were observed (Figure 3.2) in PM_{10}, 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 PM_{10} levels continue to gradually increase in winter or tend to stabilize. It is interesting to note that in the month of May, levels increase and show significant variability. Paonta Sahib may have been dust storms in the months of May and June. However, PM_{10} levels in the most of months except months (July to October), exceed the 24-hr national air quality standard at station-I while PM_{10} levels of all the months at station-II exceed the 24-hr national air quality standard.

The NO_x levels are highest in April, May, October, November and December months at station-I and station-II respectively while lowest concentration observed in July and August (months of monsoon) (Figure 3.3). There is no harp increase is seen in NO_x. The NO_x levels meet the 24-hr national standard and well below the acceptable limit. However, it is a concern in the winter months to take necessary measures to prevent high levels of NO_x.

The annual time-series variations of PM_{10} and NO_x mean concentrations over 2008-2019 for one site is presented in Figures 3.4 – 3.5.



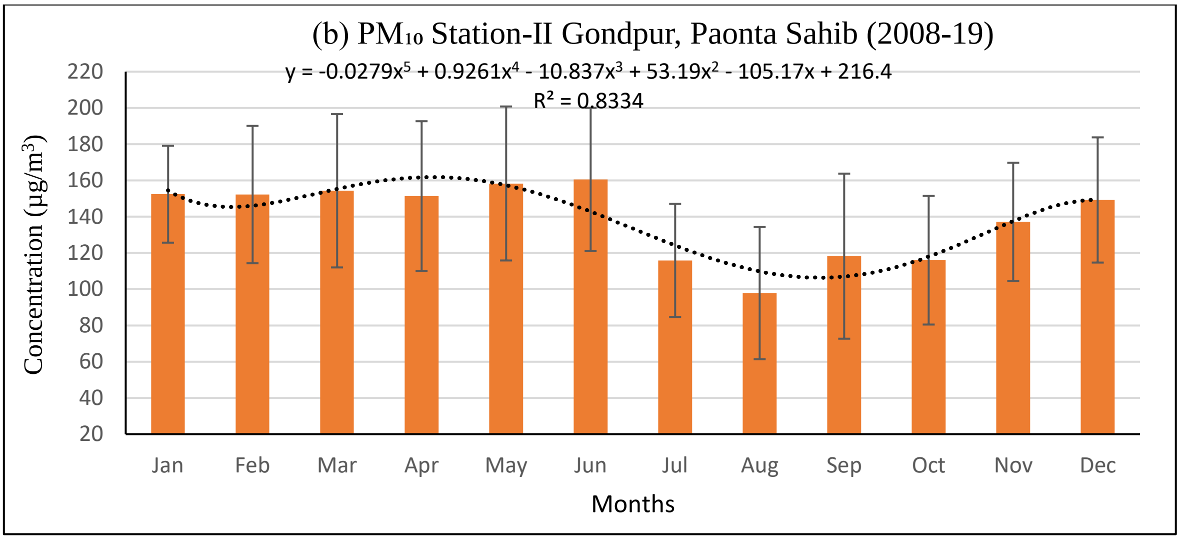
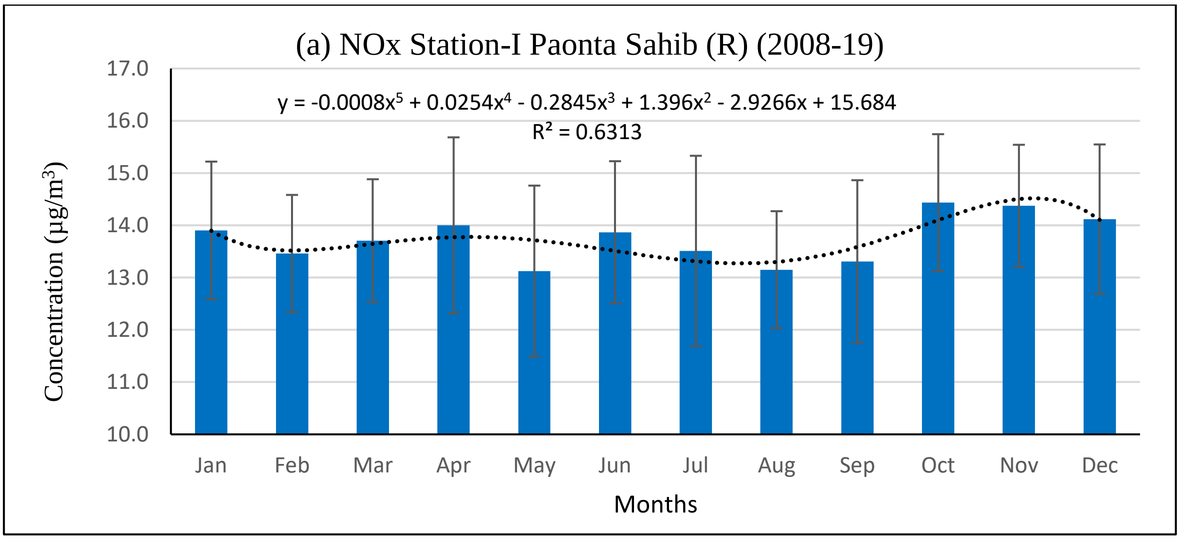


Figure 3.2: Variation in PM_{10} at (a) Station-I Paonta Sahib and (b) Station-II Gondpur



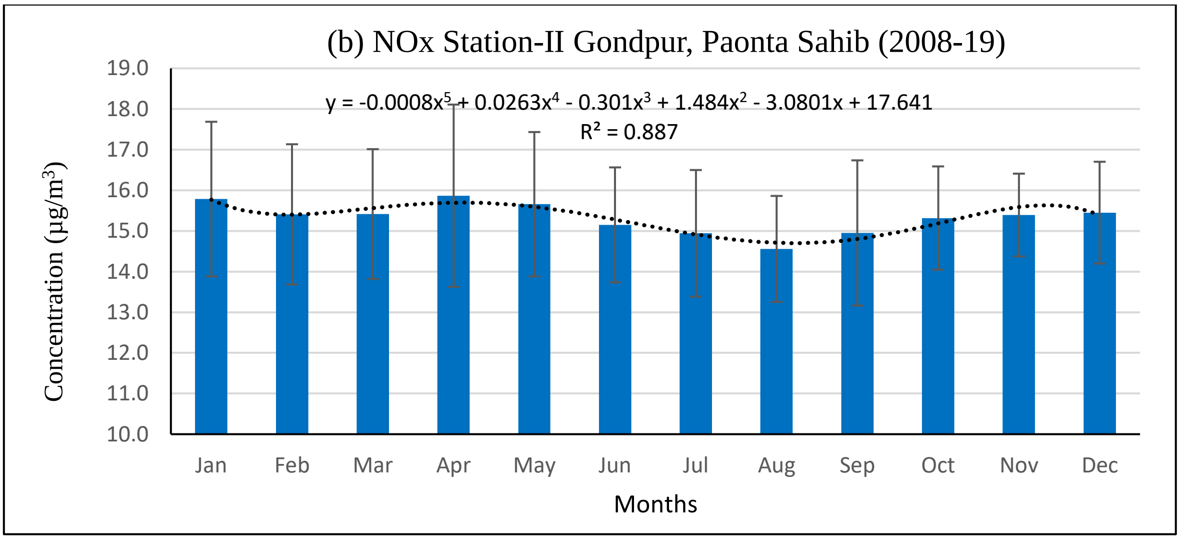
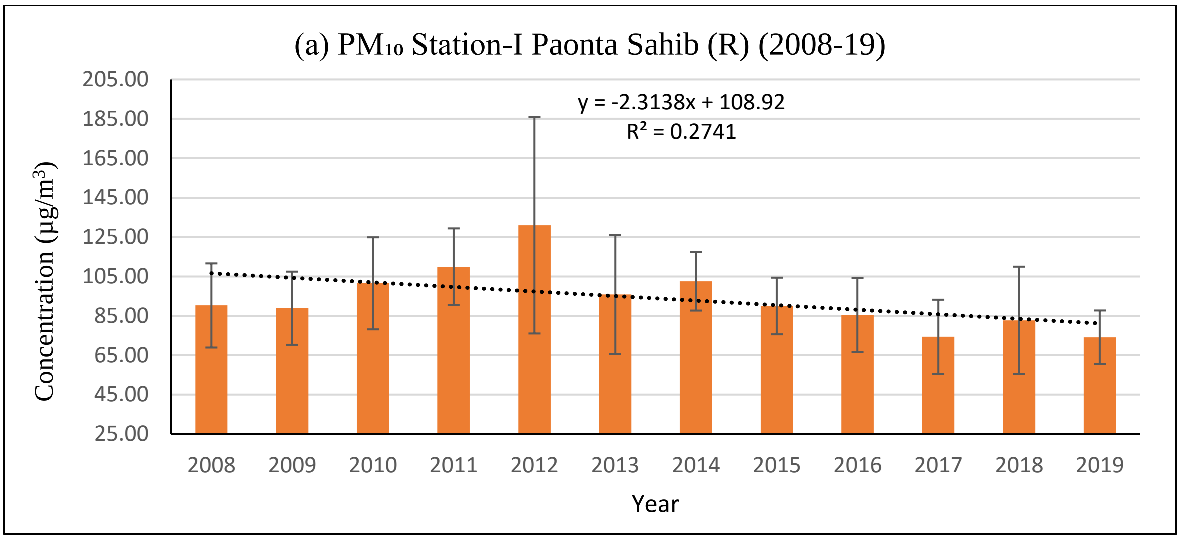


Figure 3.3: Variation in NO_x at (a) Station-I Paonta Sahib and (b) Station-II Gondpur



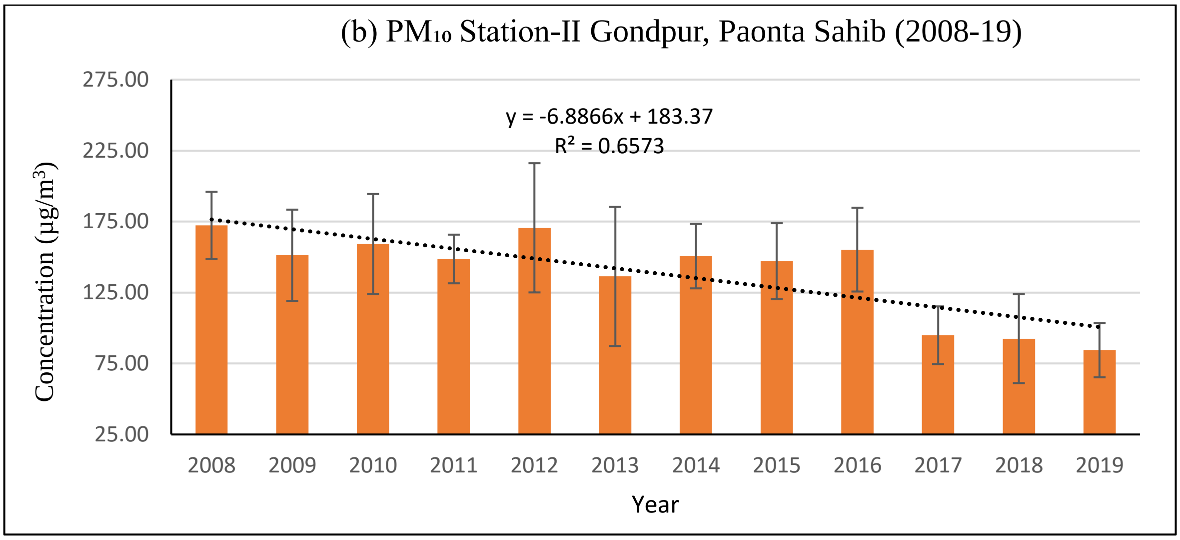
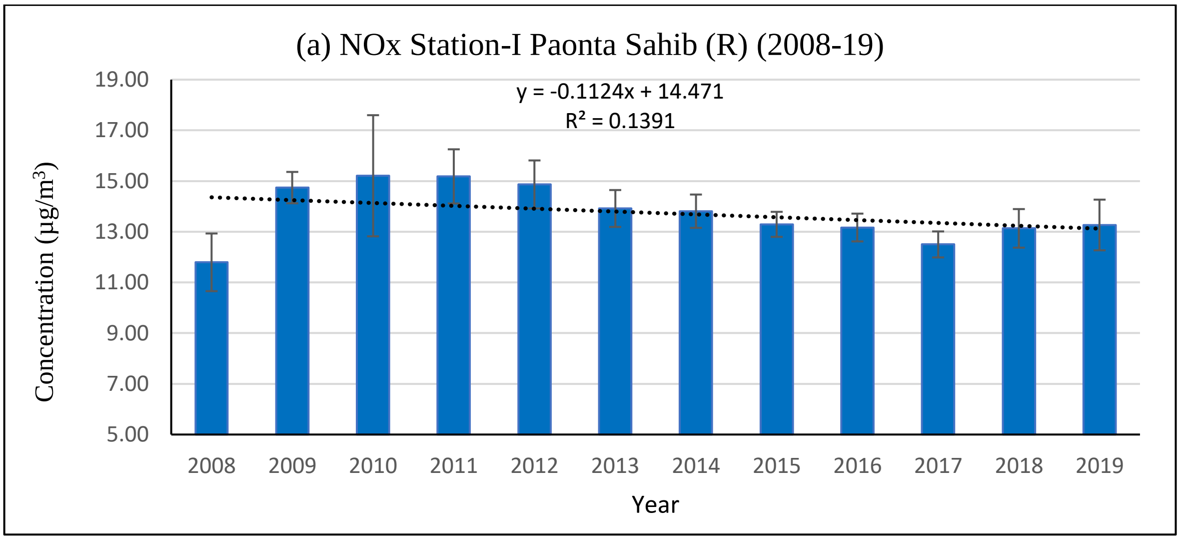


Figure 3.4: Timeseries of annual mean levels of PM_{10}



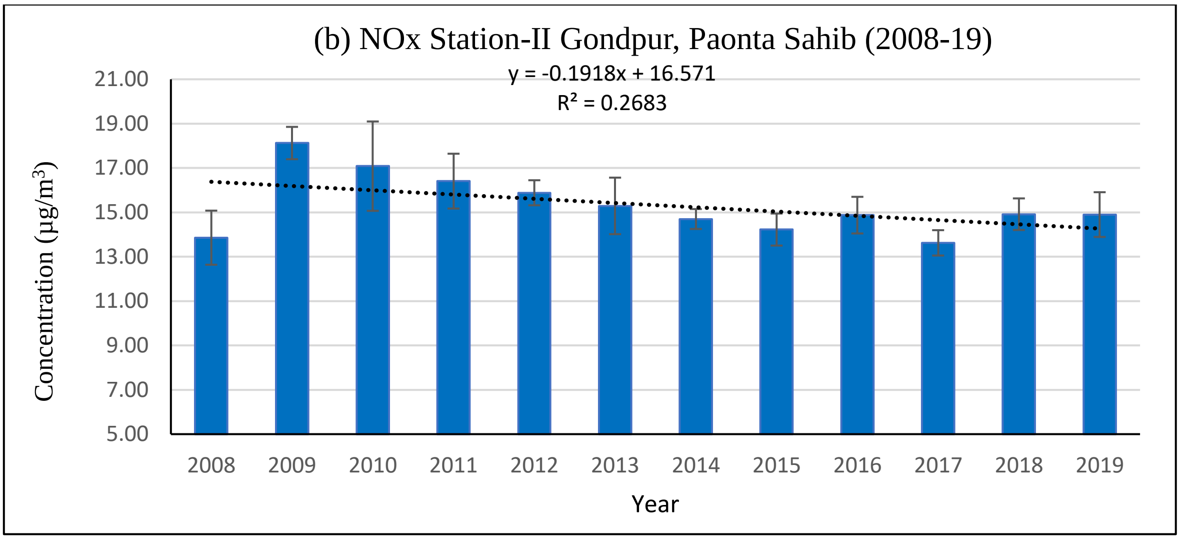


Figure 3.5: Timeseries of annual mean levels of NO_x

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 PM_{10} and NO_x at two sites in Paonta Sahib. 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 PM_{10} in Paonta Sahib as few months show a decreasing trend and most of months indicate no trend. However, NO_x shows decreasing trend in most of months and no trend in few months at both sites. The annual levels of PM_{10} and NO_x show decreasing trend at Station I and no trend at Station II.

Table 3.1: Comparison of mean PM_{10} slopes (in µg/m³/year) and trends in monthly slots during 2008-2019

Sites	PM_{10}	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Station I	Slope	-3.20	-1.83	-5.80	-4.33	-3.50	-2.50	-3.67	-2.00	-1.13	-1.78	-2.00	-2.89	-3.47
	Trend (MK)	No (↔)	No (↔)	Yes (↓)	No (↔)	No (↔)	No (↔)	No (↔)	No (↔)	No (↔)	No (↔)	No (↔)	Yes (↓)	Yes (↓)
Station II	Slope	-6.00	-7.64	-7.23	-9.56	-9.20	-5.70	-6.16	-6.29	-6.80	-6.14	-7.40	-5.43	-7.04
	Trend (MK)	Yes (↓)	No (↔)	No (↔)	Yes (↓)	Yes (↓)	No (↔)	Yes (↓)	No (↔)	No (↔)	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 $\mu g/m^3/year$) and trends in monthly slots during 2008-2019

Sites	PM_{10}	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Station I	Slope	-0.23	-0.18	-0.30	-0.40	-0.24	-0.27	-0.20	-0.26	-0.29	-0.20	-0.12	-0.33	-0.25
	Trend (MK)	Yes (↓)	Yes (↓)	Yes (↓)	Yes (↓)	No (↔)	Yes (↓)	Yes (↓)	Yes (↓)	Yes (↓)	No (↔)	No (↔)	Yes (↓)	Yes (↓)
Station II	Slope	-0.44	-0.50	-0.40	-0.60	-0.53	-0.30	-0.40	-0.20	-0.23	-0.07	-0.05	-0.34	-0.42
	Trend (MK)	Yes (↓)	Yes (↓)	Yes (↓)	Yes (↓)	Yes (↓)	No (↔)	Yes (↓)	No (↔)	No (↔)	No (↔)	No (↔)	Yes (↓)	Yes (↓)
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 Paonta Sahib city for the year 2020 is presented.

Paonta Sahib is an industrial city in Himachal Pradesh. It's also an important place of worship for Sikhs, hosting a large Gurudwara named Gurudwara Paonta Sahib, on the banks of river Yamuna. The river is the boundary between the states of Himachal Pradesh and Uttarakhand.

4.2 Methodology

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

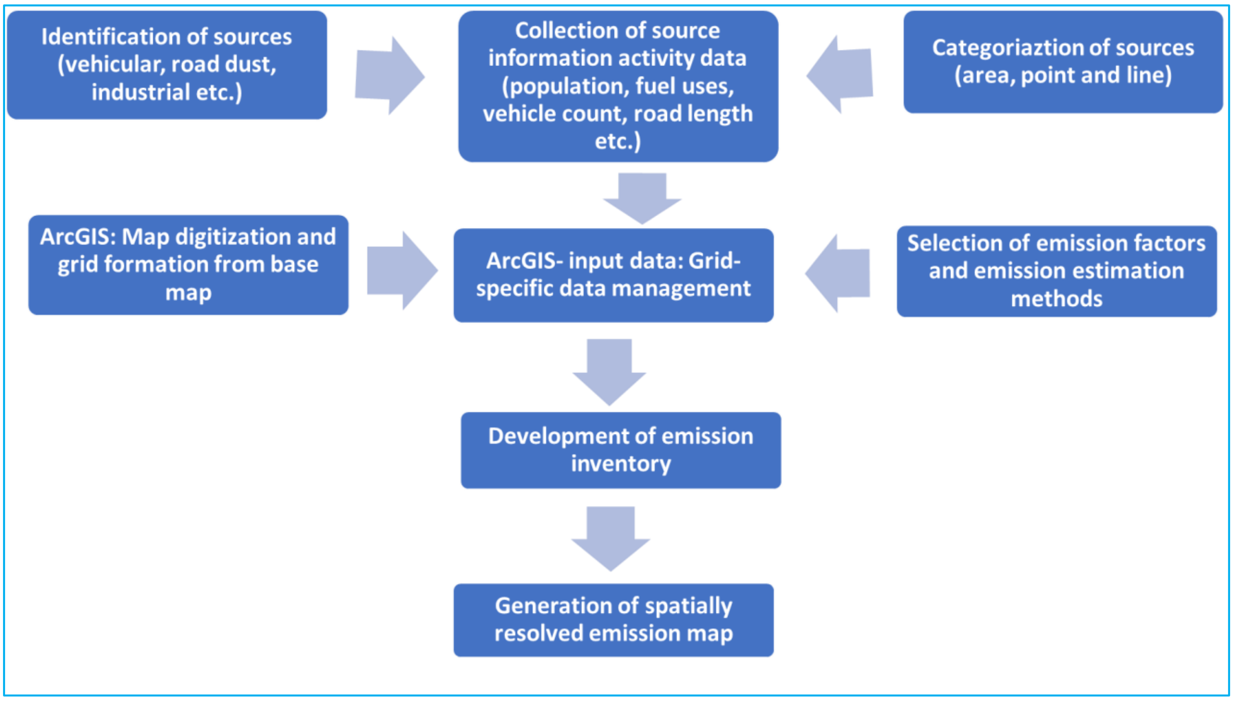


Figure 4.1: Stepwise Methodology adopted for the Study

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.

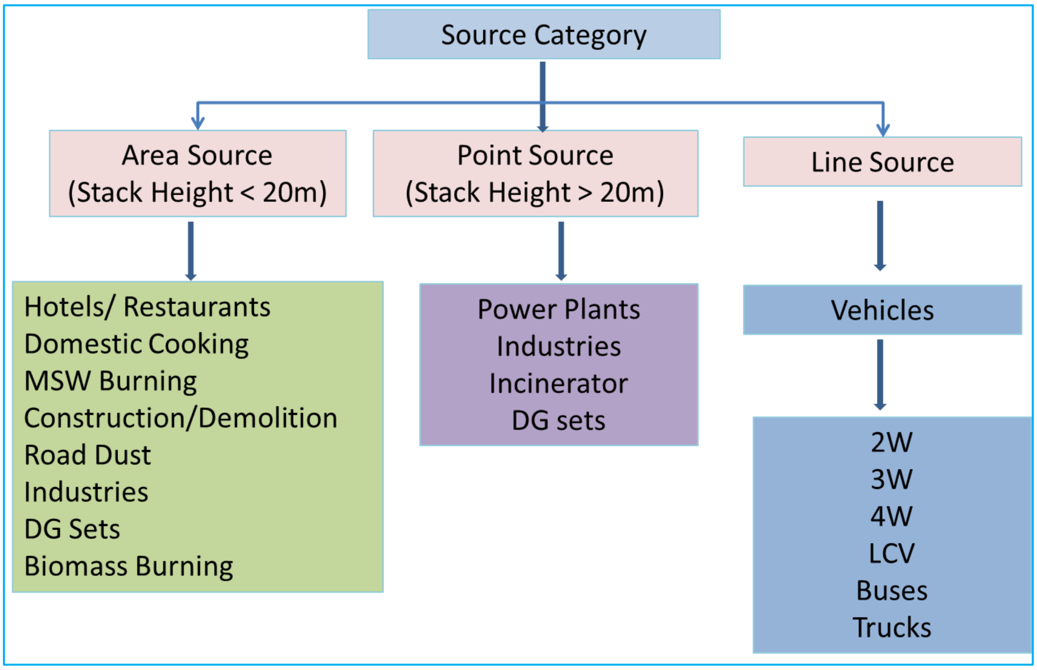


Figure 4.2: Source Category and type of sources

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. A physical survey of industrial areas was also done. The main sources of secondary data collection are from HPPCB, Census of India, CPCB website, Indian Railways, Central Electricity Authority (CEA), 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, etc. (Figure 4.3 to Figure 4.10).

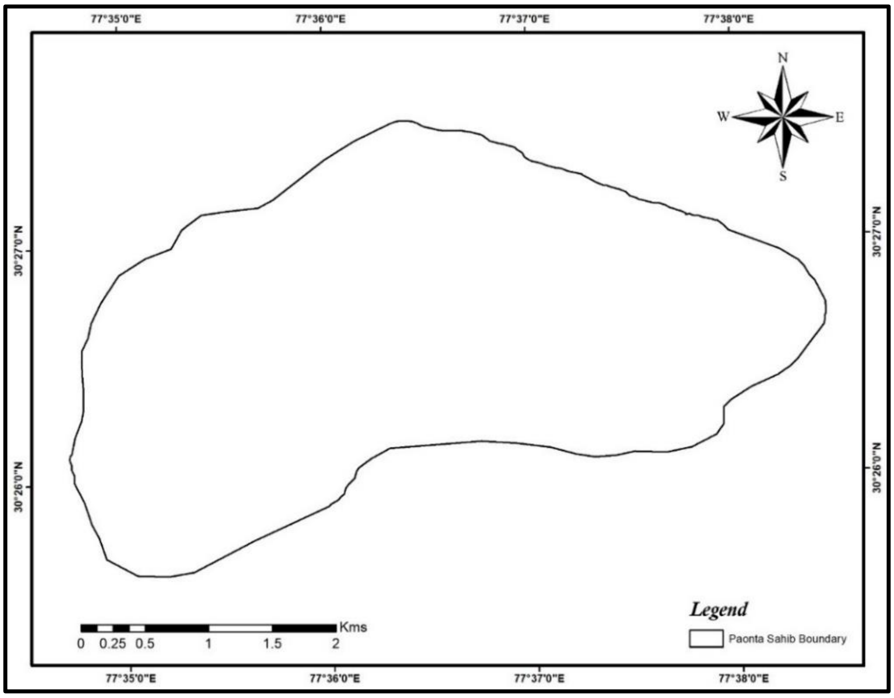


Figure 4.3: Paonta Sahib City Boundary

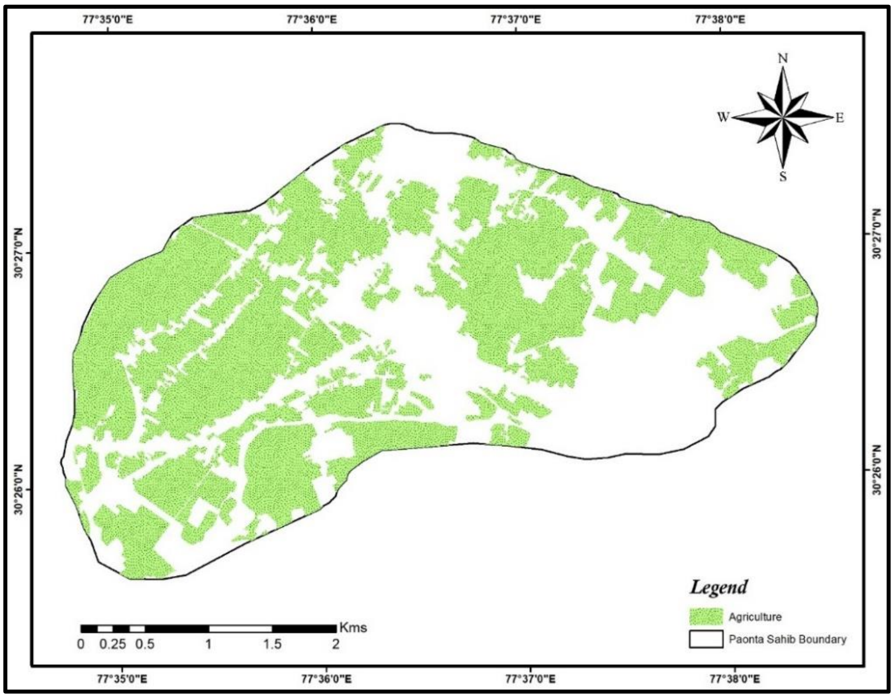


Figure 4.4: Agricultural Area Map

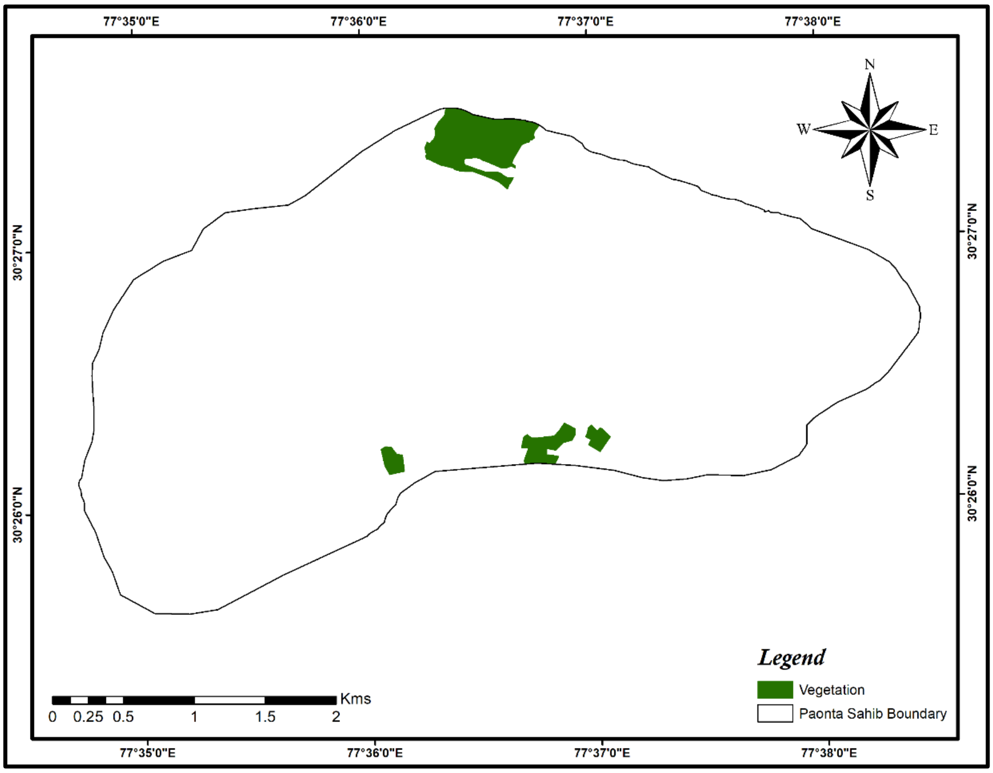


Figure 4.5: Green Area Map

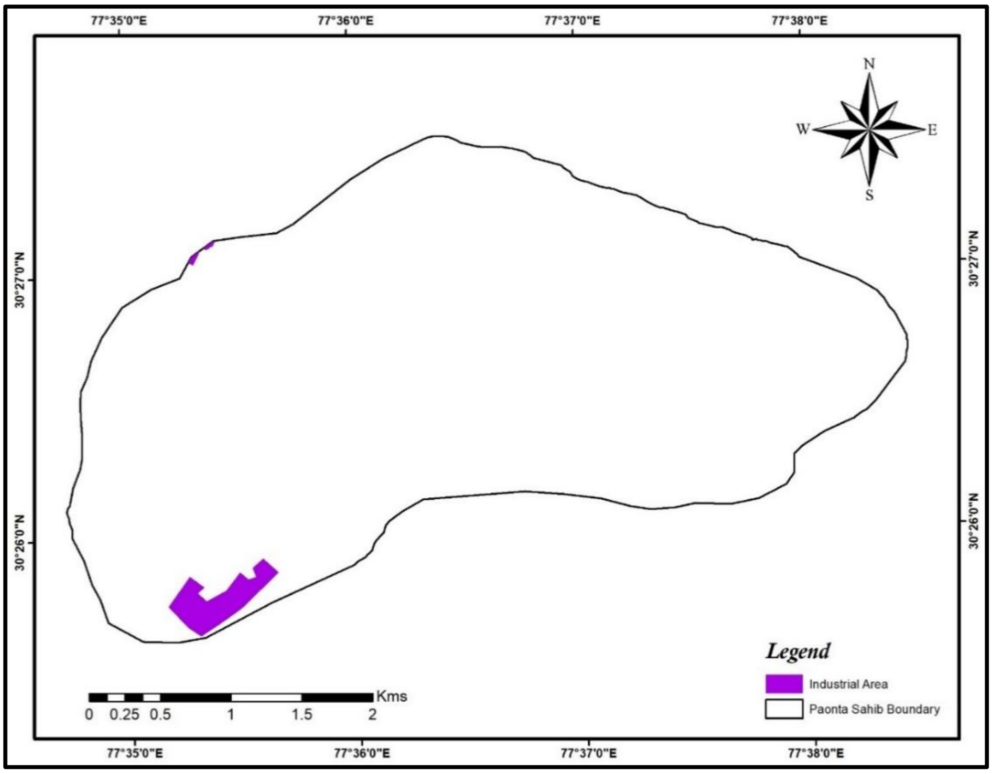


Figure 4.6: Industrial Area Map

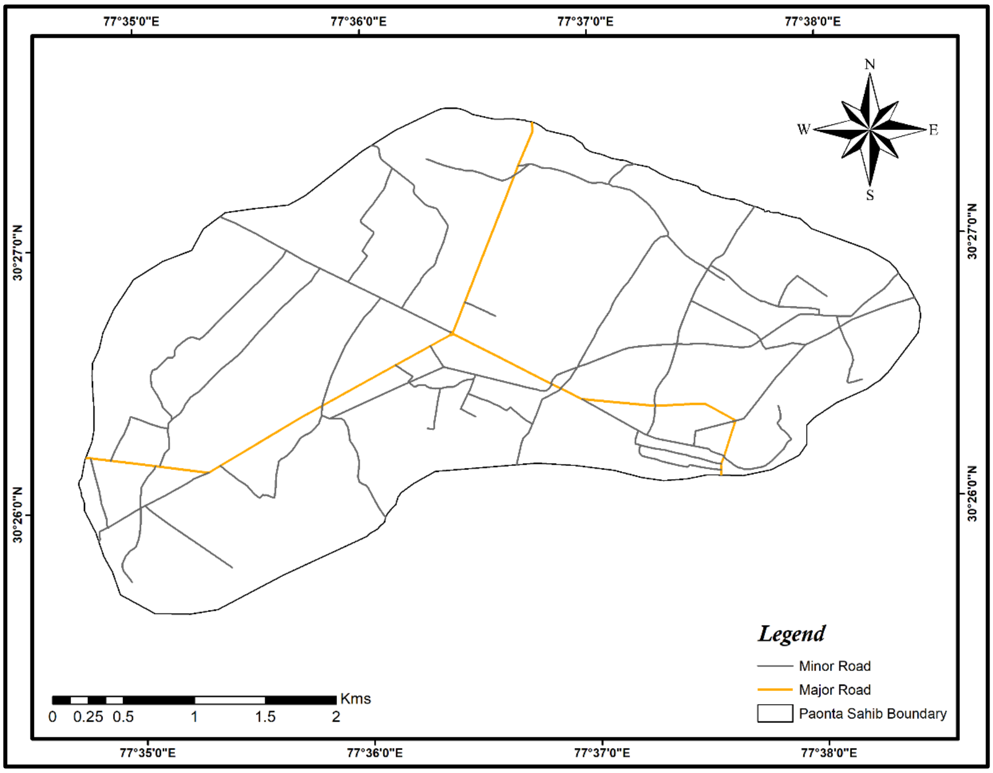


Figure 4.7: Major & Minor Road Network Map

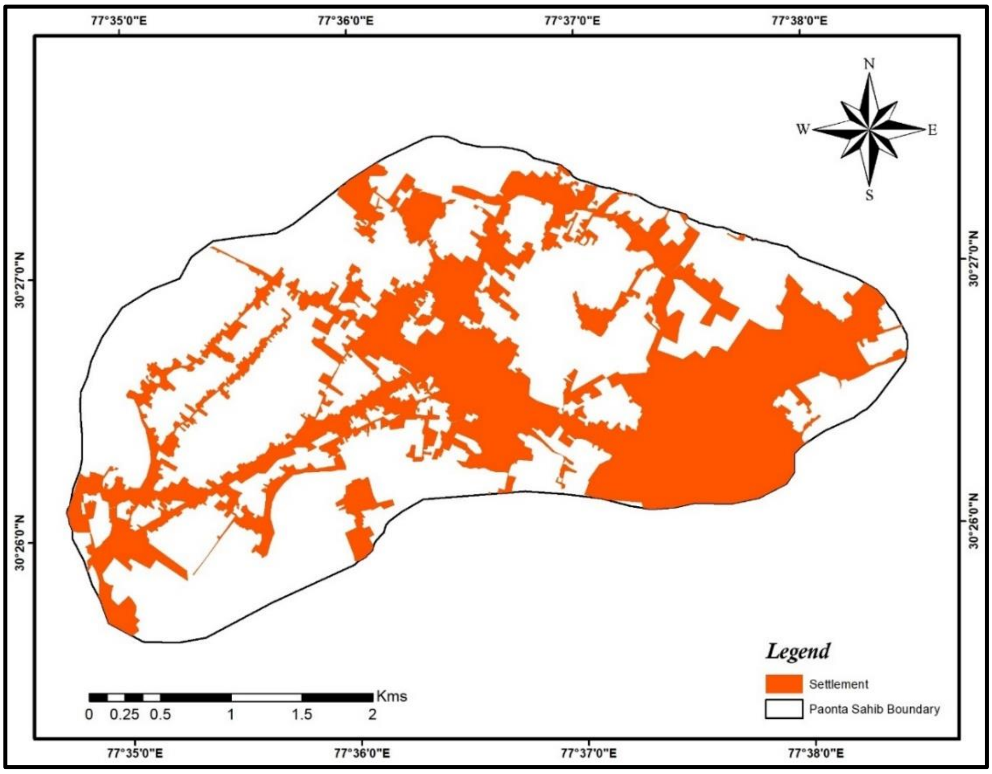


Figure 4.8: Settlement Area Map

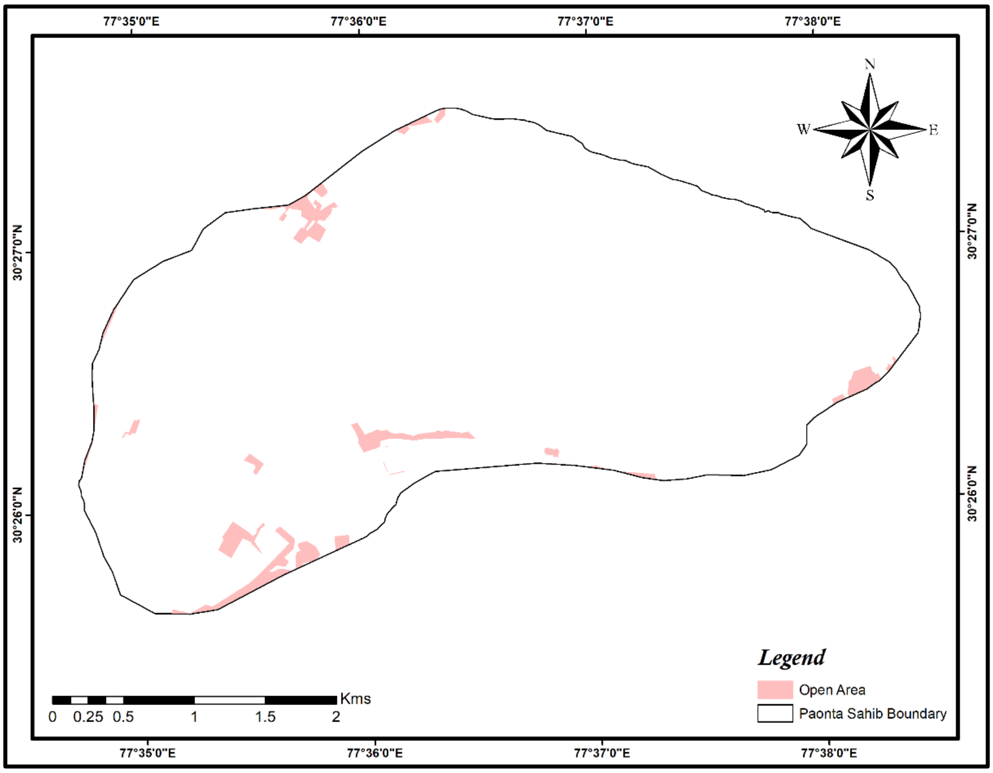


Figure 4.9: Open Area Map

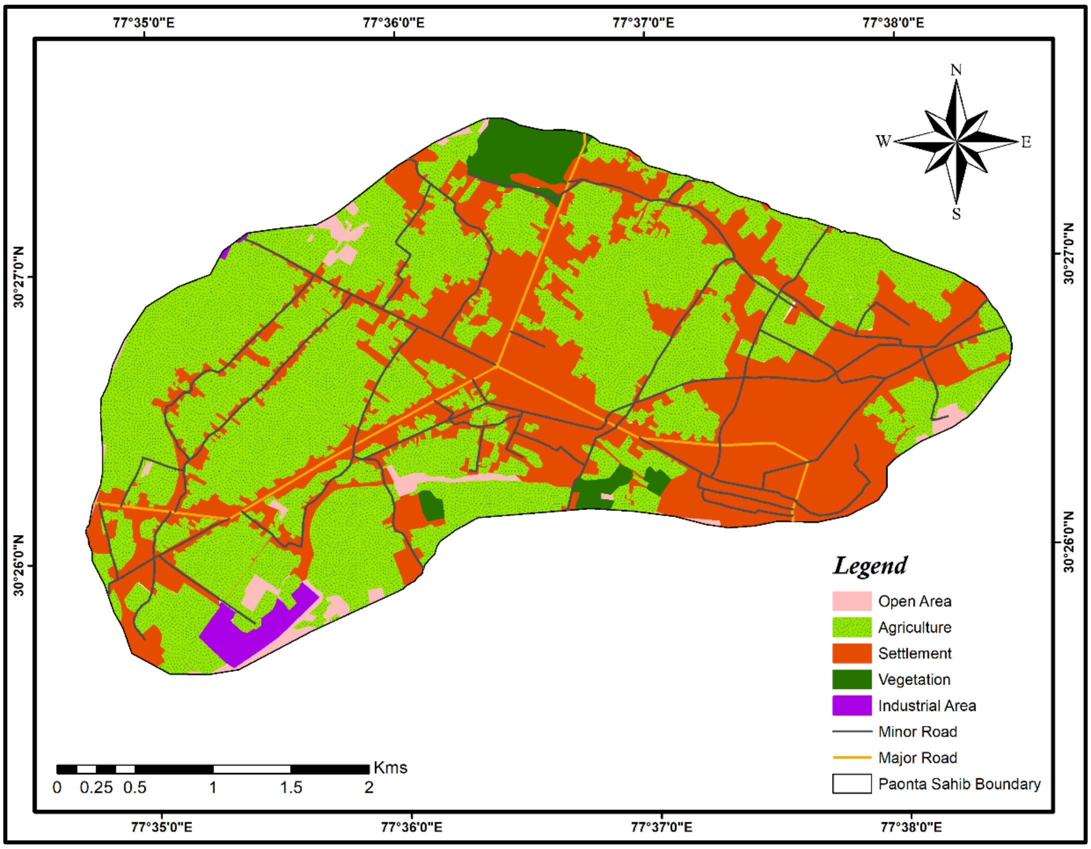


Figure 4.10: Land use Map of Paonta Sahib City

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 Paonta Sahib city. The Grid map of Paonta Sahib with grid identity numbers is shown in Figure 4.11. The entire study area was divided into grid cells of 0.5 km x 0.5 km.

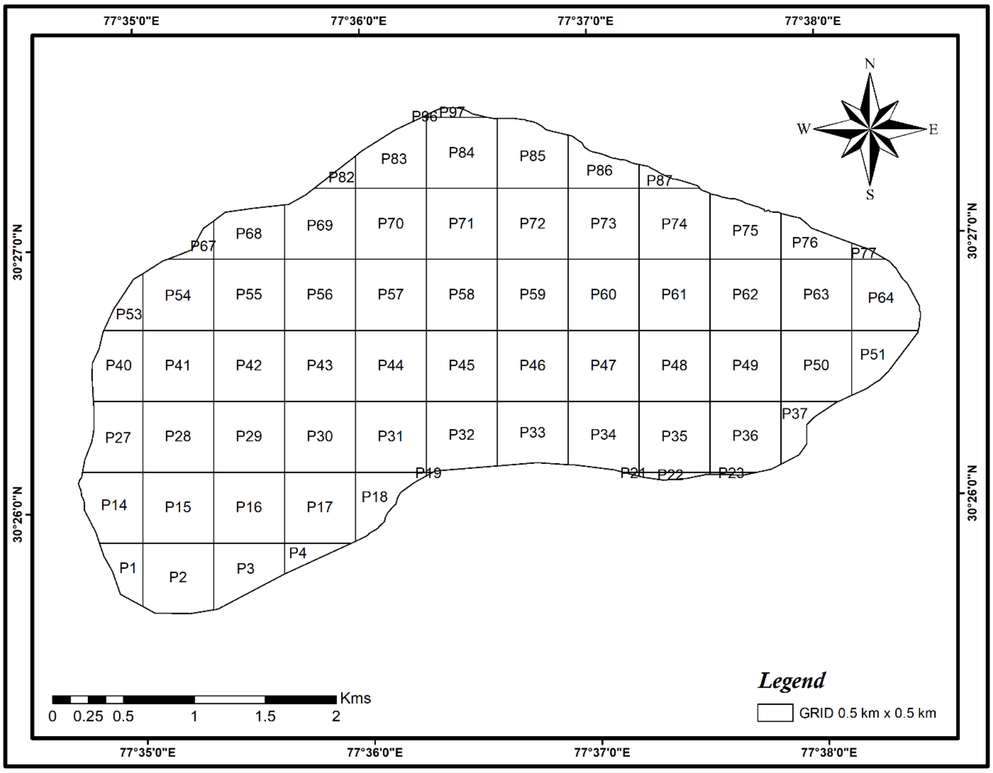


Figure 4.11: Grid Map of Paonta Sahib City showing Grid Identity Numbers

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:

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

Where:

E = Emissions;

A = Activity rate;

EF = Emission factor, and

ER = Overall emission reduction efficiency, %

4.2.5 Domestic Sector

The projected population of Paonta Sahib for the year 2020 is approximately 34000 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, after obtaining the area of wards, the emission density for each ward is calculated for different pollutants (PM_{10}, $PM_{2.5}$, SO_2, NOx, 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 4.12 (a) & (b). The emission contribution from different fuel types to different pollutants is shown in Figure 4.13 to Figure 4.17. For spatial distribution of different pollutants (Figure 4.18 to Figure 4.22), emission per capita, in each ward was calculated, as activity data was available based on per capita.

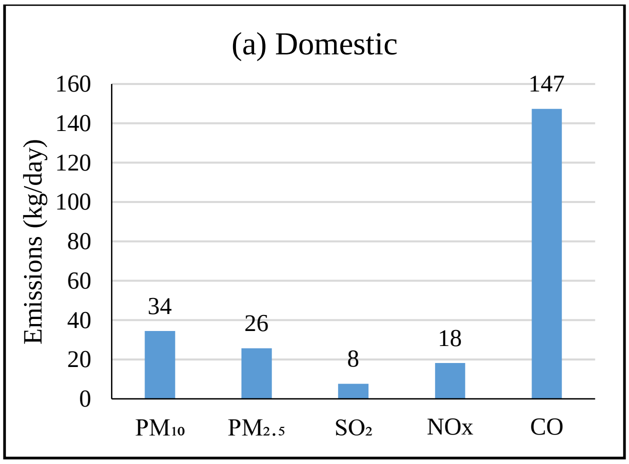
The emission density in terms of kg/day/m^2 in each ward was calculated based on the population and area of the ward for different pollutants (PM_{10}, $PM_{2.5}$, SO_2, NOx, and CO); see below.

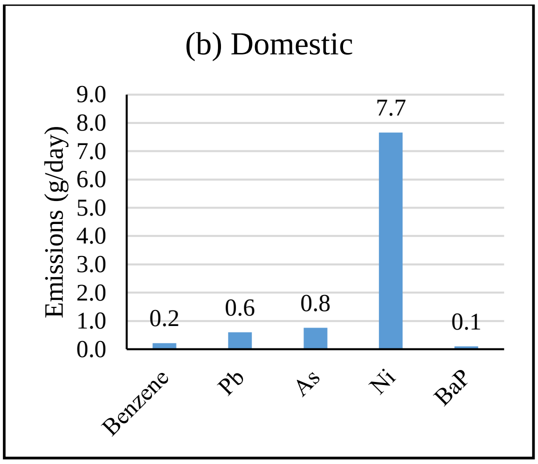
$$\text{Emission Density (kg/day/m}^2\text{)} = \text{Emission of Ward (kg/day)/Ward Area (m}^2\text{)} \quad \text{..... (Eq. 4.2)}$$

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.

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

Where N= no. of wards in the grid.





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

Figure 4.12: Emission Load from Domestic Sector

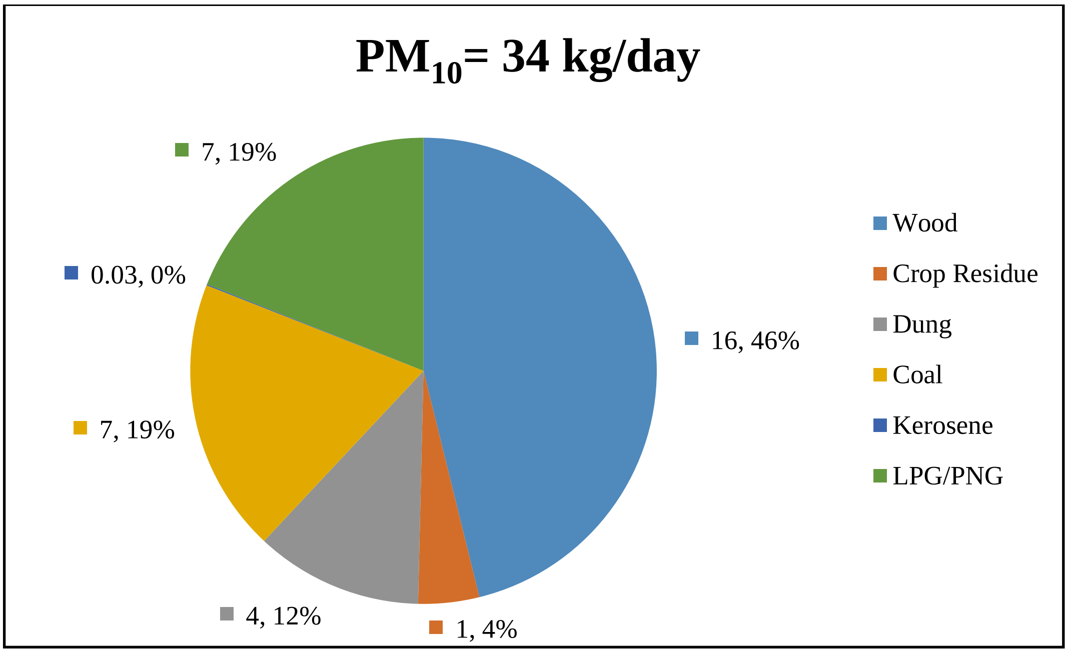


Figure 4.13: PM_{10} Emission load from Domestic Sector (Kg/day, %)

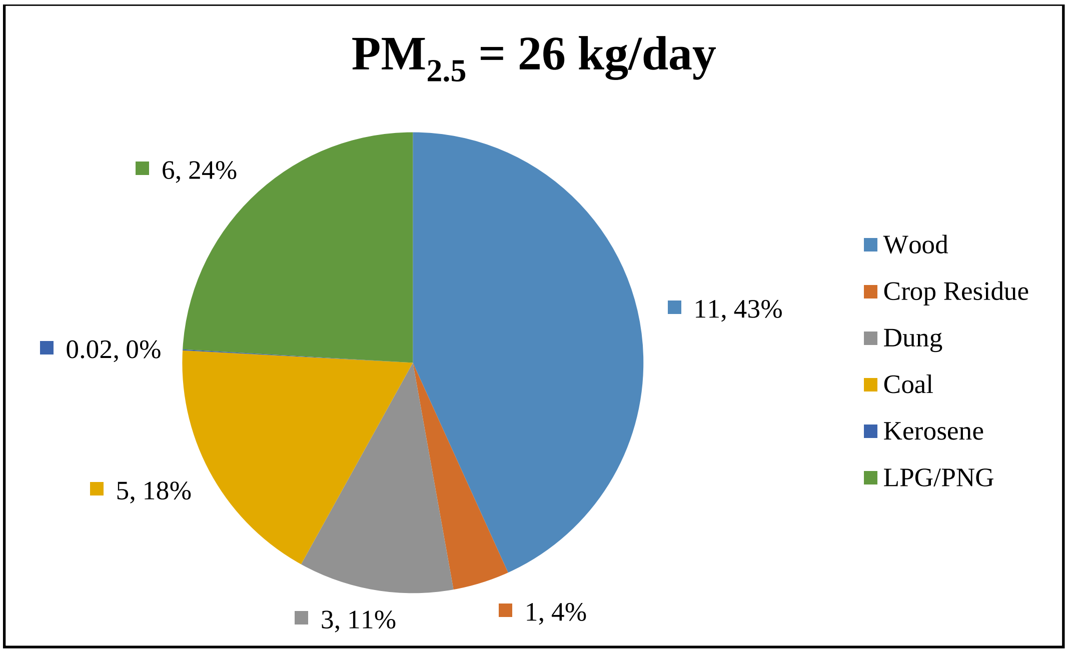


Figure 4.14: $PM_{2.5}$ Emission load from Domestic Sector (Kg/day, %)

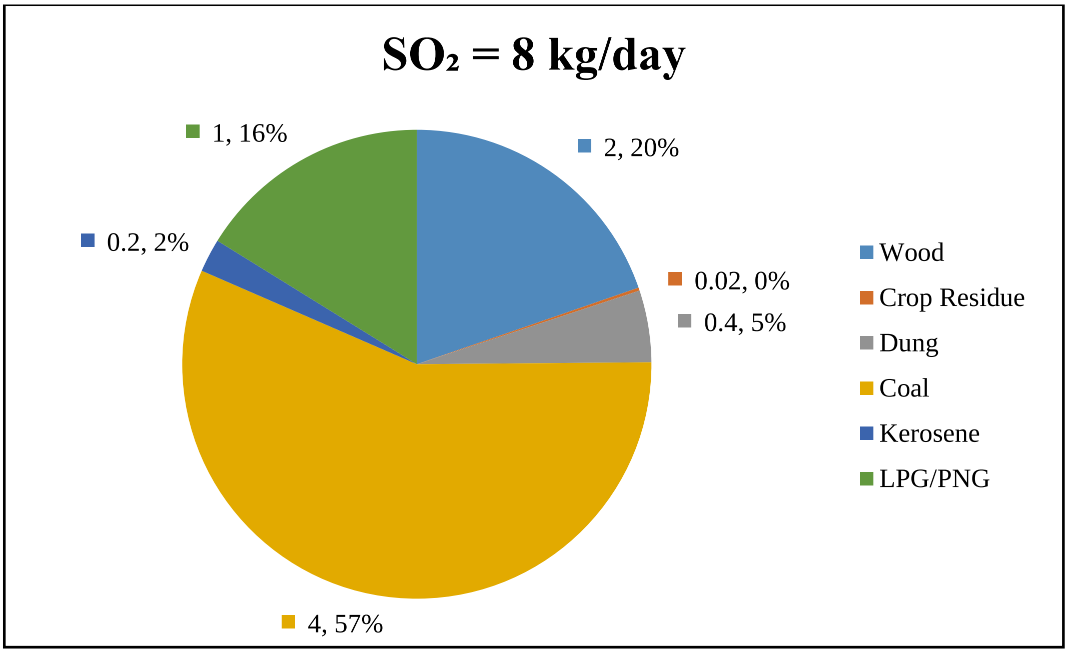


Figure 4.15: SO_2 Emission load from Domestic Sector (Kg/day, %)

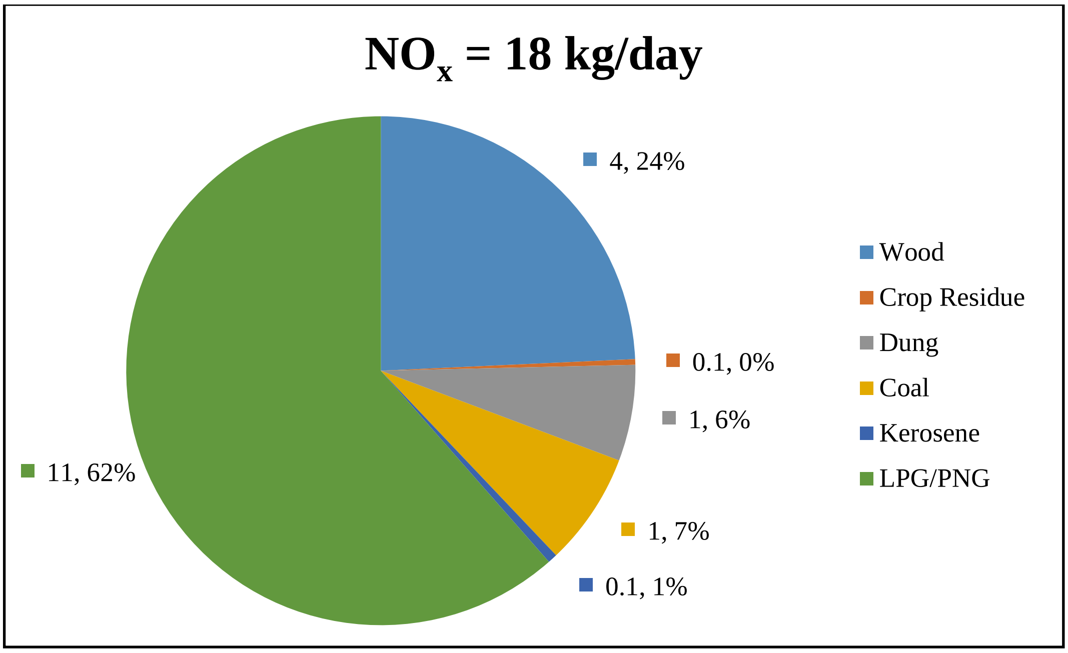


Figure 4.16: NOx Emission load from Domestic Sector (Kg/day, %)

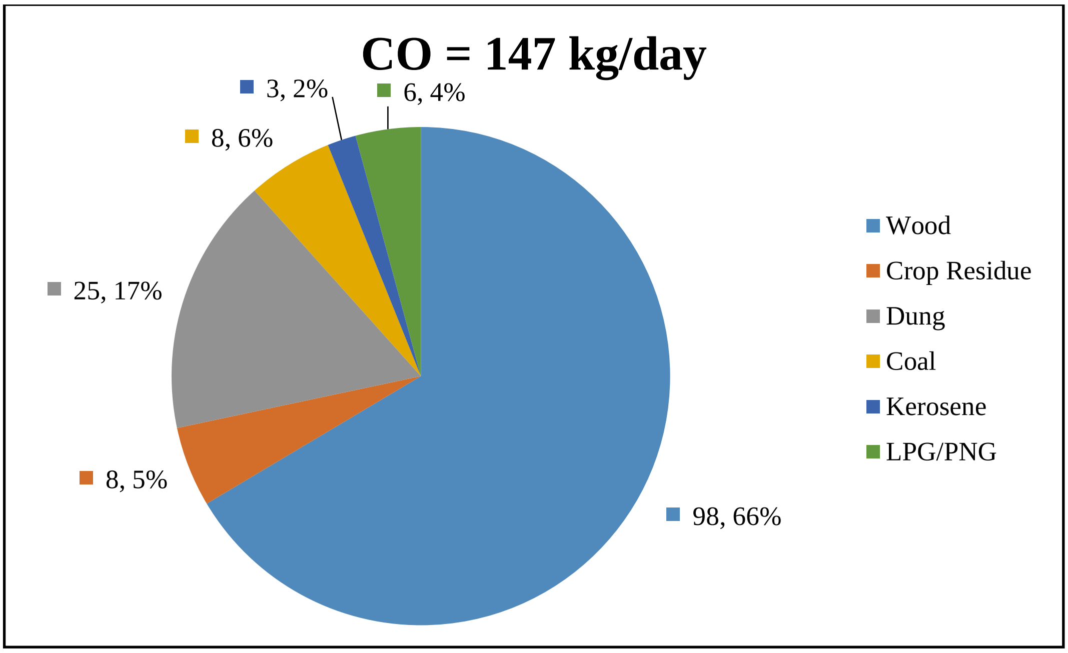


Figure 4.17: CO Emission load from Domestic Sector (Kg/day, %)

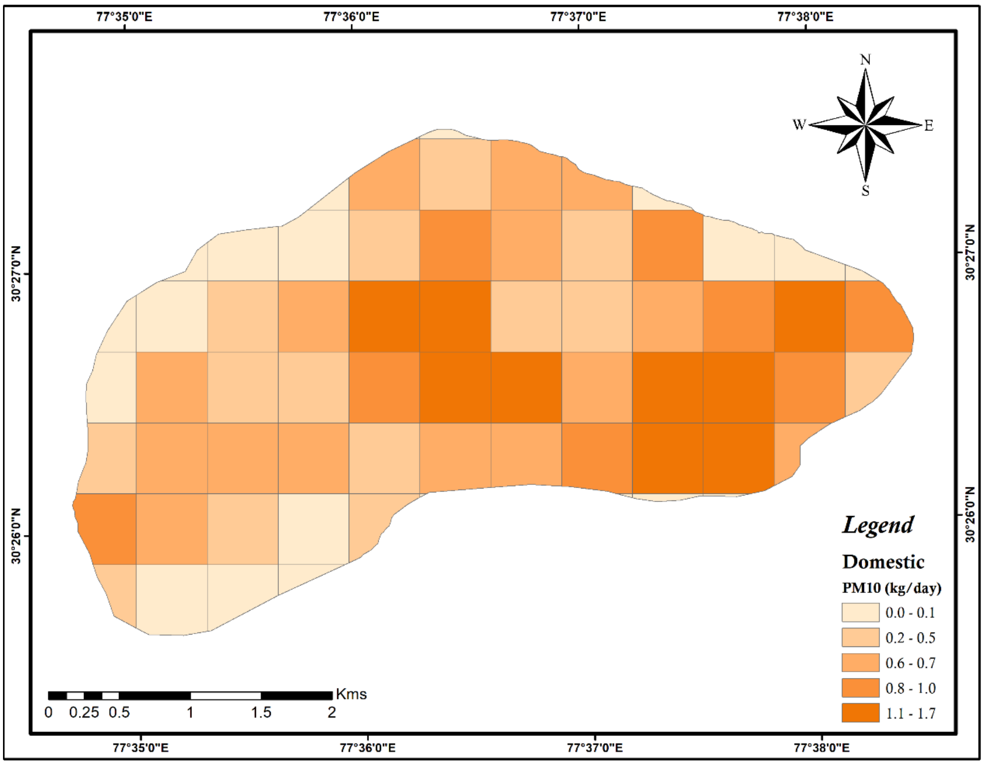


Figure 4.18: Spatial Distribution of PM_{10} Emissions from Domestic Sector

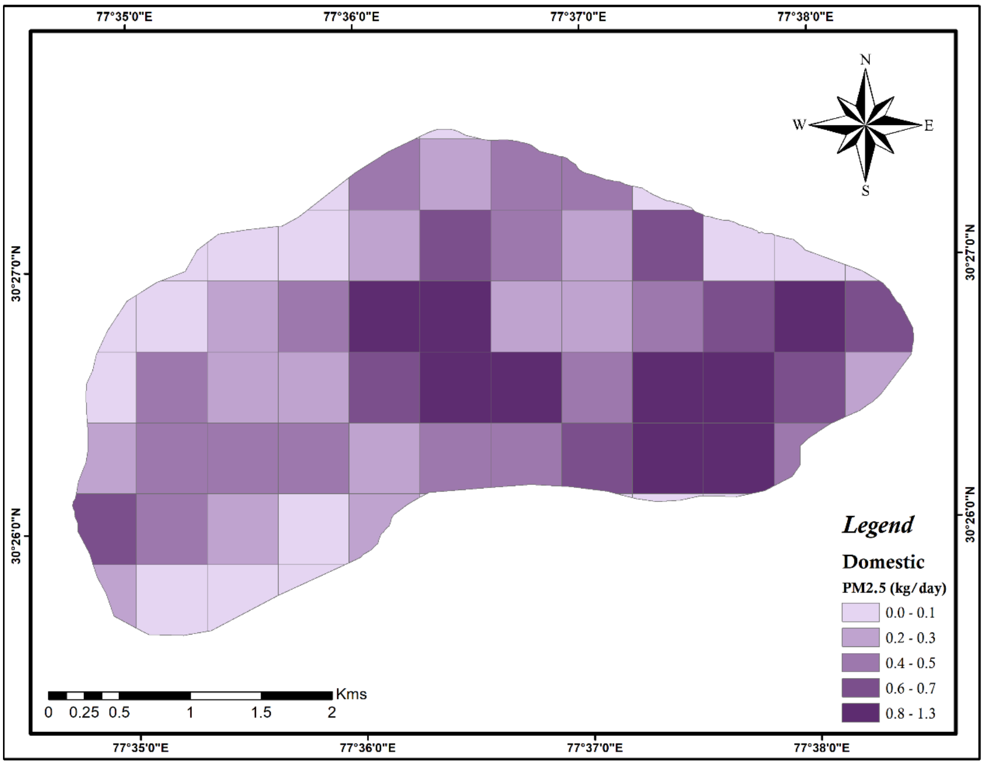


Figure 4.19: Spatial Distribution of $PM_{2.5}$ Emissions from Domestic Sector

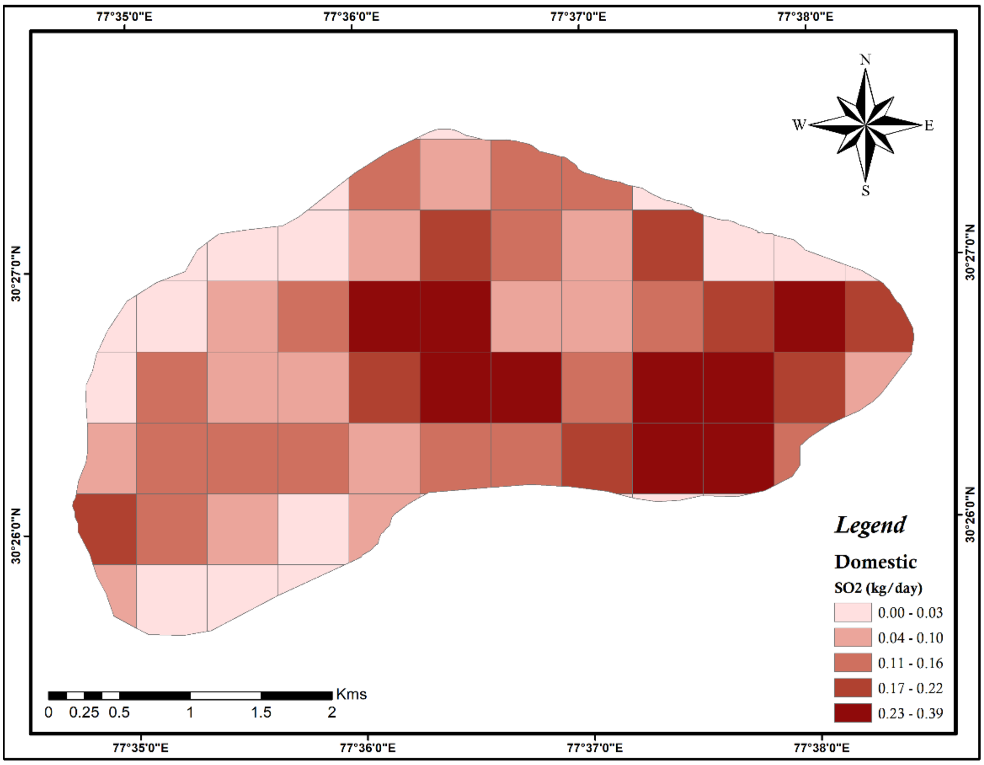


Figure 4.20:Spatial Distribution of SO_2 Emissions from Domestic Sector

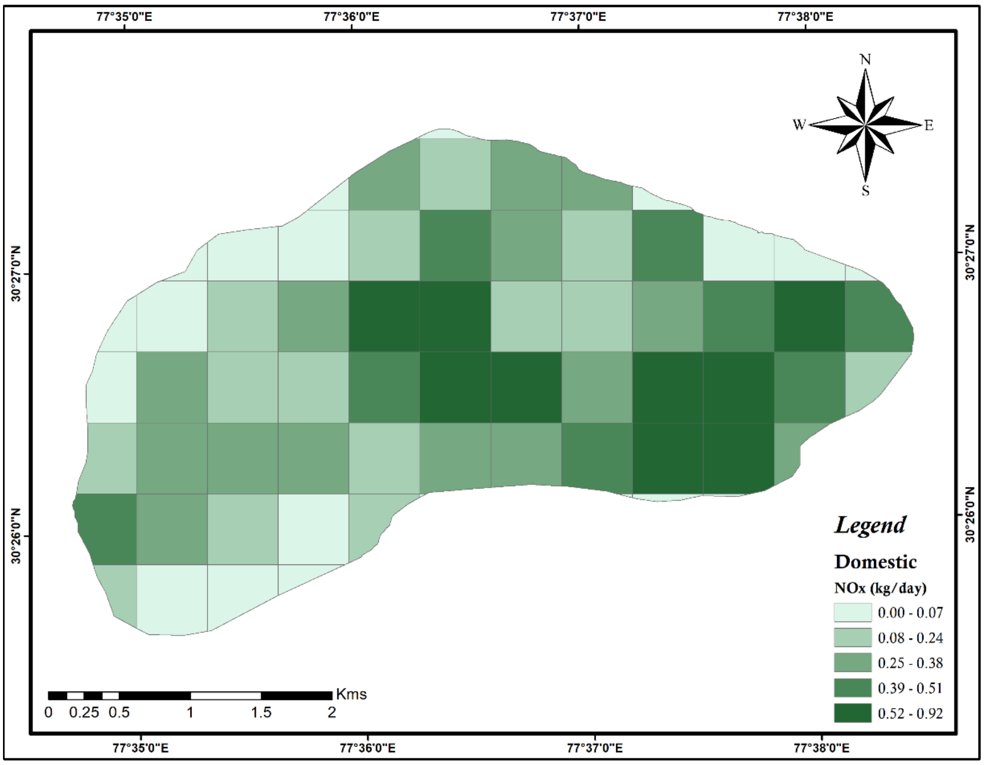


Figure 4.21: Spatial Distribution of NOx Emissions from Domestic Sector

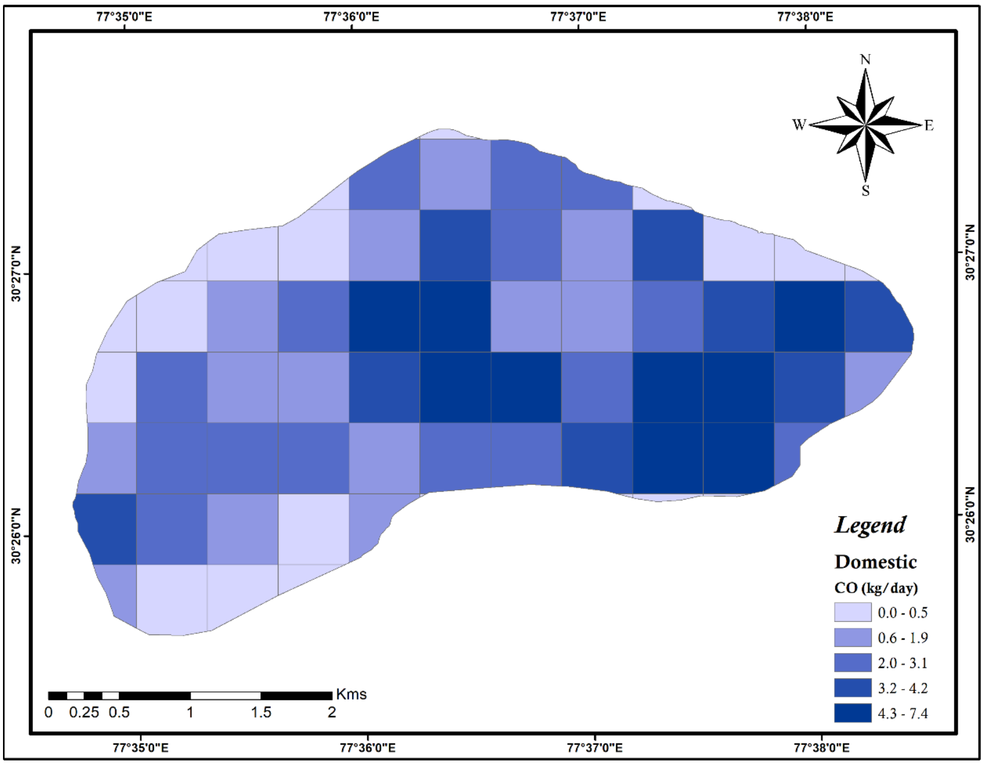


Figure 4.22: Spatial Distribution of CO Emissions from Domestic Sector

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 Paonta Sahib Nagar Nigam, PWD, CPWD, and a detailed survey were 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 4.23). The areas under construction activities were calculated based on survey data and GIS. The location of construction and demolition sites at Paonta Sahib city is given in Figure 4.24. The emissions were estimated using Eq (4.4) given by AP-42 (USEPA, 2000).

E = 1.2 tons/acre/month of activity ....(Eq 4.4)

Figure 4.23: Construction material and debris near construction sites

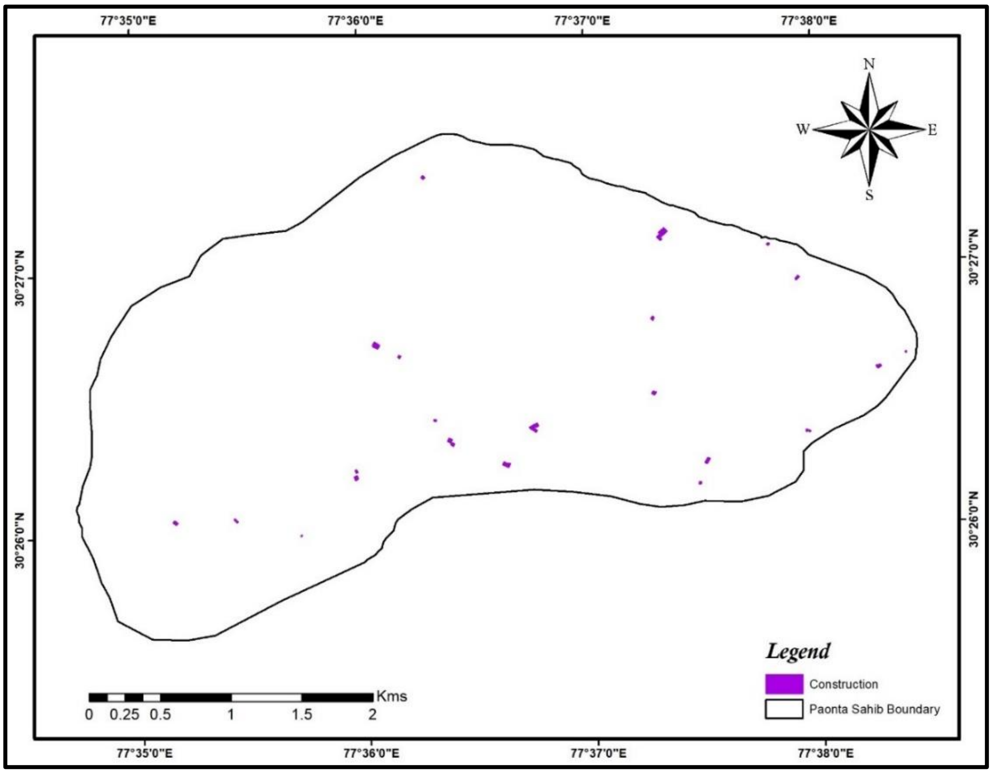
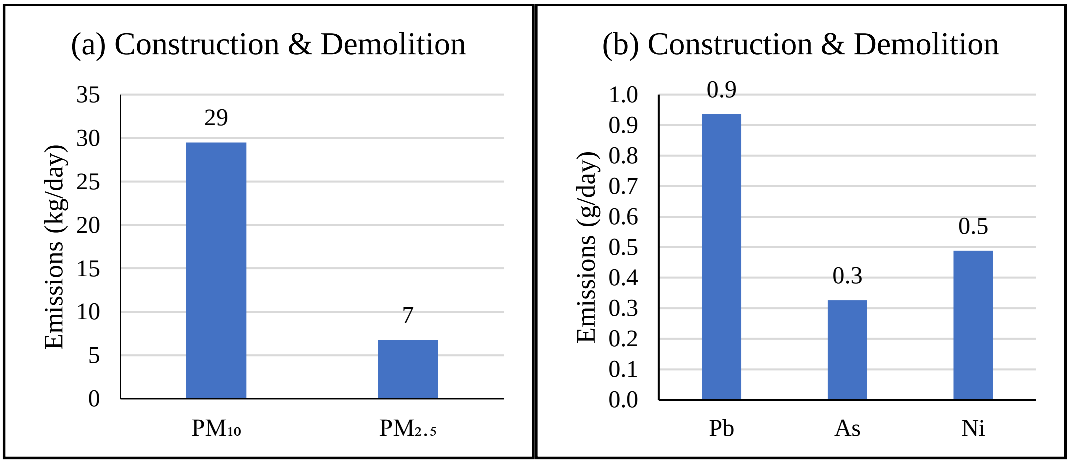


Figure 4.24: Location of Construction and Demolition sites at Paonta Sahib city

Total emissions from construction and demolition activities are presented in Figure 4.25 (a) & (b). The spatially resolved map of construction and demolition activities is shown in Figure 4.26 to Figure 4.27. The Emission load of PM_{10} and $PM_{2.5}$ from construction and demolition is 29 kg/day and 7 kg/day.



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

Figure 4.25: Emission Load from Construction and Demolition activities

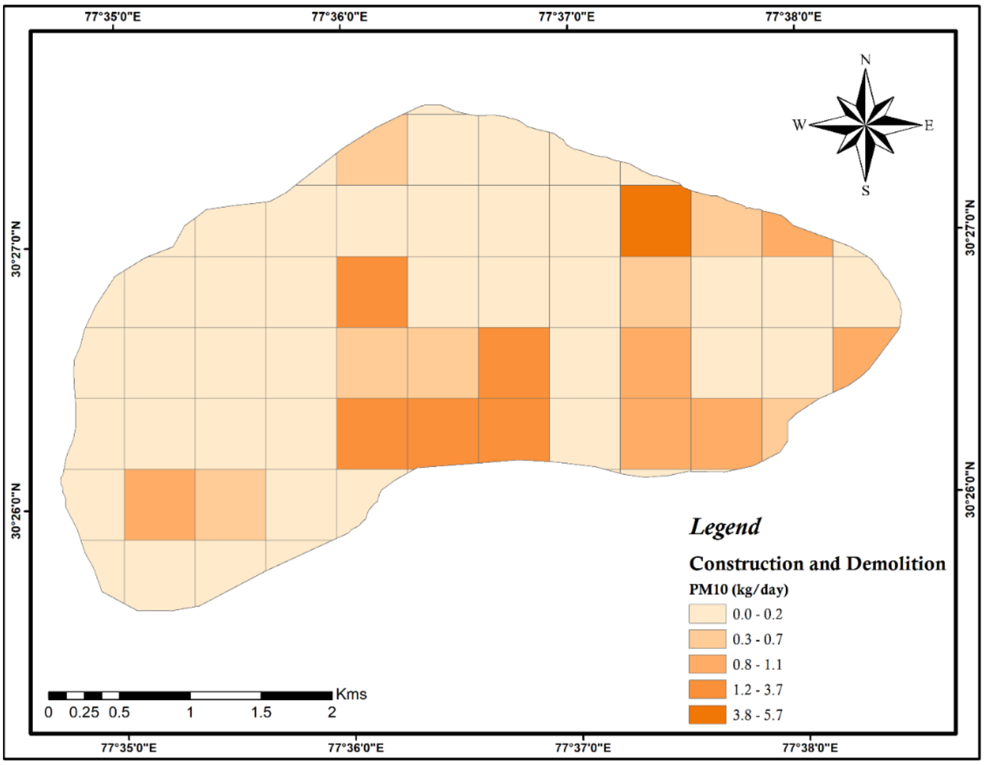


Figure 4.26: Spatial Distribution of PM_{10} Emissions from Construction/Demolition

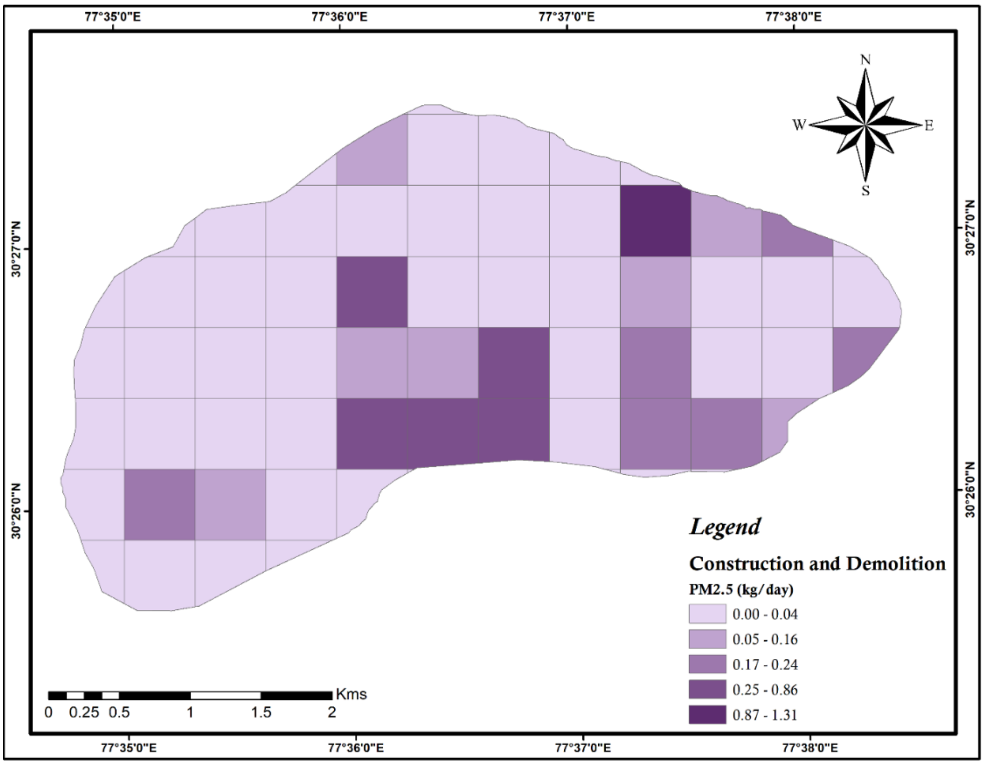


Figure 4.27: Spatial Distribution of $PM_{2.5}$ Emissions from Construction/Demolition

4.2.7 Industrial Diesel Generator Sets (DG sets)

The location of the Industrial DG sets is shown in Figure 4.28. The industries use DG sets as a backup, approximately nine DG sets are installed in industries (source: consent data) out of which two DG sets lie within the city boundary, we have considered all nine Industrial DG Sets to estimate the emissions. The capacities of Industrial DG sets are in the range of 63 KVA to 2250 KVA with an average capacity of 950 KVA. During the industrial survey, it was found that 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 CPCB (2011) emission factors were used for emission estimation. The total emissions from Industrial DG sets are shown in Figure 4.29 (a) & (b), the spatial distribution of emissions from Industrial DG sets lying within the boundary is shown in Figure 4.30 to Figure 4.34.

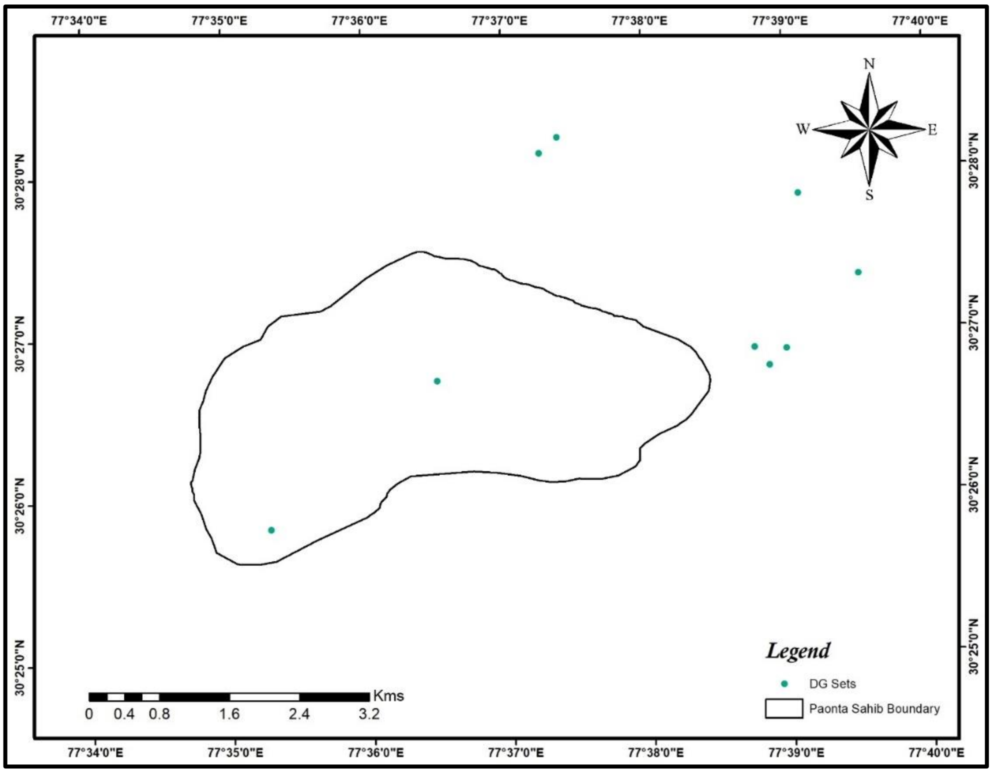
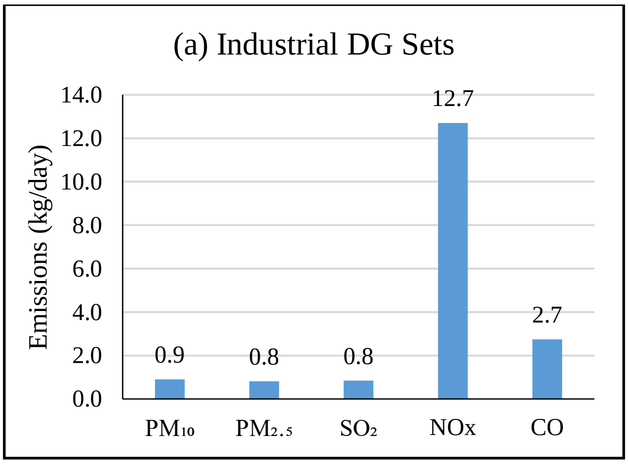
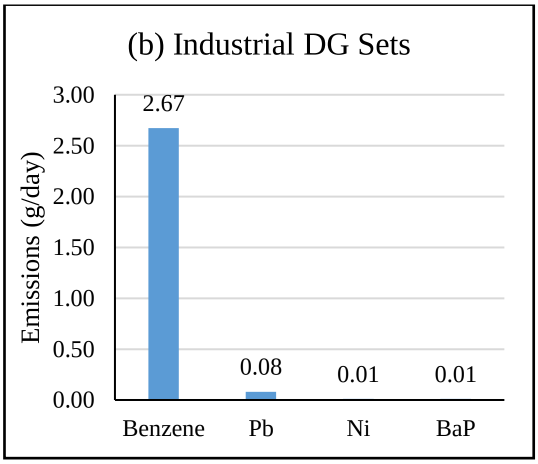


Figure 4.28: Location of Industrial DG Sets





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

Figure 4.29: Emission Load from Industrial DG sets

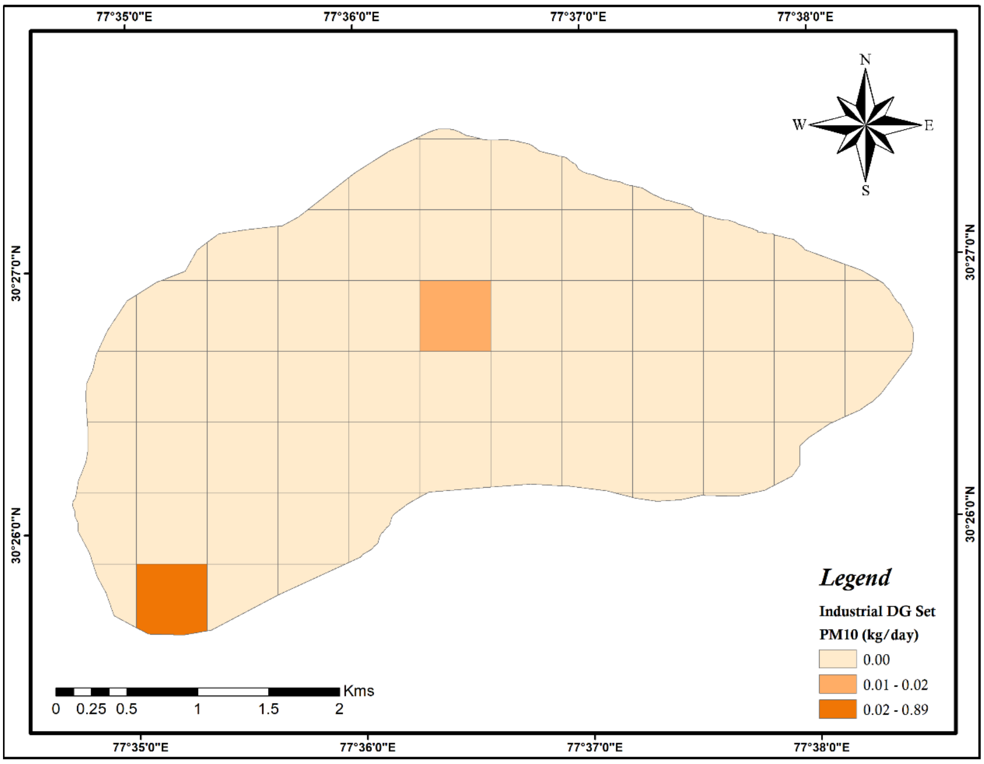


Figure 4.30: Spatial Distribution of PM_{10} Emissions from Industrial DG Sets

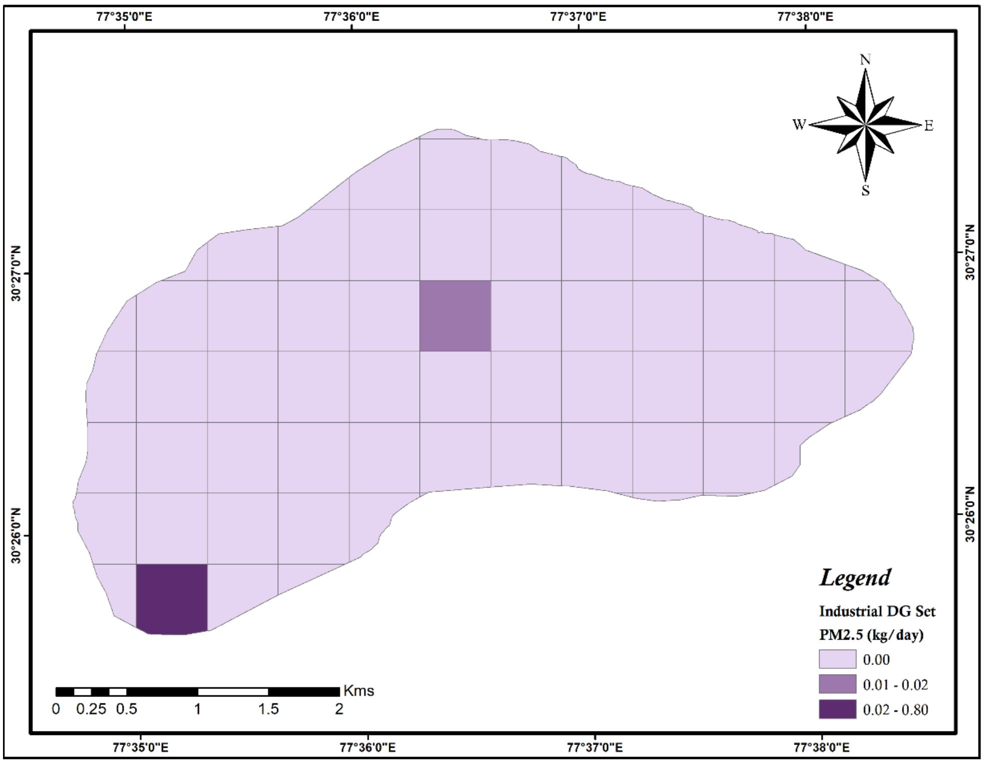


Figure 4.31: Spatial Distribution of $PM_{2.5}$ Emissions from Industrial DG Sets

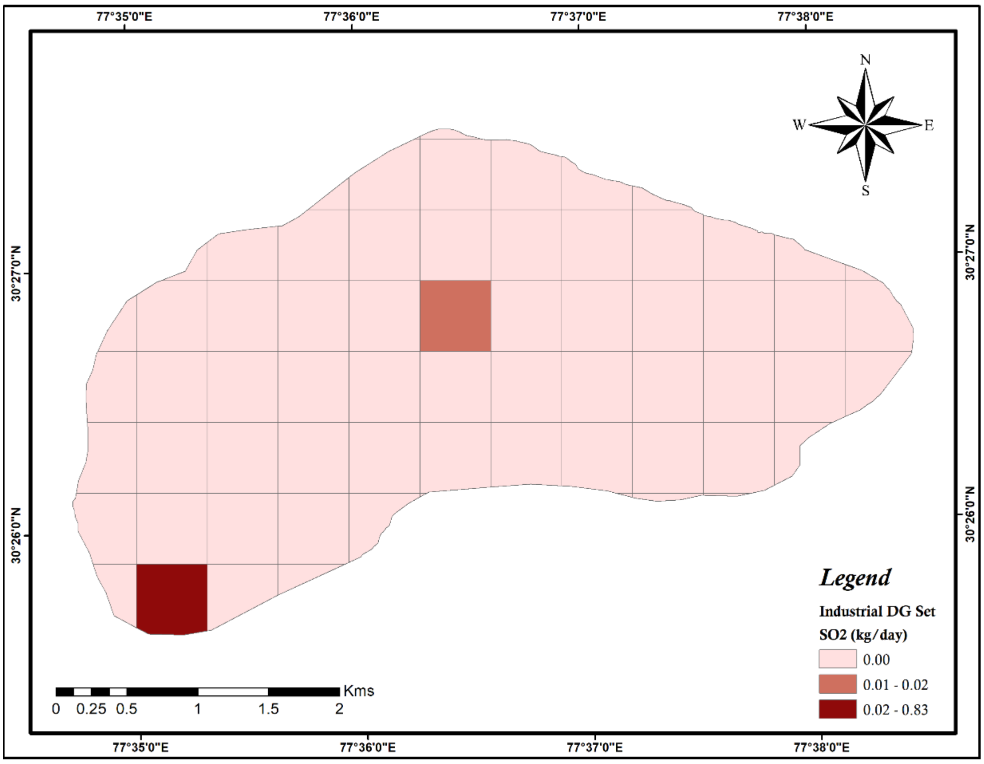


Figure 4.32: Spatial Distribution of SO_2 Emissions from Industrial DG Sets

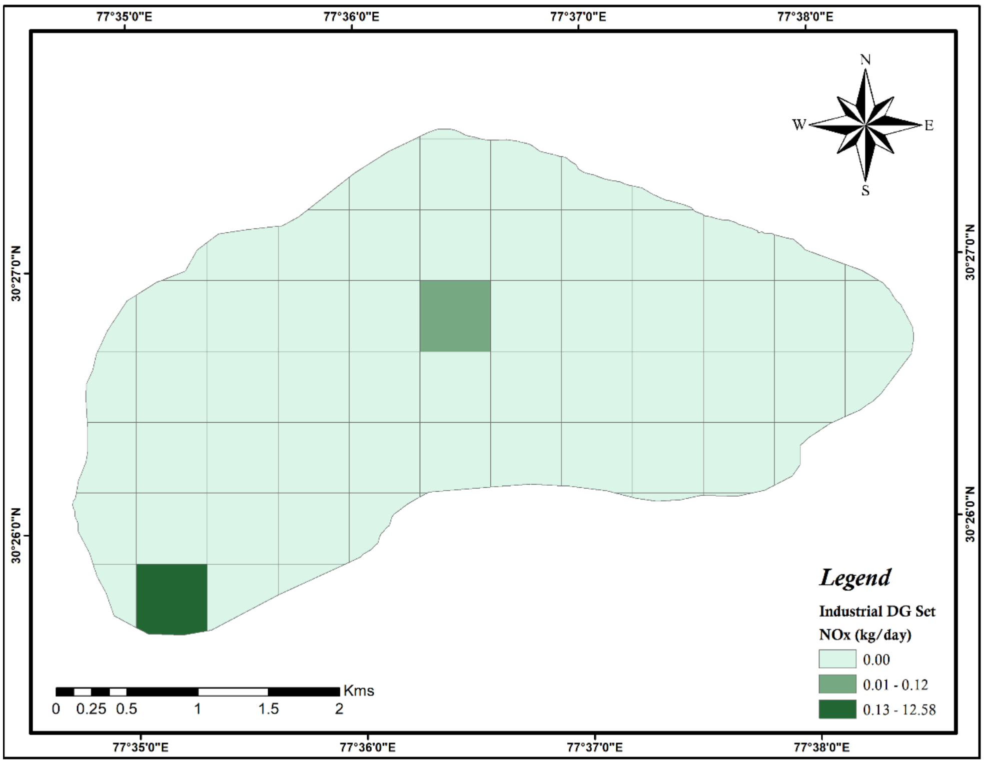


Figure 4.33: Spatial Distribution of NOx Emissions from Industrial DG Sets

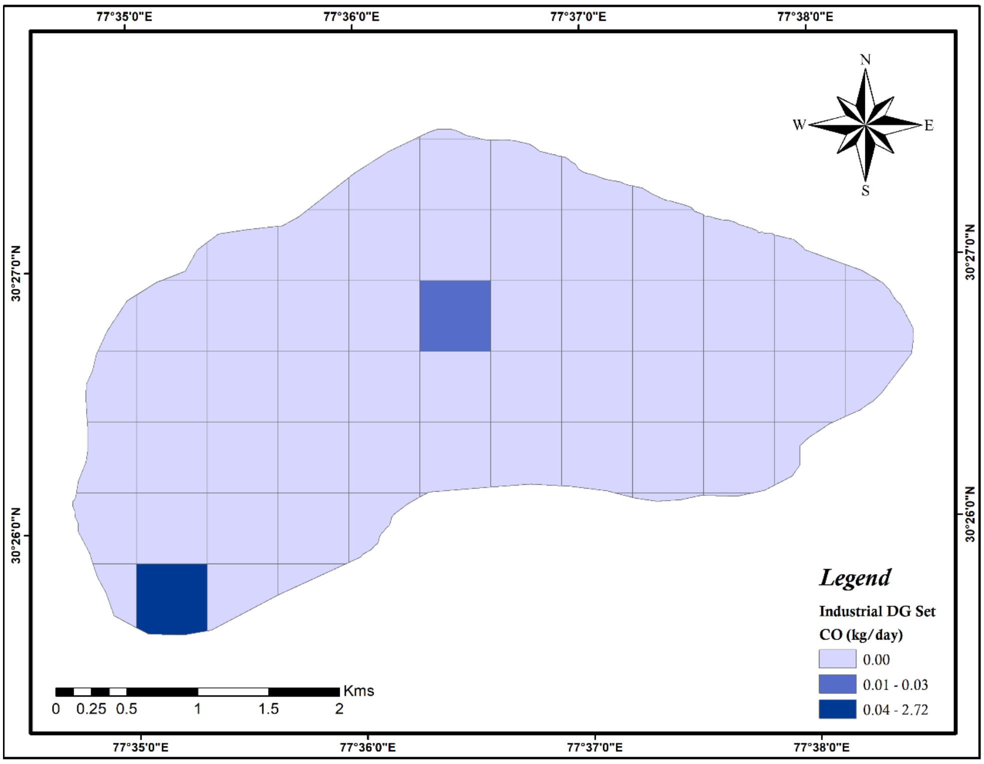


Figure 4.34: Spatial Distribution of CO Emissions from Industrial DG Sets

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 a 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, GHs & BHs around the city was approximately 58 out of which 54 lie within the city boundary (Figure 4.35), we have considered all 58 Hotels, Restaurants, GHs & BHs to estimate the emissions. 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, NOx, 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 this area source (Hotels, Restaurants, GHs & BHs) is shown in Figure 4.36 (a) & (b). The spatial distribution of emissions from Hotels, Restaurants, GHs & BHs within the city boundary is shown in Figure 4.37 to Figure 4.41.

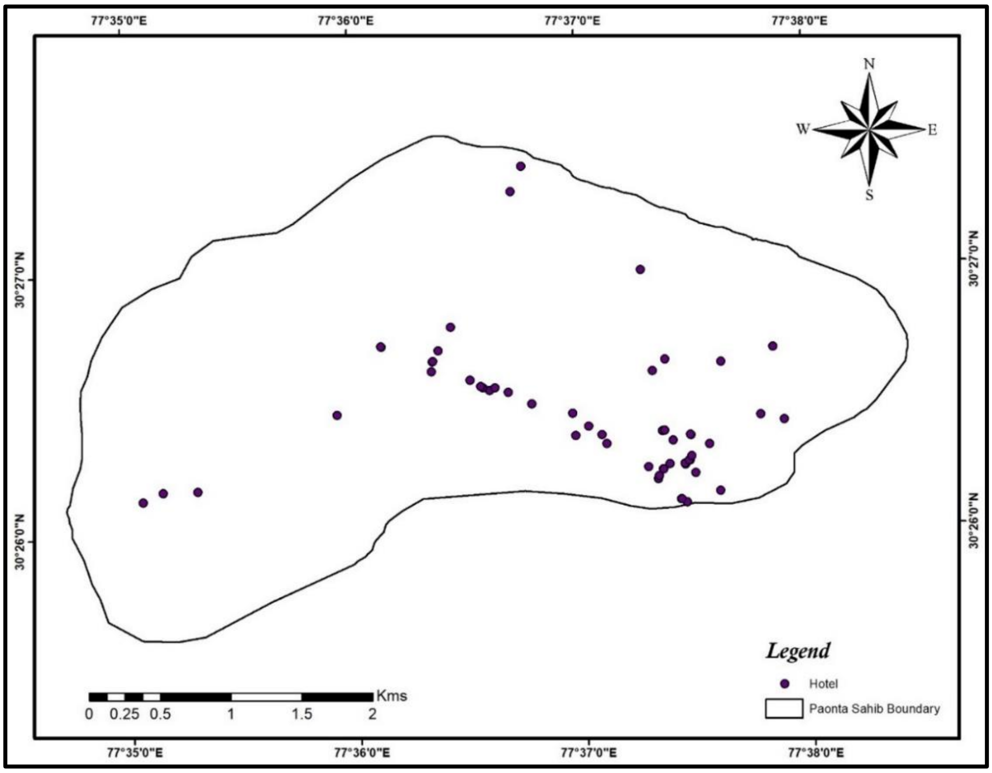
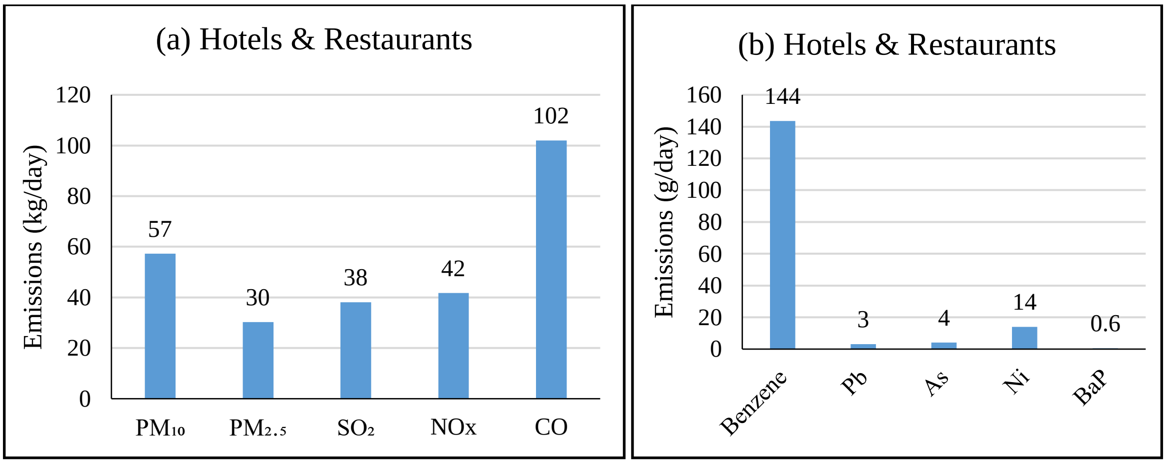


Figure 4.35: Location of Hotels, Restaurants, GHs & BHs



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

Figure 4.36: Emission Load from Hotels, Restaurants, GHs & BHs

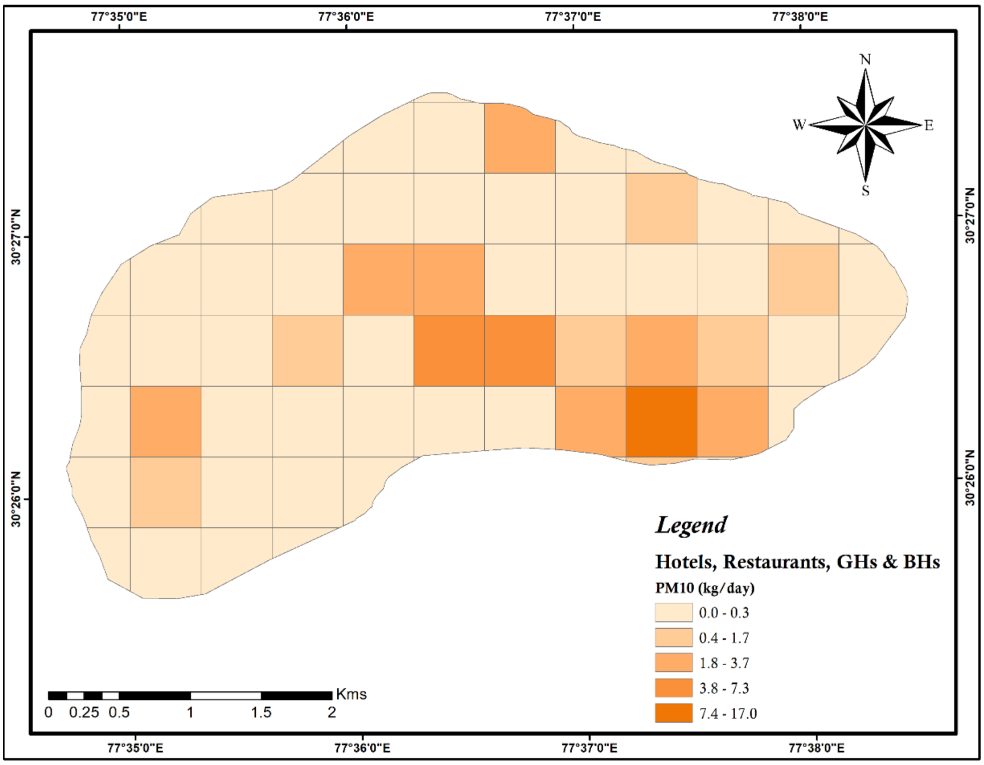


Figure 4.37: Spatial Distribution of PM_{10} Emissions from Hotels, Restaurants, GHs & BHs

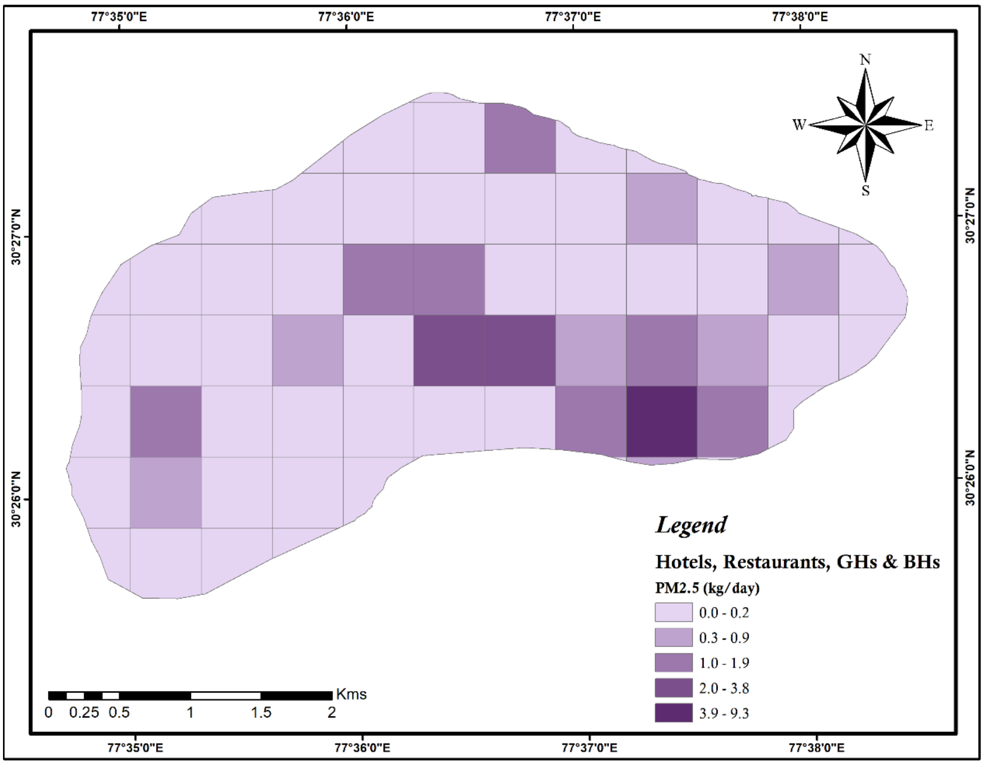


Figure 4.38: Spatial Distribution of $PM_{2.5}$ Emissions from Hotels, Restaurants, GHs & BHs

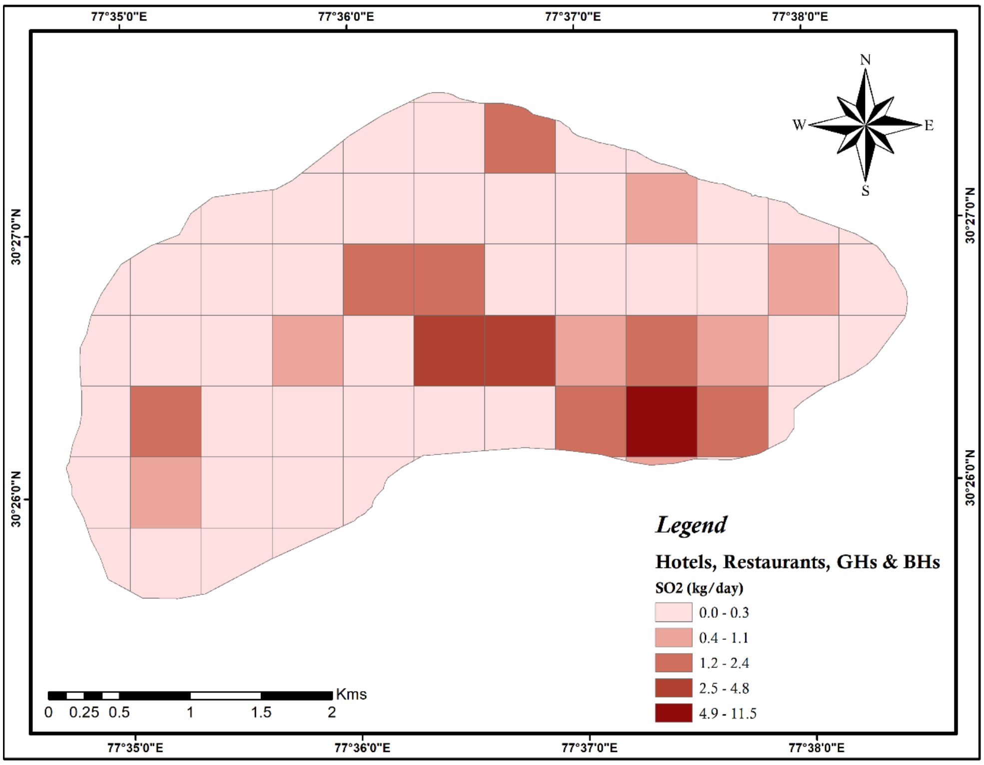


Figure 4.39: Spatial Distribution of SO_2 Emissions from Hotels, Restaurants, GHs & BHs

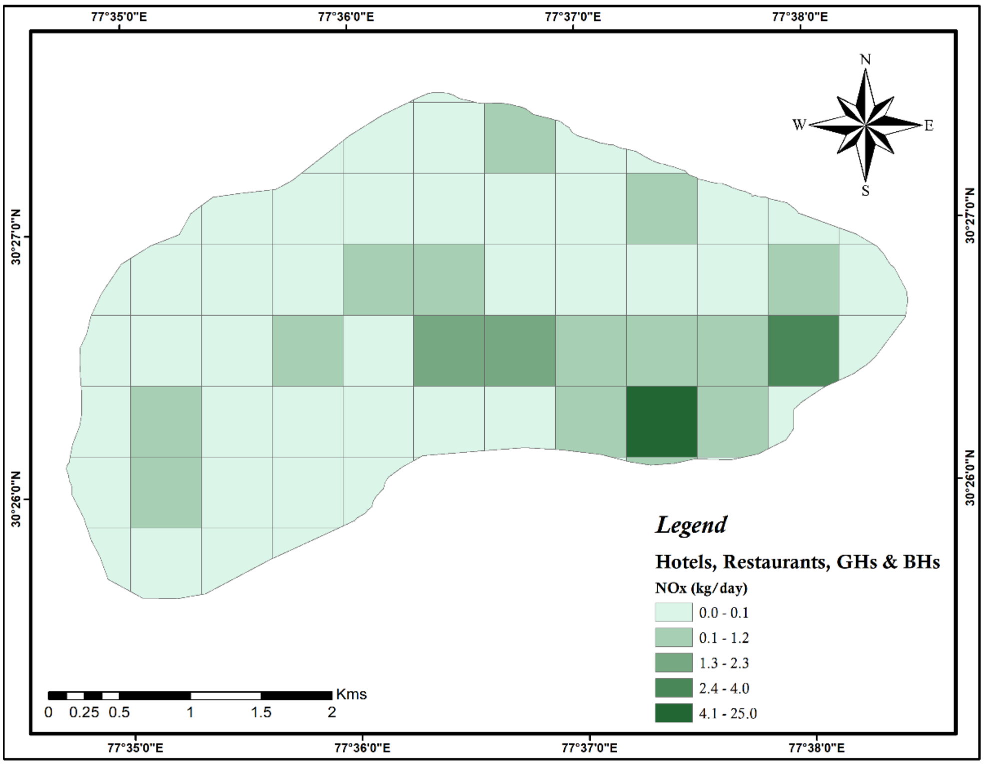


Figure 4.40: Spatial Distribution of NO_X Emissions from Hotels, Restaurants, GHs & BHs

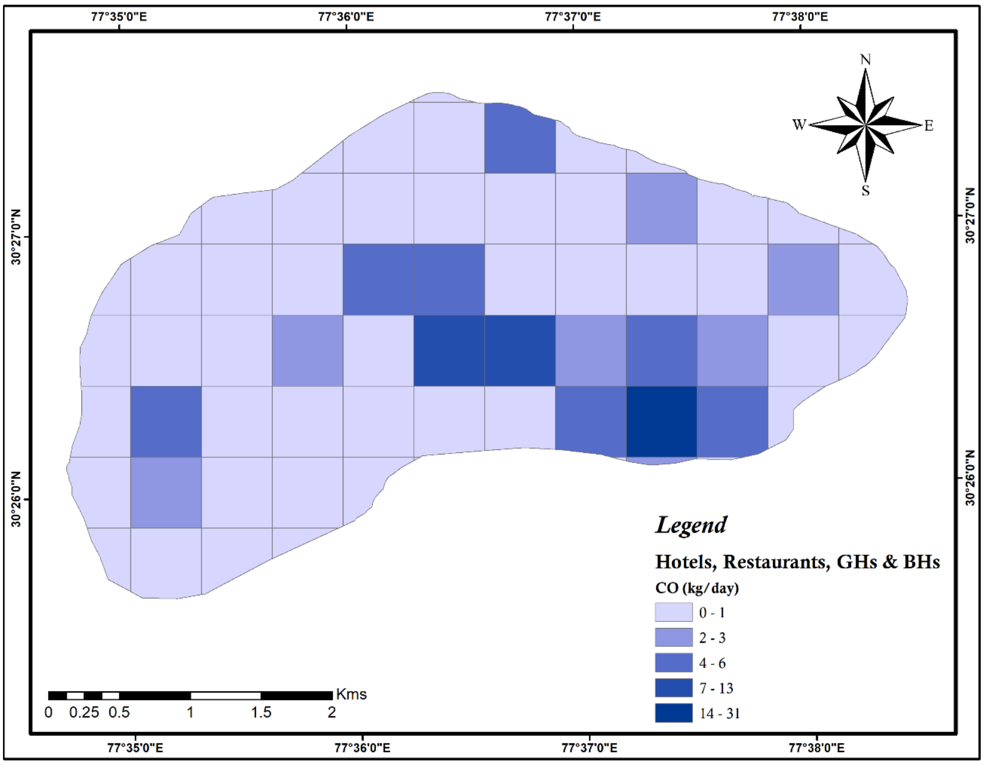


Figure 4.41: Spatial Distribution of CO Emissions from Hotels, Restaurants, GHs & BHs

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 kilns (outside the city boundary) affect the local air quality of the city. A detailed survey was conducted by the IITK team and activity data were collected. There are approximately eight brick kiln presents around the city out of which two lie within the city boundary (Figure 4.42), we have considered all eight Brick Kilns to estimate the emissions. These kilns use wood and coal as fuel. The emissions of various parameters such as PM_{10}, $PM_{2.5}$, SO_2, NOx, 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 4.43 (a) & (b). The spatial distribution of emissions from Brick Kilns lying within the city boundary is shown in Figure 4.44 to Figure 4.48.

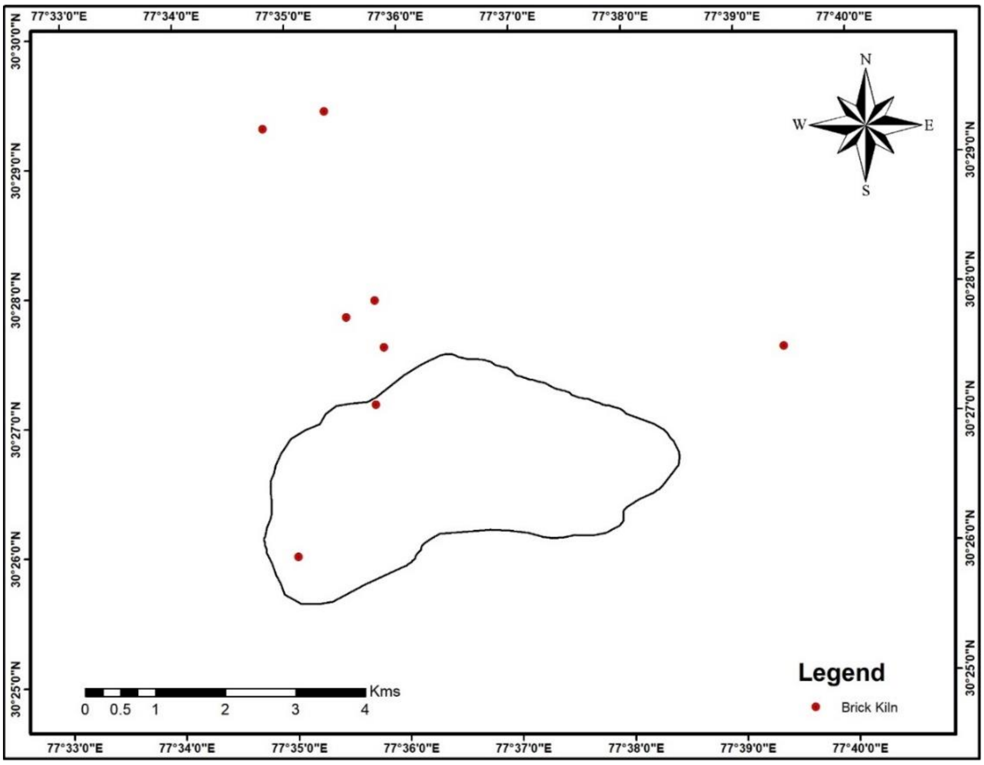
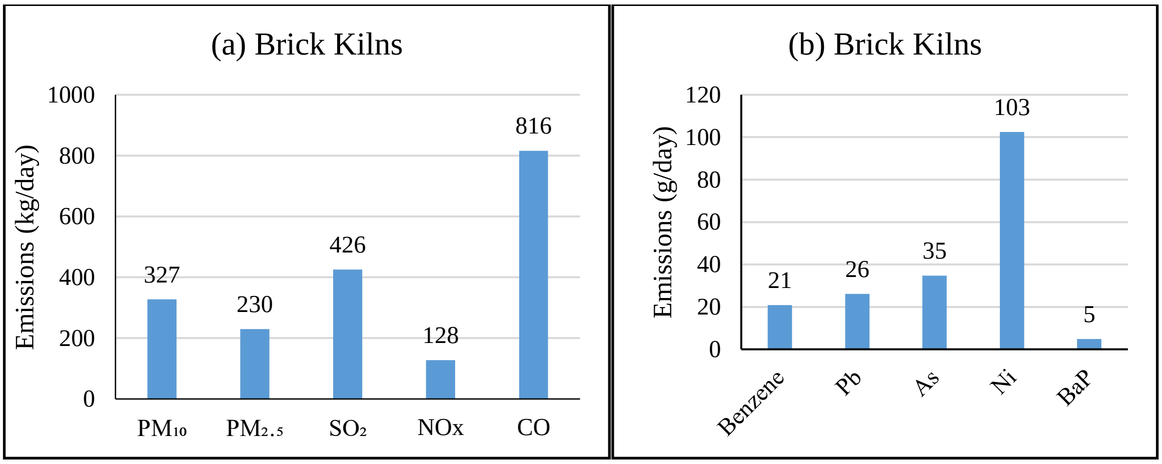


Figure 4.42: Location of Brick kiln in Paonta Sahib city



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

Figure 4.43: Emission Load from Brick kilns

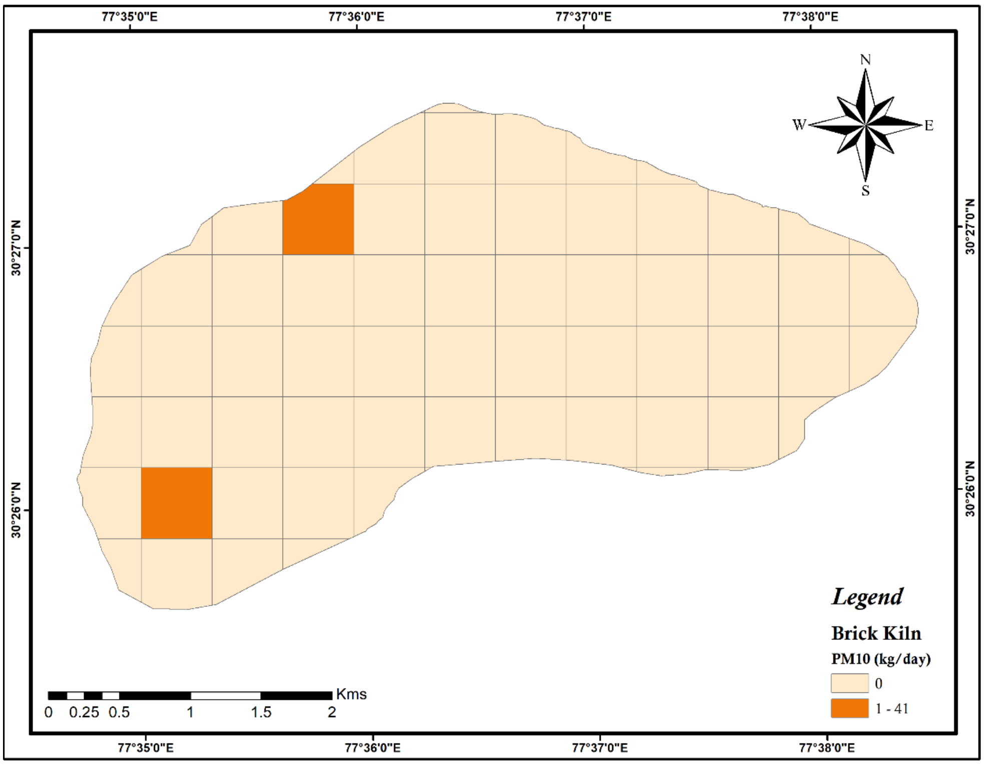


Figure 4.44: Spatial Distribution of PM_{10} Emissions from Brick kilns

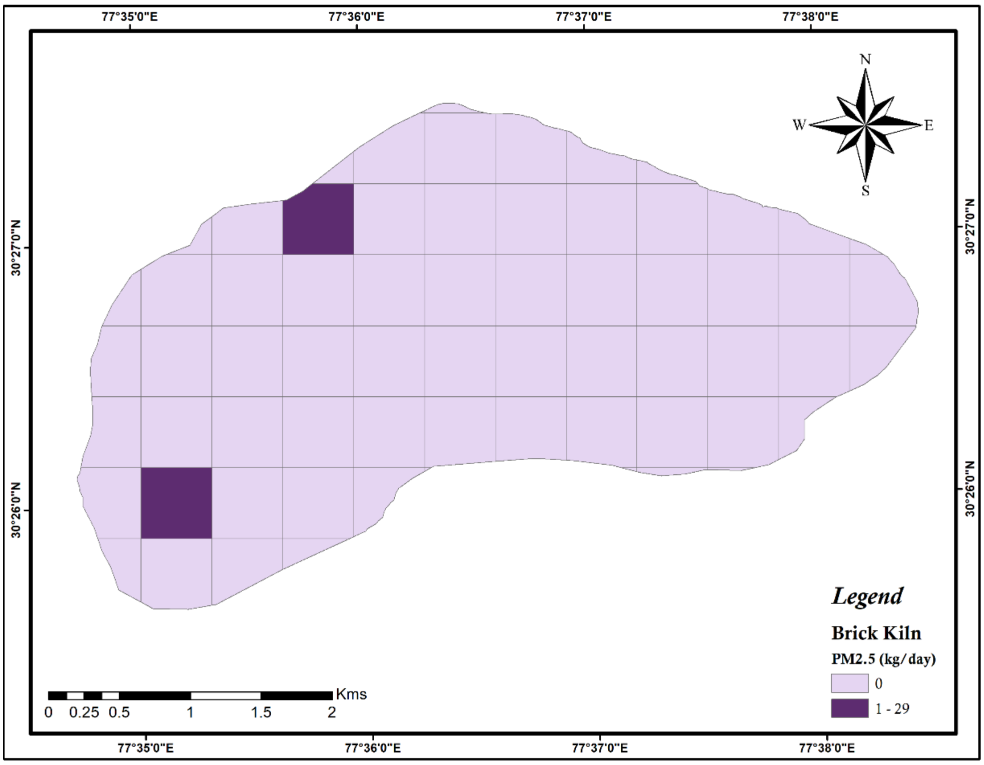


Figure 4.45: Spatial Distribution of $PM_{2.5}$ Emissions from Brick kilns

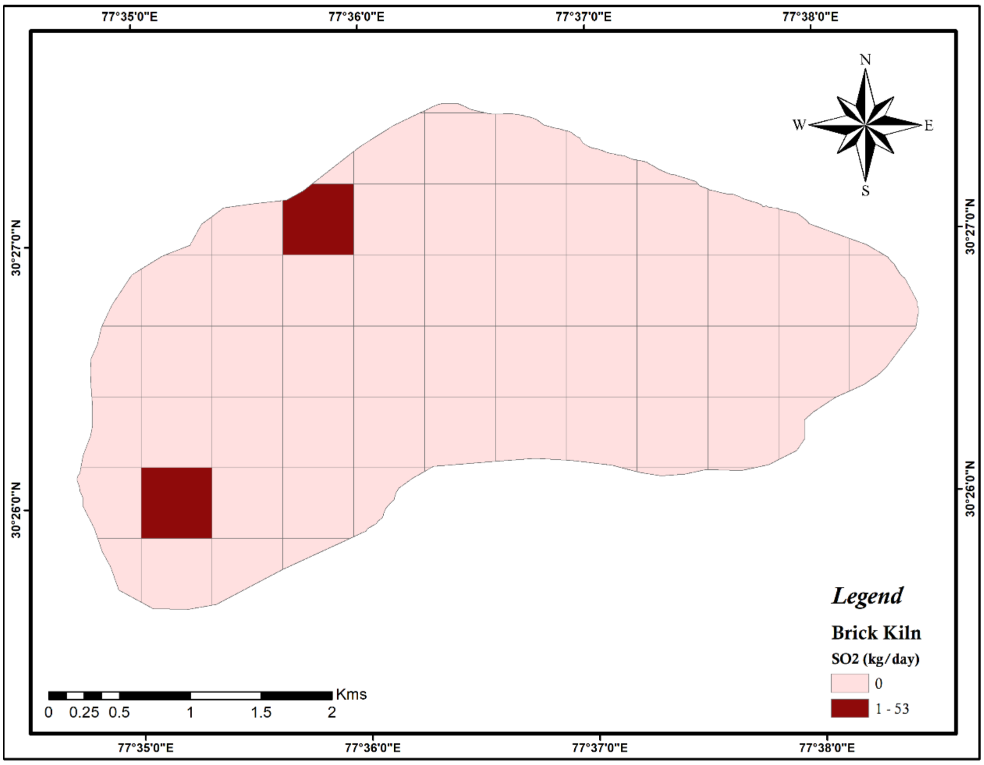


Figure 4.46: Spatial Distribution of SO_2 Emissions from Brick kilns

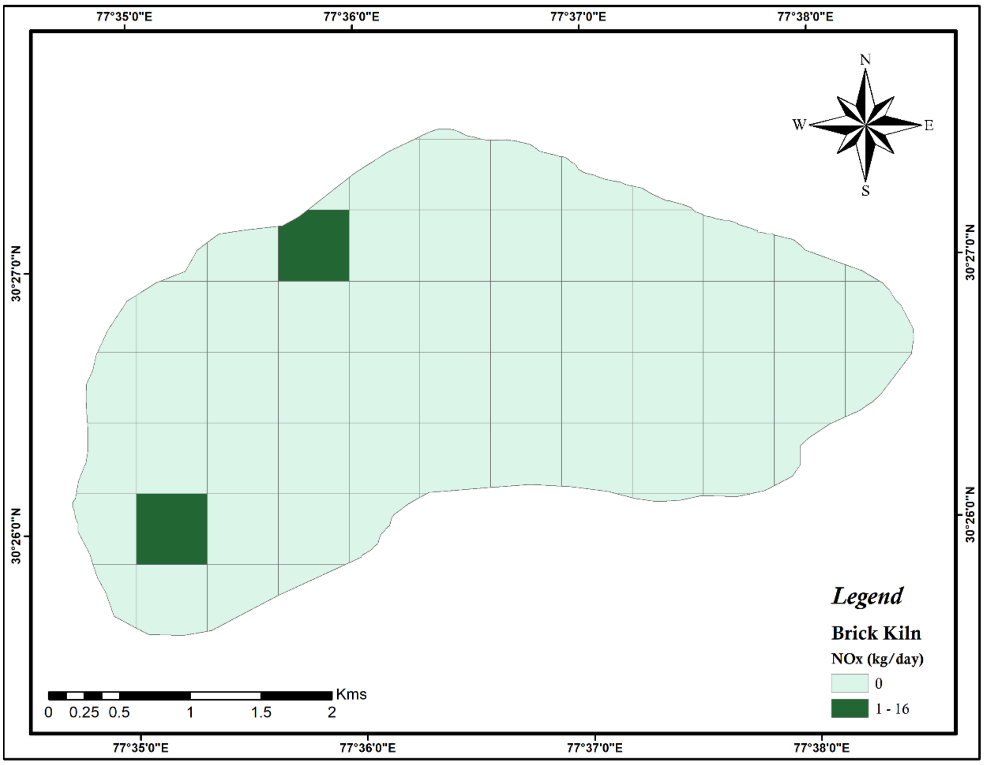


Figure 4.47: Spatial Distribution of NO_X Emissions from Brick kilns

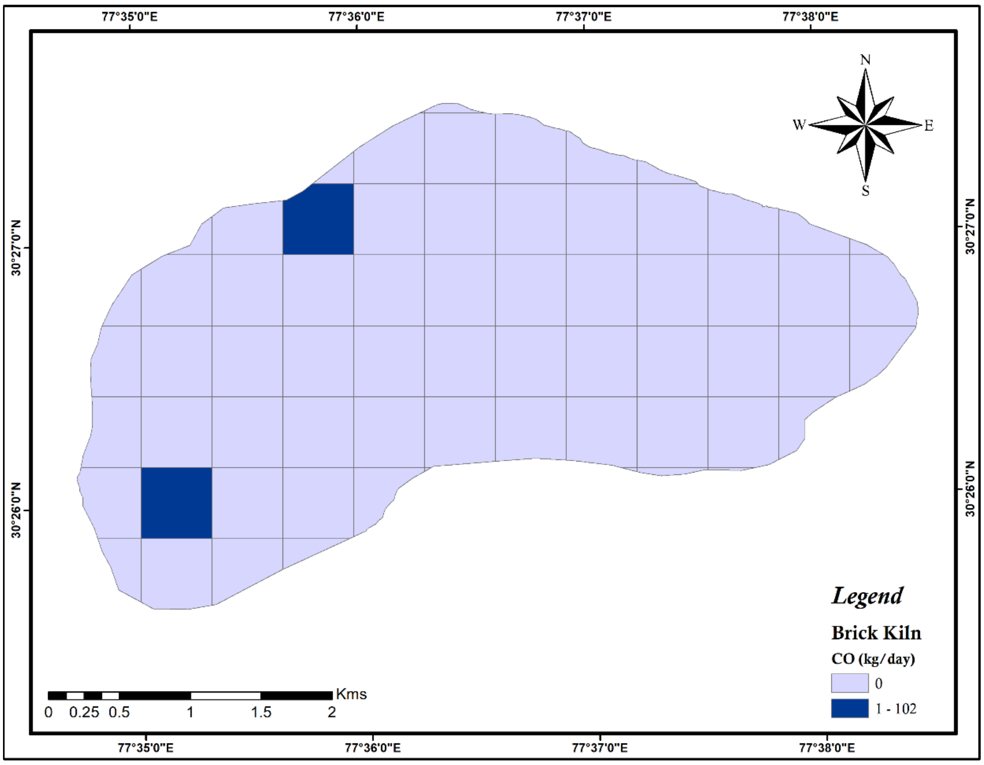


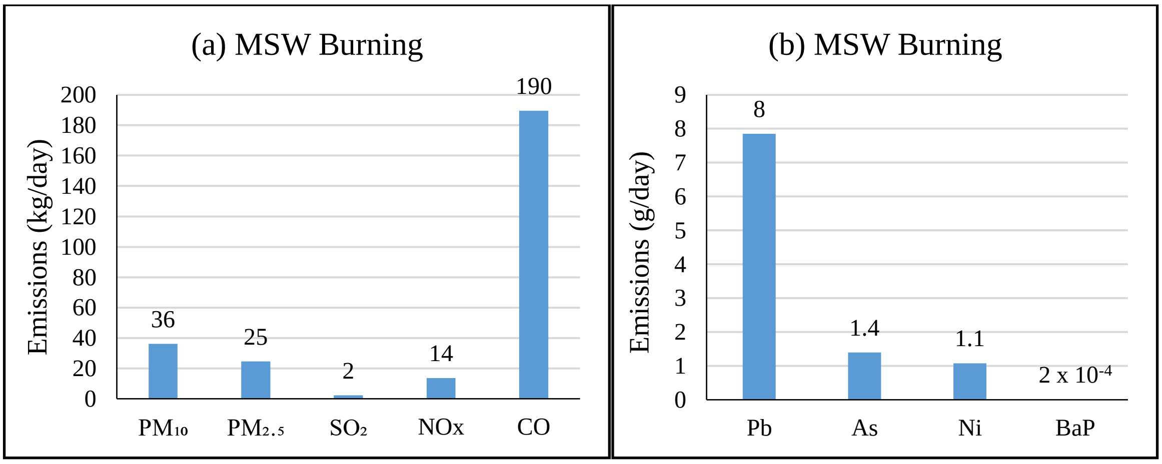
Figure 4.48: Spatial Distribution of CO Emissions from Brick kilns

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 11.28 MT/day and the waste collected is approx. 6.77 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 Paonta Sahib city (Sharma et al., 2018) 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 of Paonta Sahib city is shown in Figure 4.49.

Figure 4.49: MSW Burning in several parts of Paonta Sahib city

The emission factors 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 4.50 (a) & (b) and spatial distribution in Figure 4.51 to Figure 4.55.



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

Figure 4.50: Emission Load from MSW Burning

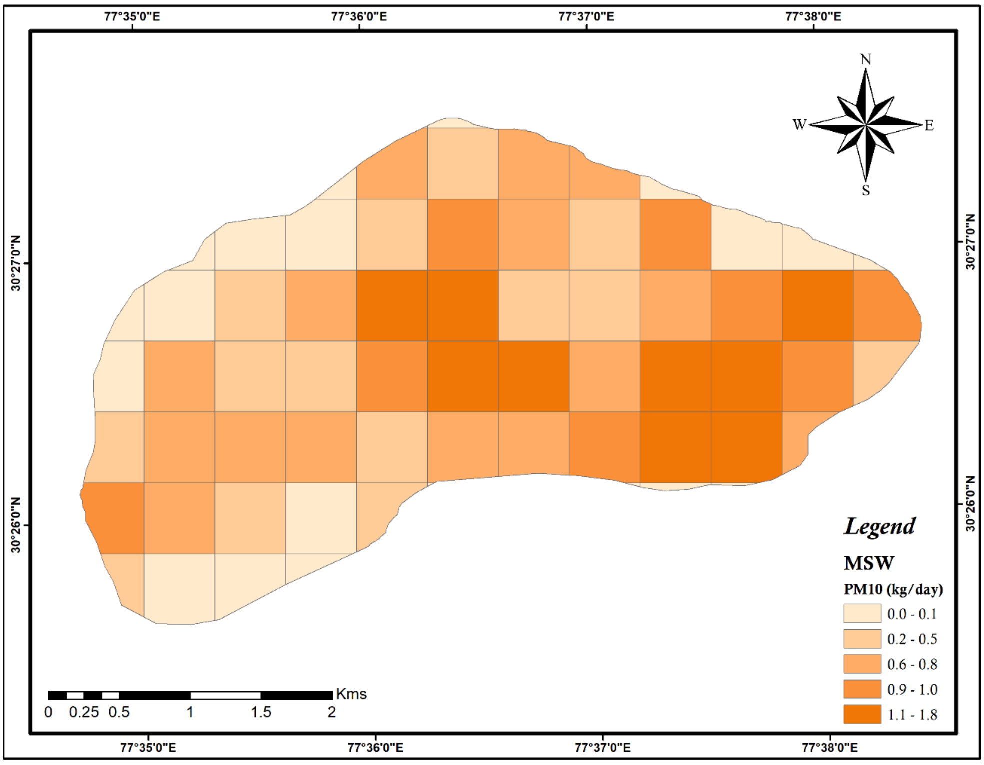


Figure 4.51: Spatial Distribution of PM_{10} Emissions from MSW Burning

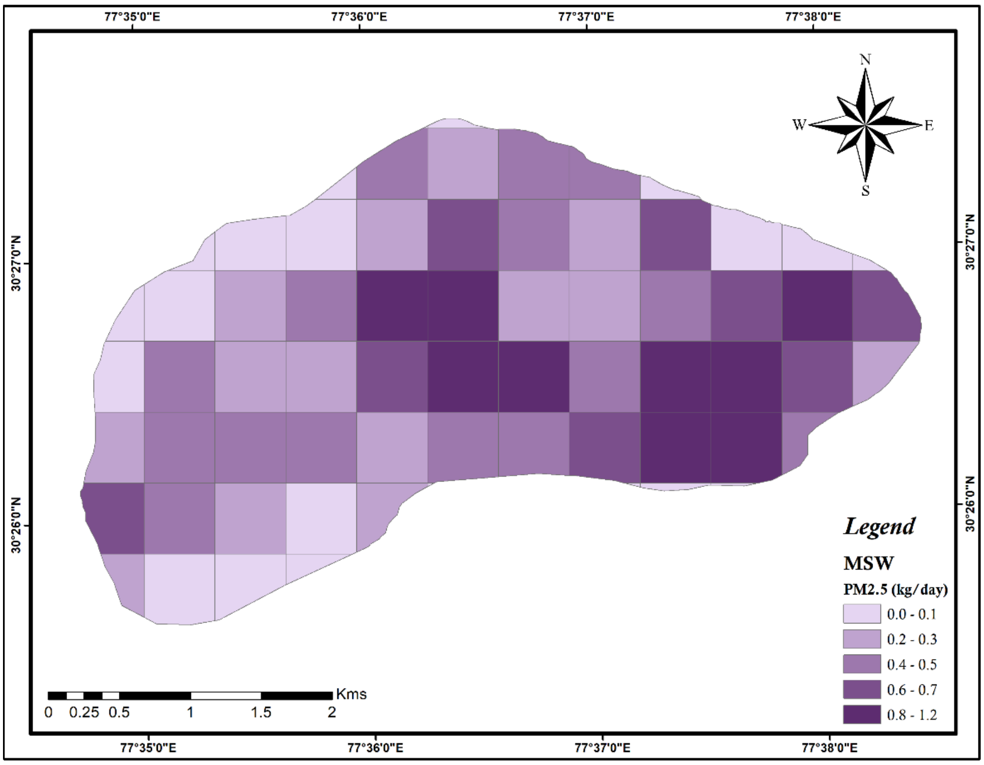


Figure 4.52: Spatial Distribution of $PM_{2.5}$ Emissions from MSW Burning

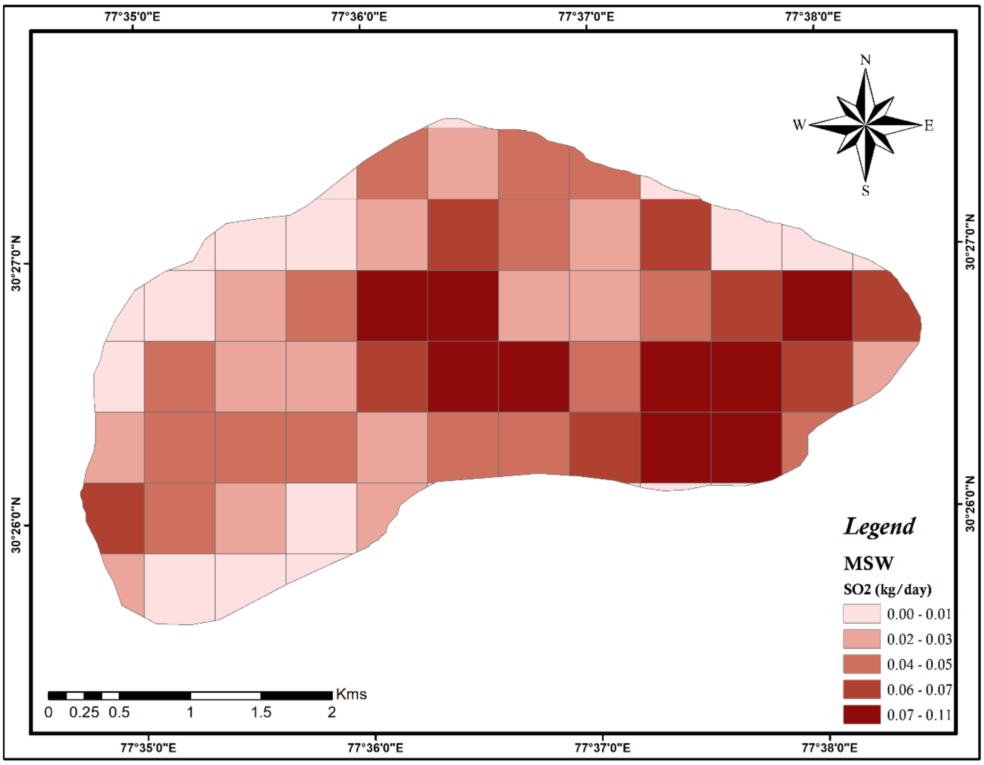


Figure 4.53: Spatial Distribution of SO_2 Emissions from MSW Burning

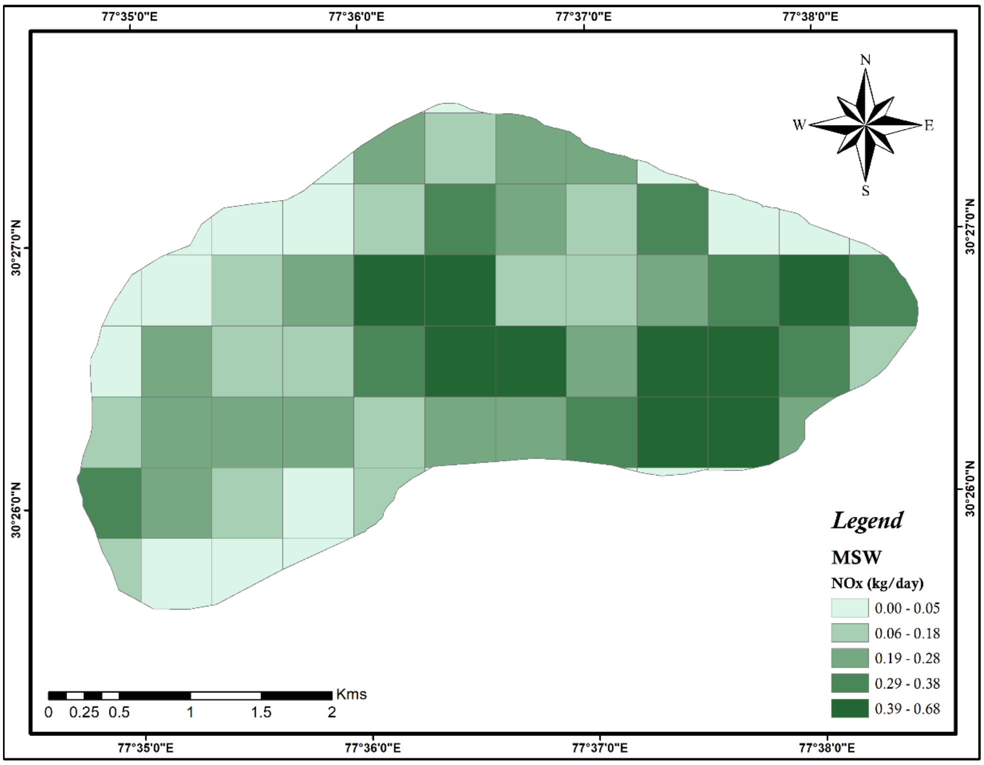


Figure 4.54: Spatial Distribution of NO_X Emissions from MSW Burning

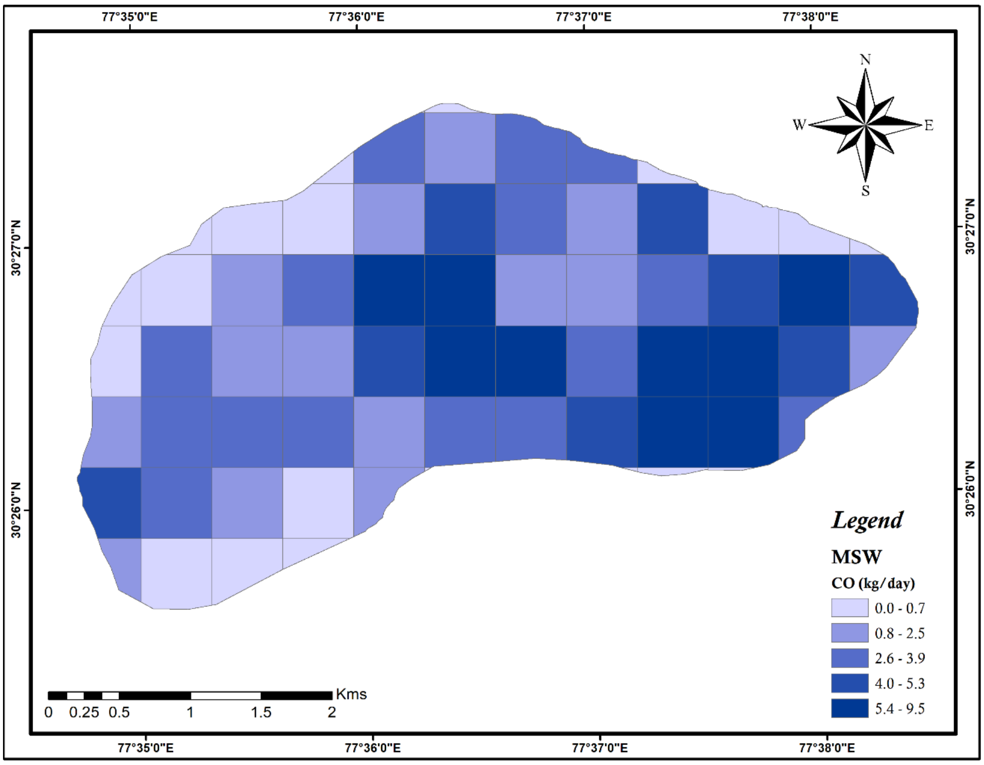


Figure 4.55: Spatial Distribution of CO Emissions from MSW Burning

4.2.11 Hospitals

A detailed survey was undertaken to estimate the emission from hospitals in Paonta Sahib City. There are approximately 35 hospitals present around the city out of which 19 lie within the city boundary, we have considered all 35 hospitals to estimate the emissions. The locations of Hospitals within the Paonta Sahib city boundary are given in Figure 4.56. The emission of pollutants from hospitals is shown in Figure 4.57 (a) & (b). The overall emissions from hospitals along with their average DG set capacity and running hours are presented in Table 4.1.

.

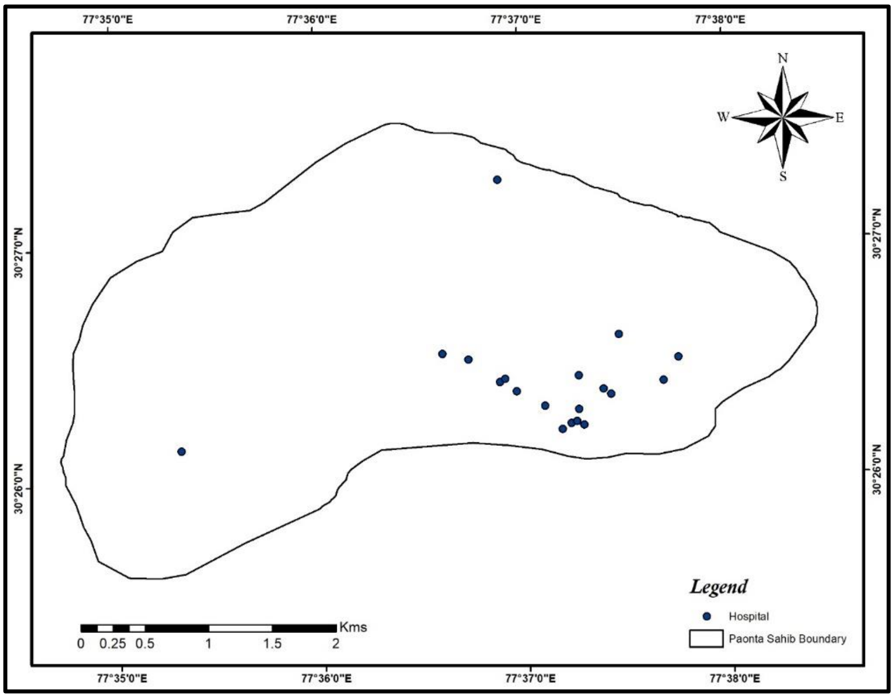
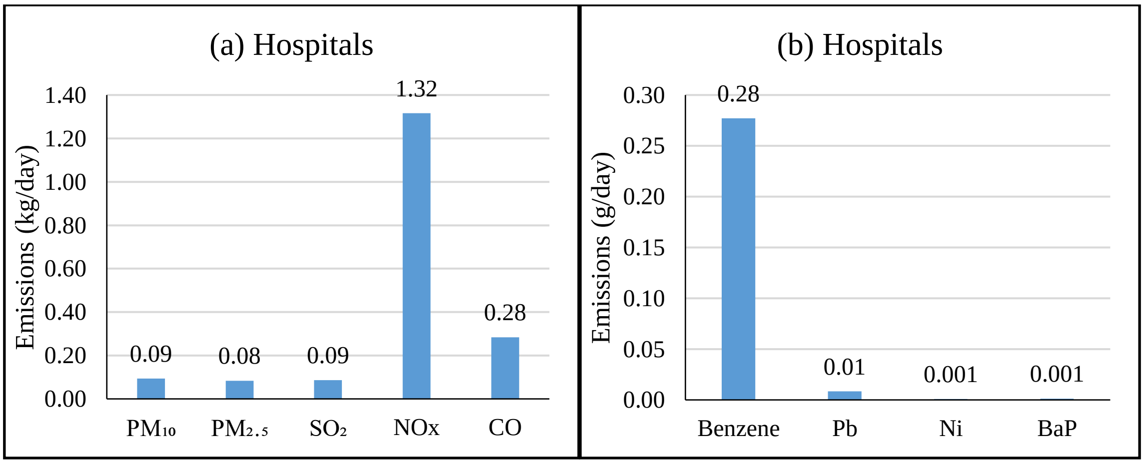


Figure 4.56: Locations of Hospitals in Paonta Sahib City

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

No. of Hospitals	DG set Average Capacity		PM_{10} (kg/d)	$PM_{2.5}$ (kg/d)	SO_2 (kg/d)	NOx (kg/d)	CO (kg/d)	Benzene (g/d)	Pb (g/d)	As (g/d)	Ni (g/d)	BaP (g/d)
	KVA	Running Hour										
35	62.5	2	0.09	0.08	0.09	1.32	0.28	0.28	0.01	0	0.001	0.001
Data Source: Consent Data												



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

Figure 4.57: Emission Load from Hospitals

4.2.12 Industries

There are approximately nine air polluting industrial units around Paonta Sahib City and contribute to particulate as well as gaseous. It may be noted that only two industries are within municipal limits and the rest seven are outside the municipal limits, we have considered all nine industries to estimate the emissions. The overall emissions estimated from the different types of boilers, furnaces, etc. are presented in Table 4.2. The Major industries at Paonta Sahib are Cement, Pharmaceuticals, Food, and Limestones. Major fuels that contribute to emissions are coal, wood, and diesel. The industrial locations are given in Figure 4.58. The information on stacks, fuel, and their consumption was obtained from HPPCB. The AP-42 (USEPA, 2000) emission factors were used to calculate the emission. The emission of pollutants from industries is shown in Figure 4.59 (a) & (b). The Spatial distribution of emissions from the industries lying within the boundary is given in Figure 4.60 to Figure 4.64.

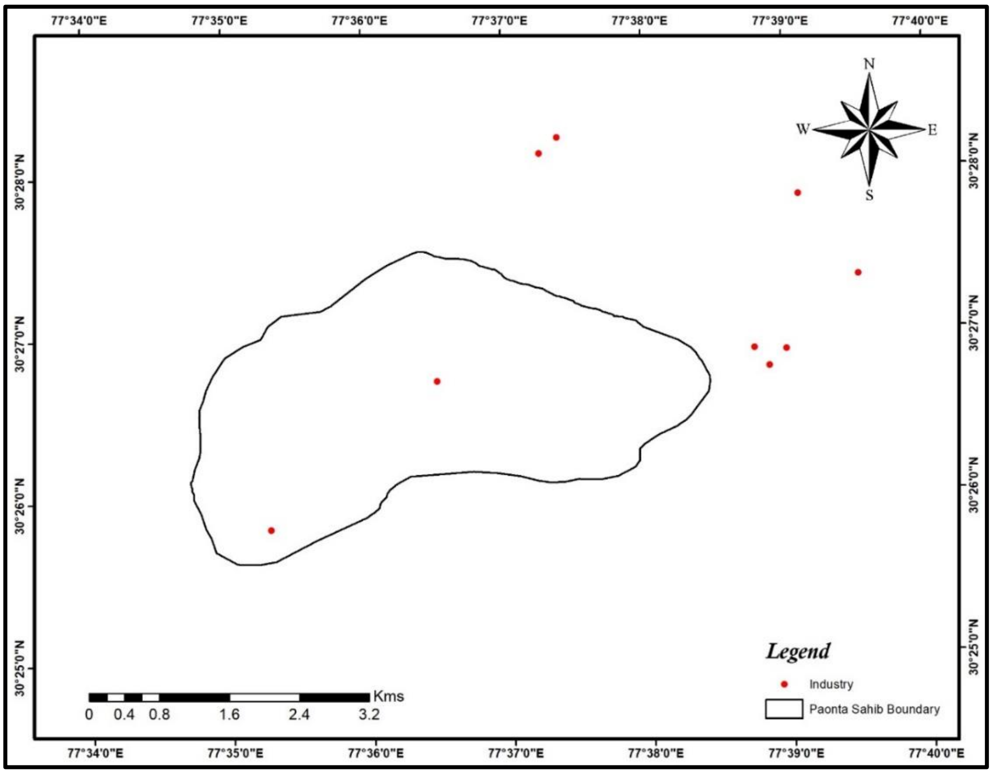
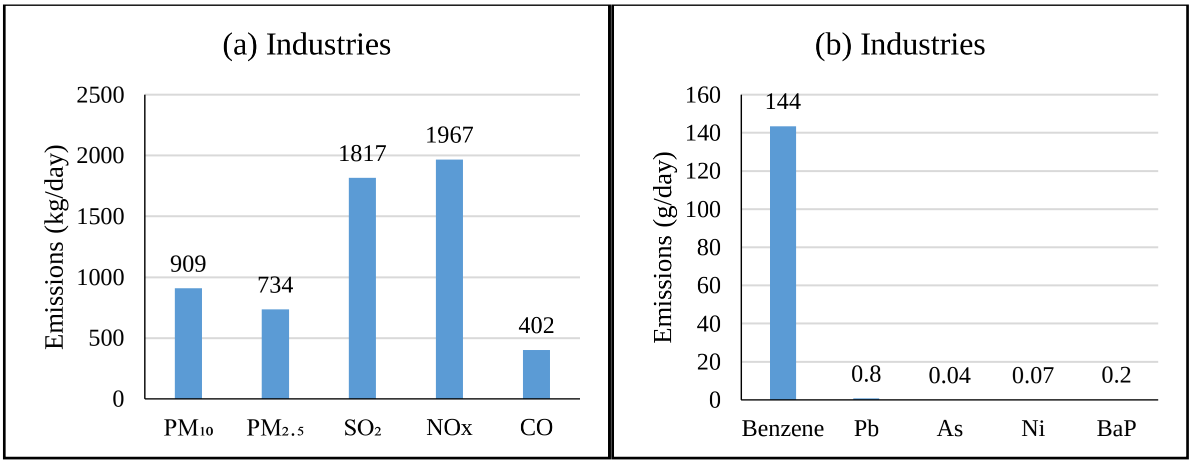


Figure 4.58: Location of Industries in Paonta Sahib city

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

Boiler/ Furnace Type	Fuel	No of Furnaces / Boilers	PM_{10} (kg/d)	$PM_{2.5}$ (kg/d)	SO_2 (kg/d)	NOx (kg/d)	CO (kg/d)	Benzene (g/d)	Pb (g/d)	As (g/d)	Ni (g/d)	BaP (g/d)
Boiler	Wood, Bio Briquette	5	72	64	249	152	361	36	0.8	0.04	0.07	0.2
Raw, Cement, Coal Mill, Kiln	Coal	1	837	670	1568	1815	41	107	0	0	0	0
Total*		**6**	**909**	**734**	**1817**	**1967**	**402**	**144**	**0.8**	**0.04**	**0.07**	**0.02**

Data Source: Consent Data
*(out of nine industries, three industries have submerged arc furnaces for their operation. The submerged arc furnaces use electricity (consent data). Hence it has not been included in the above table)



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

Figure 4.59: Emission Load from Industries

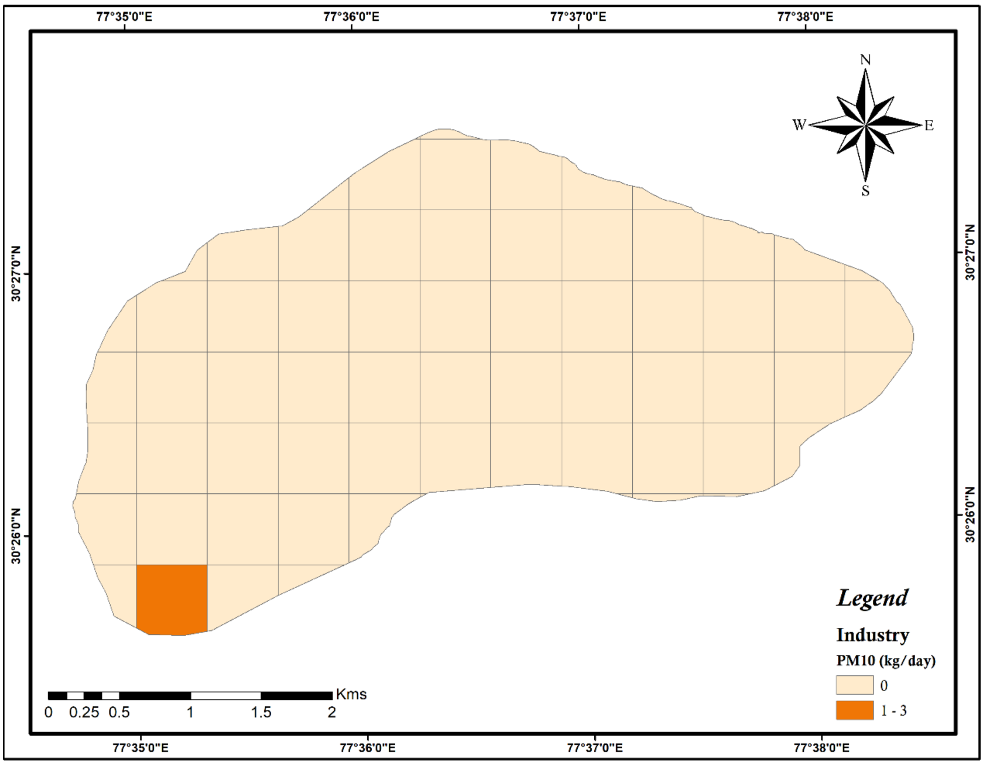


Figure 4.60: Spatial Distribution of PM_{10} Emissions from Industries

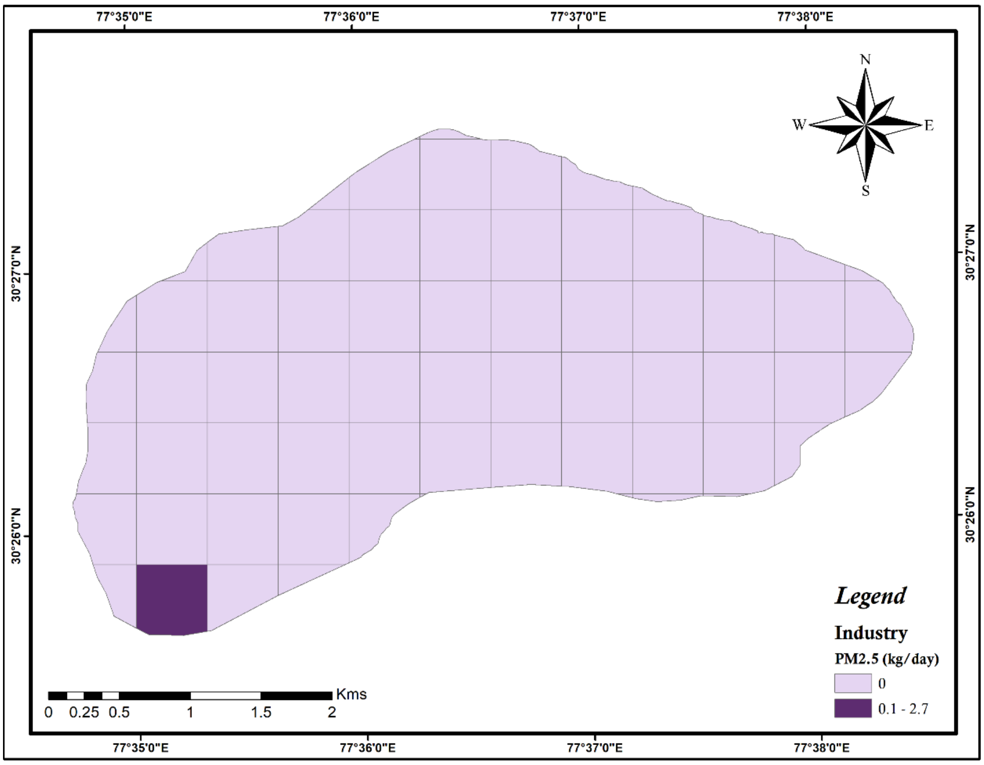


Figure 4.61: Spatial Distribution of $PM_{2.5}$ Emissions from Industries

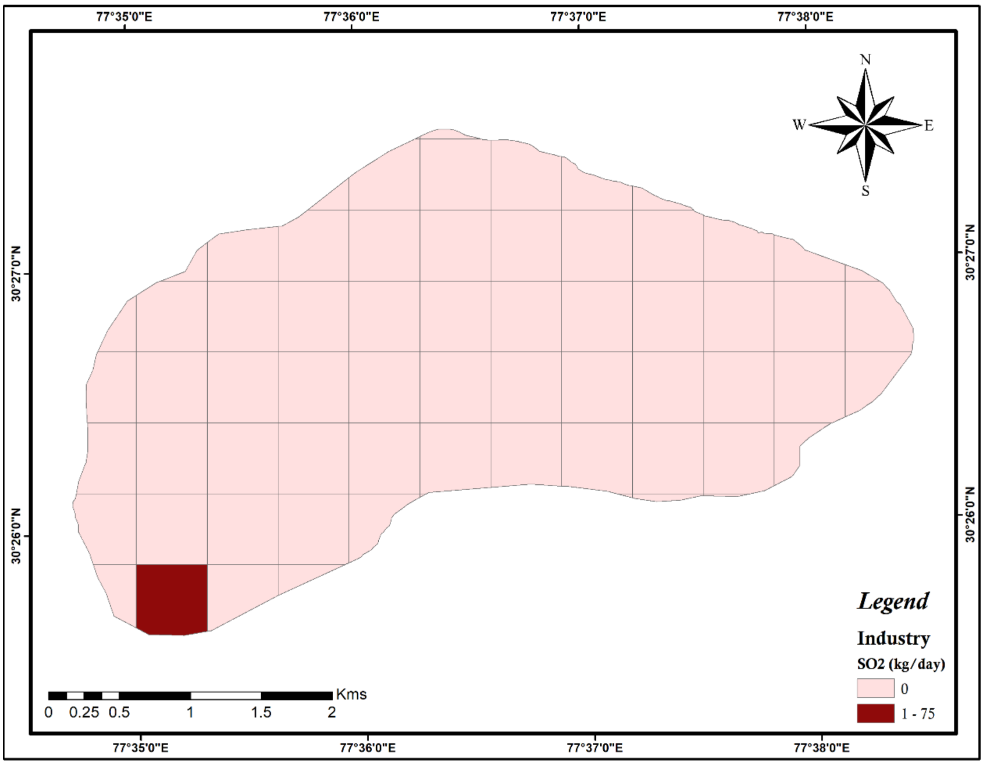


Figure 4.62: Spatial Distribution of SO_2 Emissions from Industries

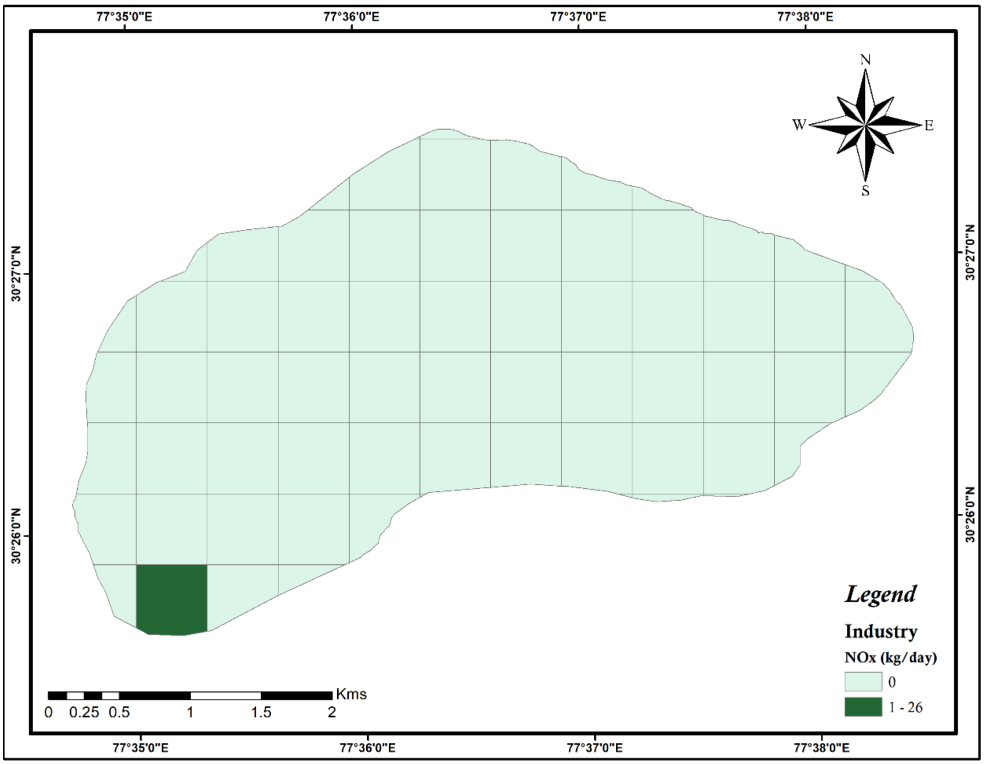


Figure 4.63: Spatial Distribution of NO_x Emissions from Industries

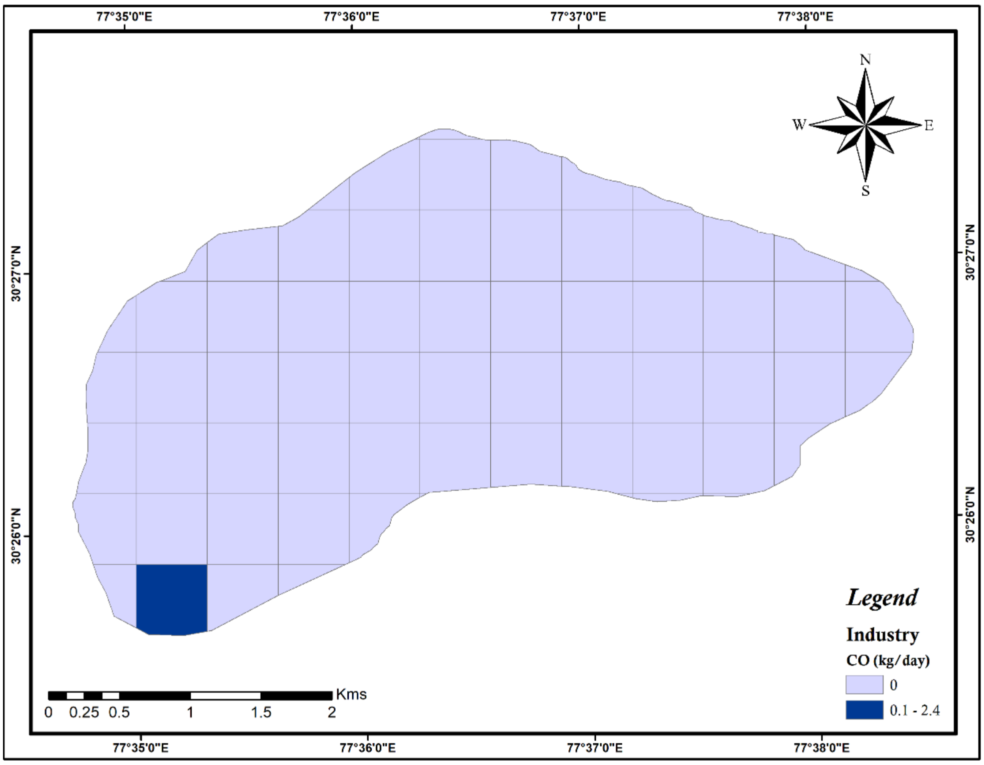


Figure 4.64: Spatial Distribution of CO Emissions from Industries

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 in the city of Paonta Sahib. ARAI (2011) and CPCB (2011) emission factors were used to calculate the emissions. Figure 4.65 and Figure 4.66 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.

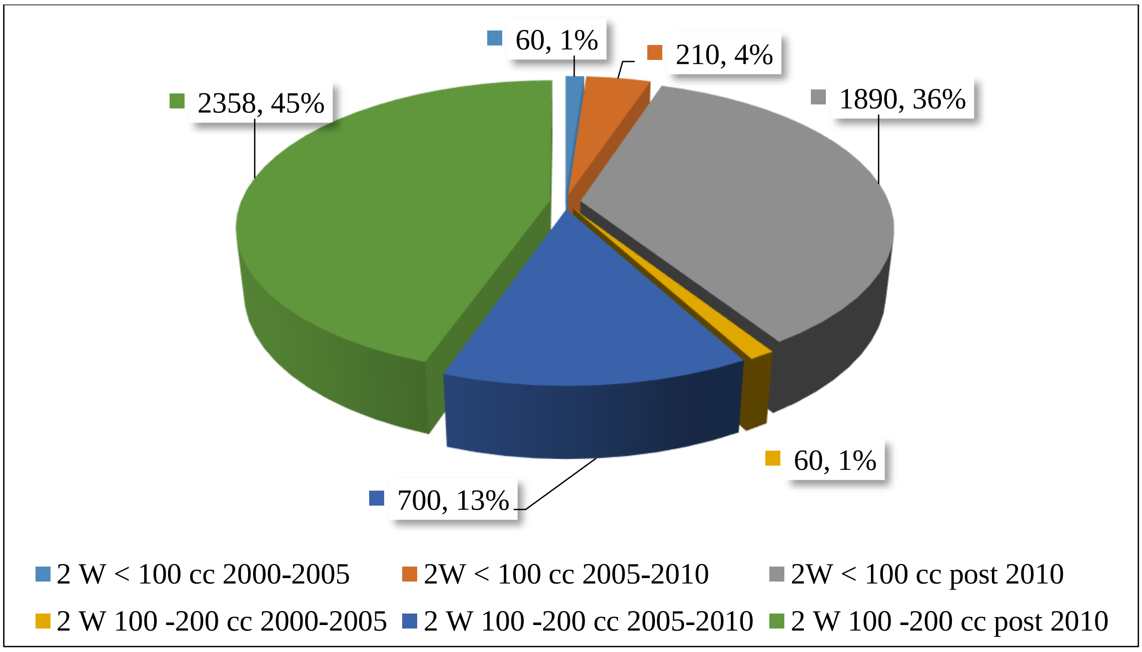


Figure 4.65: Distribution of 2-Ws in the study area (parking lot survey)

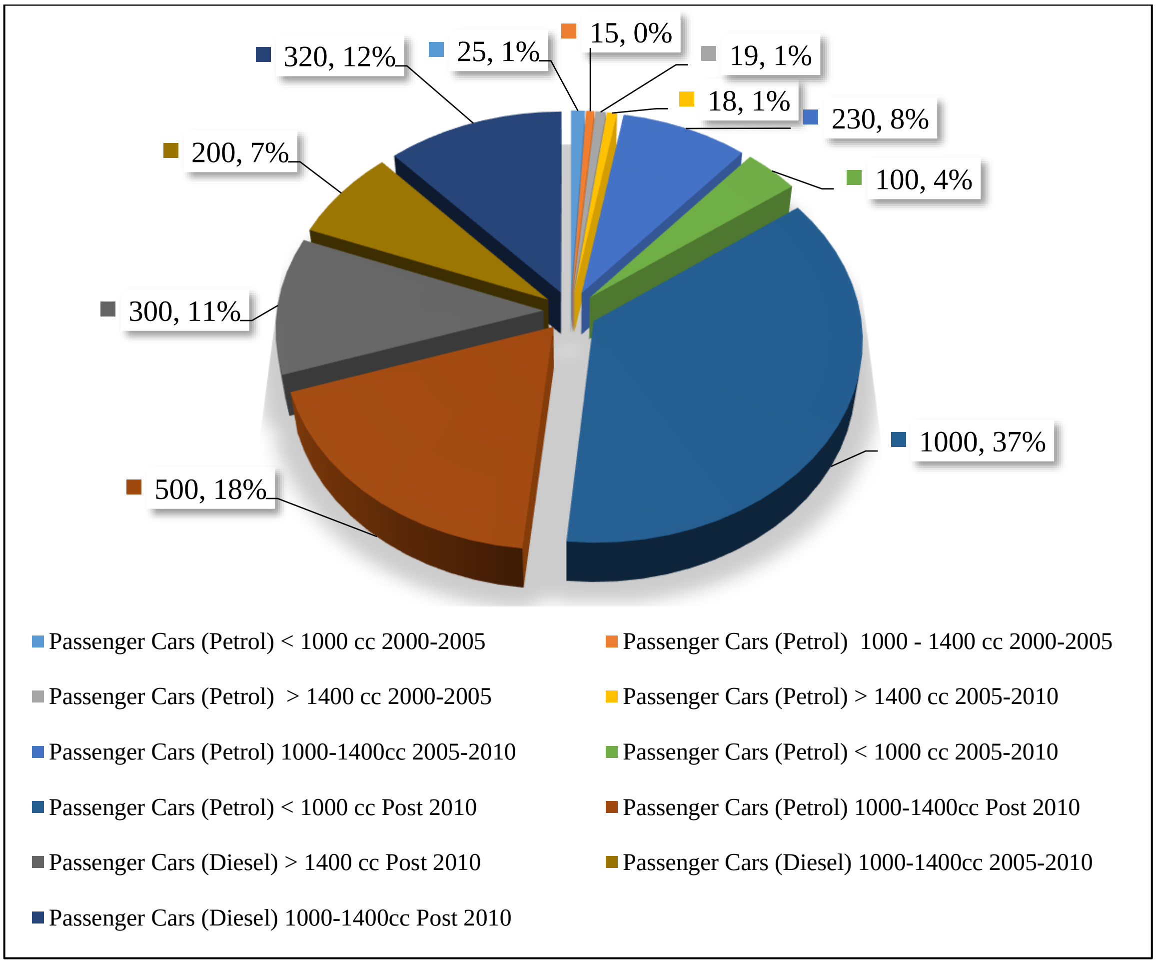


Figure 4.66: Distribution of 4-Ws in the study area (parking lot survey)

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 4.67). 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.

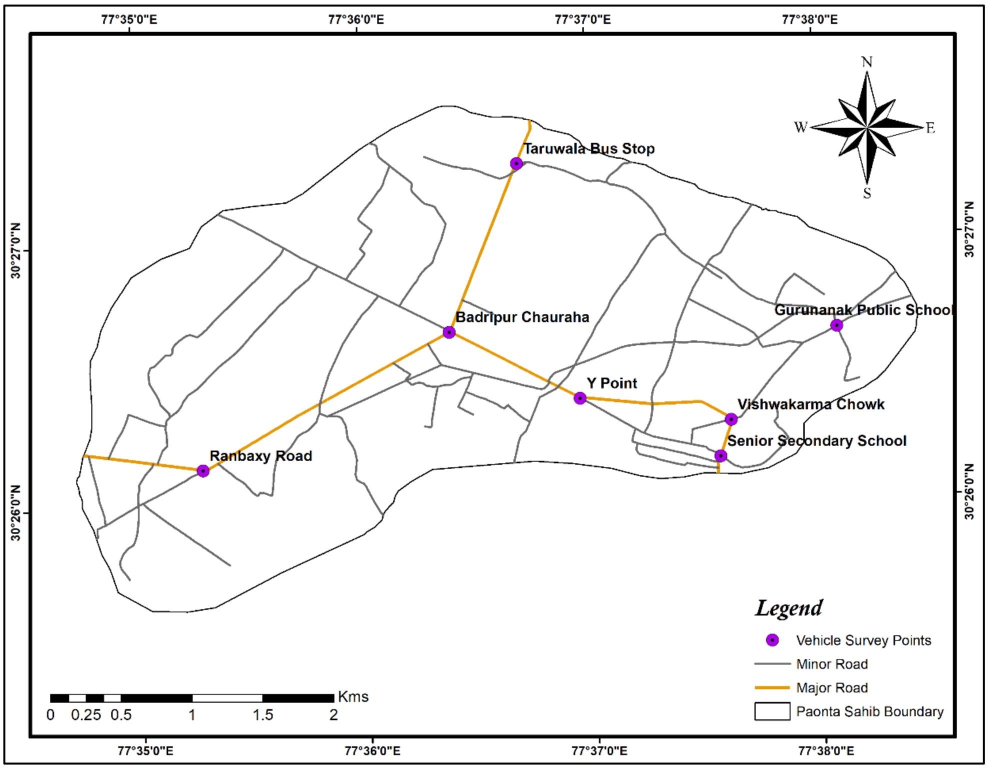
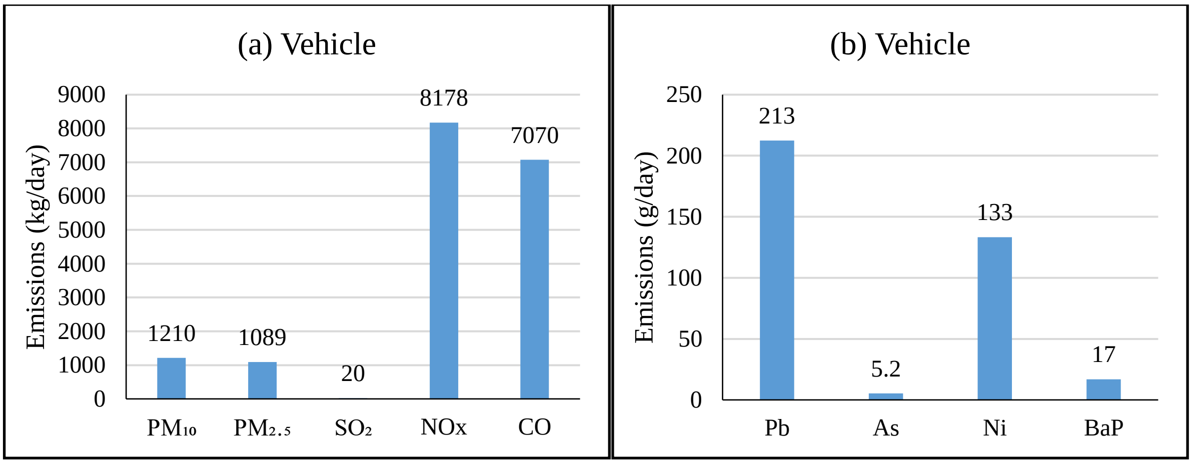


Figure 4.67: Traffic location considered for vehicle emission in the city of Paonta Sahib

The emission from vehicles is shown in Figure 4.68 (a) & (b). The emission contribution of each vehicle type in the city of Paonta Sahib city is presented in Figure 4.69 to Figure 4.73. The spatial distribution of emissions from vehicles is presented in Figure 4.74 to Figure 4.78.



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

Figure 4.68: Emission Load from Vehicles

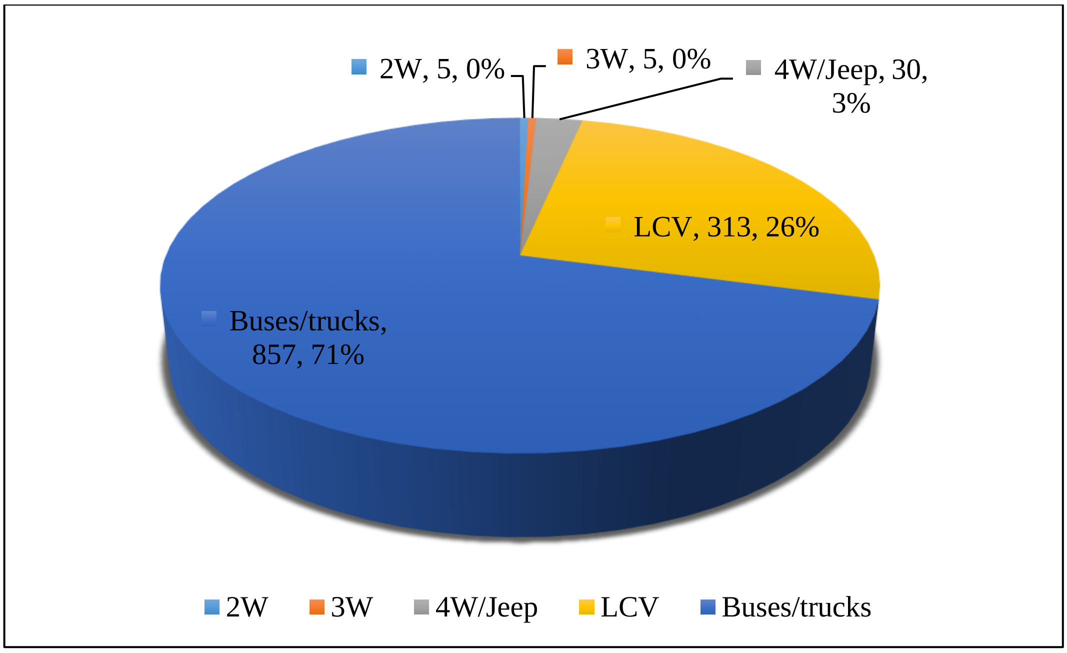


Figure 4.69: PM_{10} Emission Load contribution of each vehicle type (kg/day)

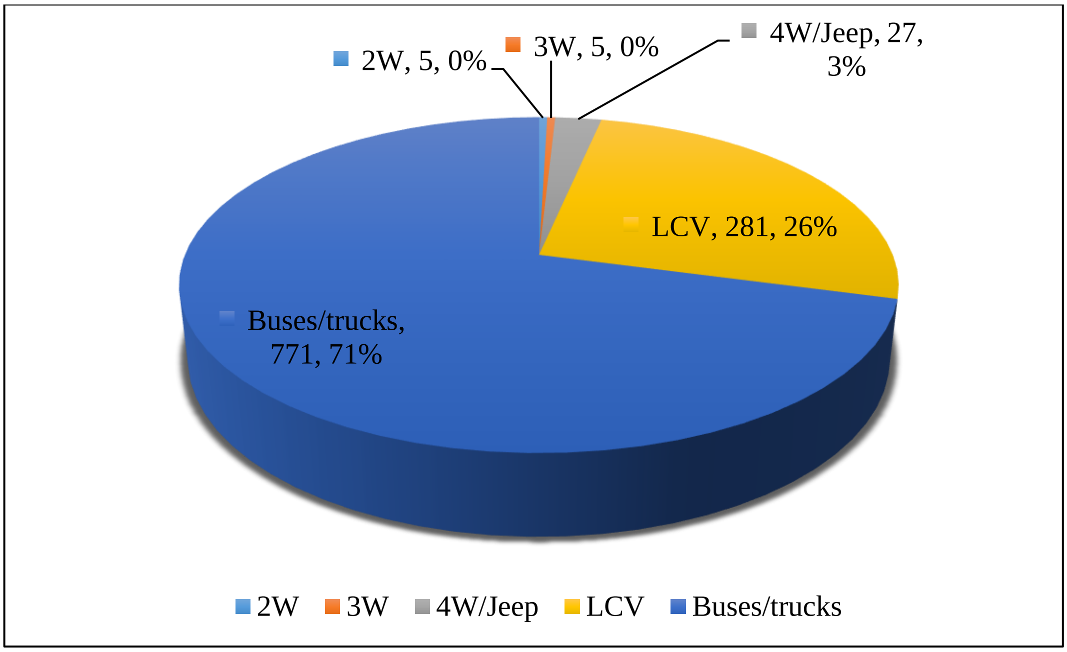


Figure 4.70: $PM_{2.5}$ Emission Load contribution of each vehicle type (kg/day)

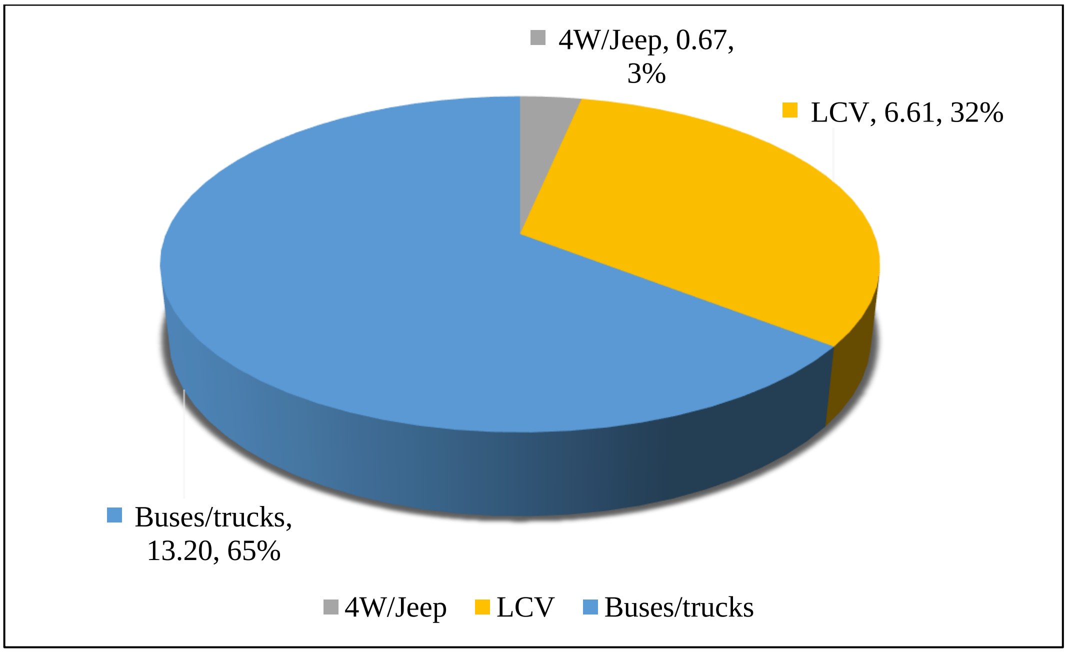


Figure 4.71: SO_2 Emission Load contribution of each vehicle type (kg/day)

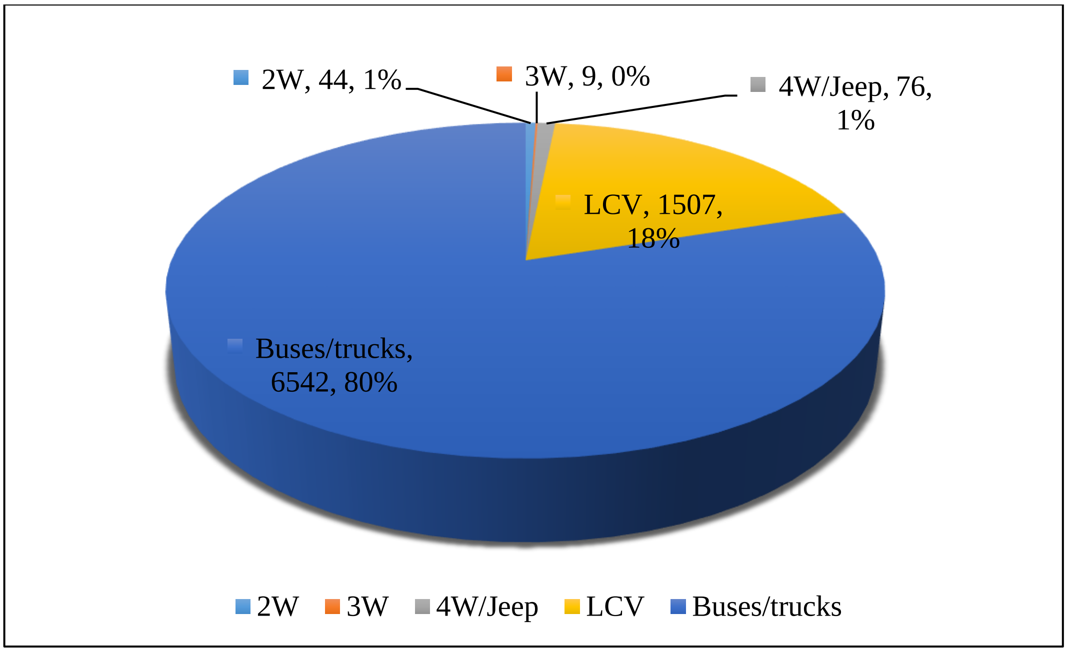


Figure 4.72: NO_x Emission Load contribution of each vehicle type (kg/day)

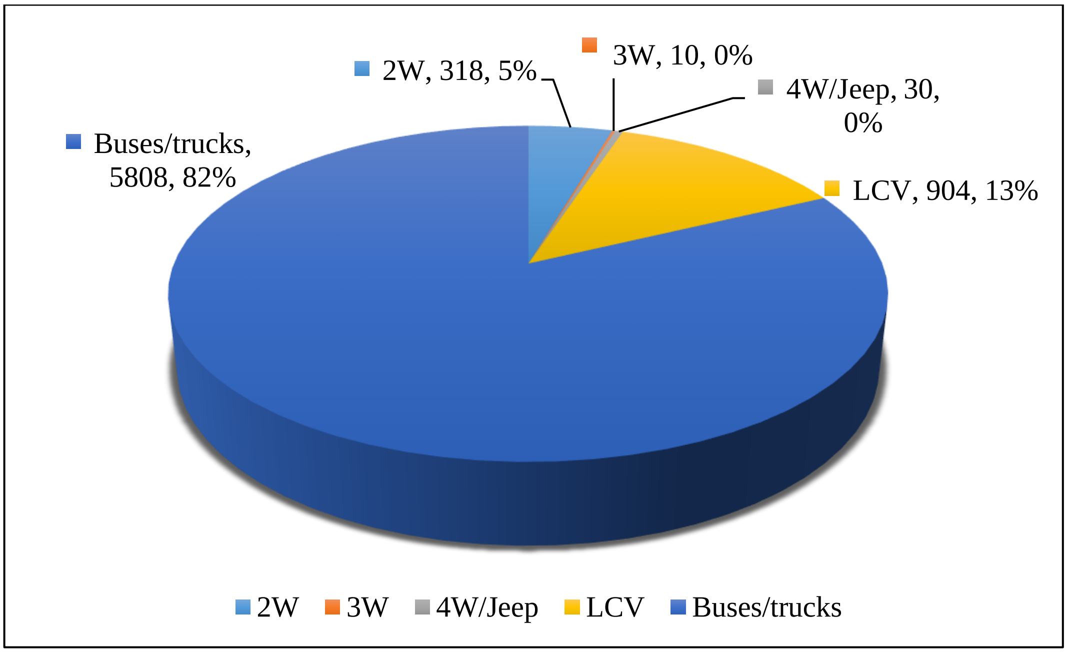


Figure 4.73: CO Emission Load contribution of each vehicle type (kg/day)

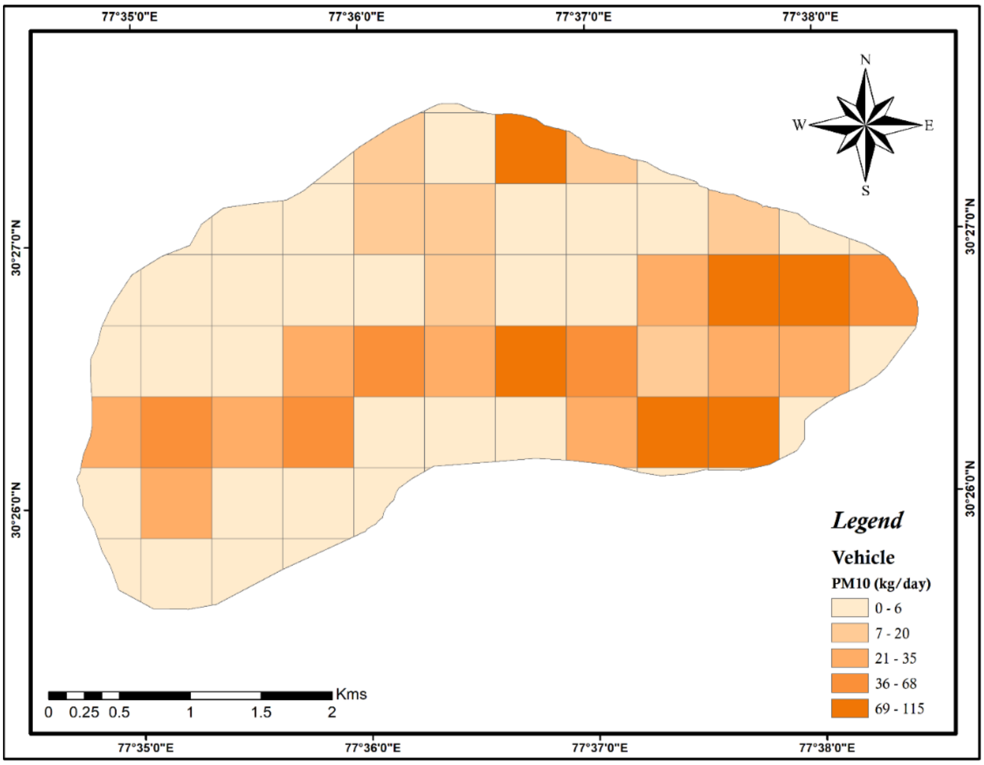


Figure 4.74: Spatial Distribution of PM_{10} Emissions from Vehicles

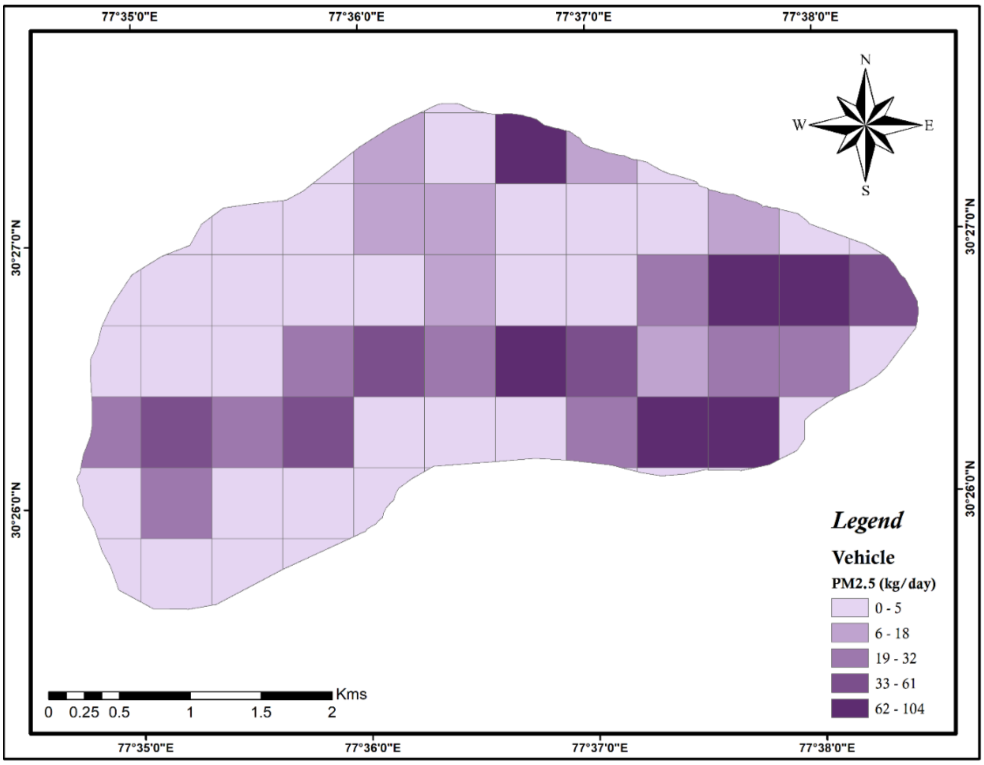


Figure 4.75: Spatial Distribution of $PM_{2.5}$ Emissions from Vehicles

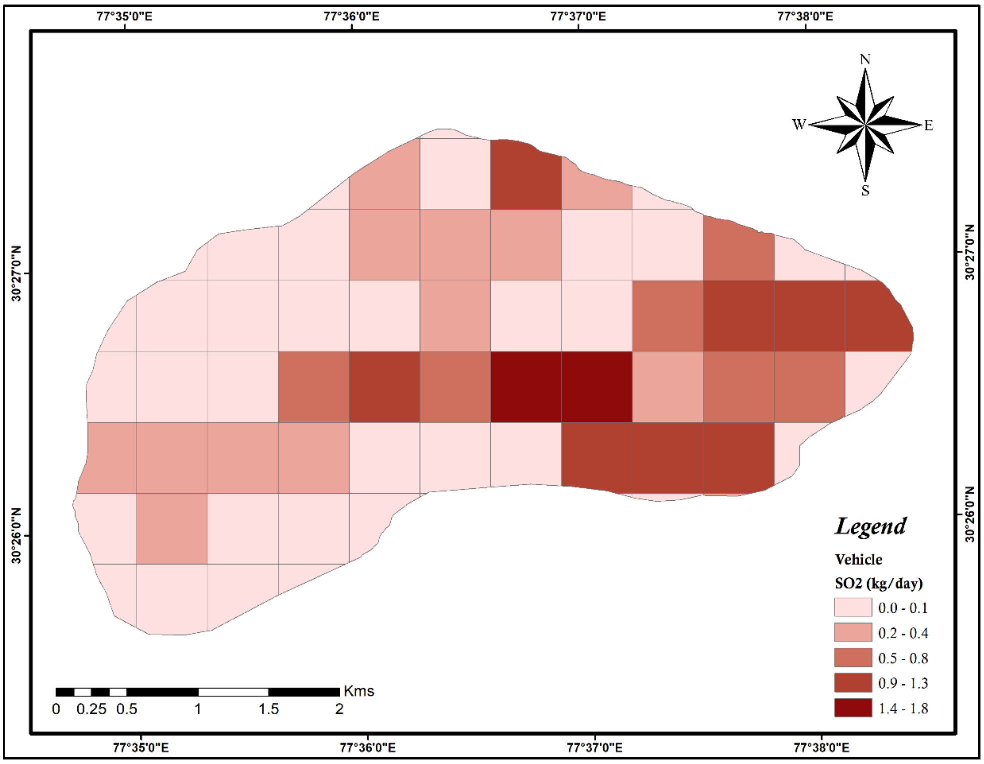


Figure 4.76: Spatial Distribution of SO_2 Emissions from Vehicles

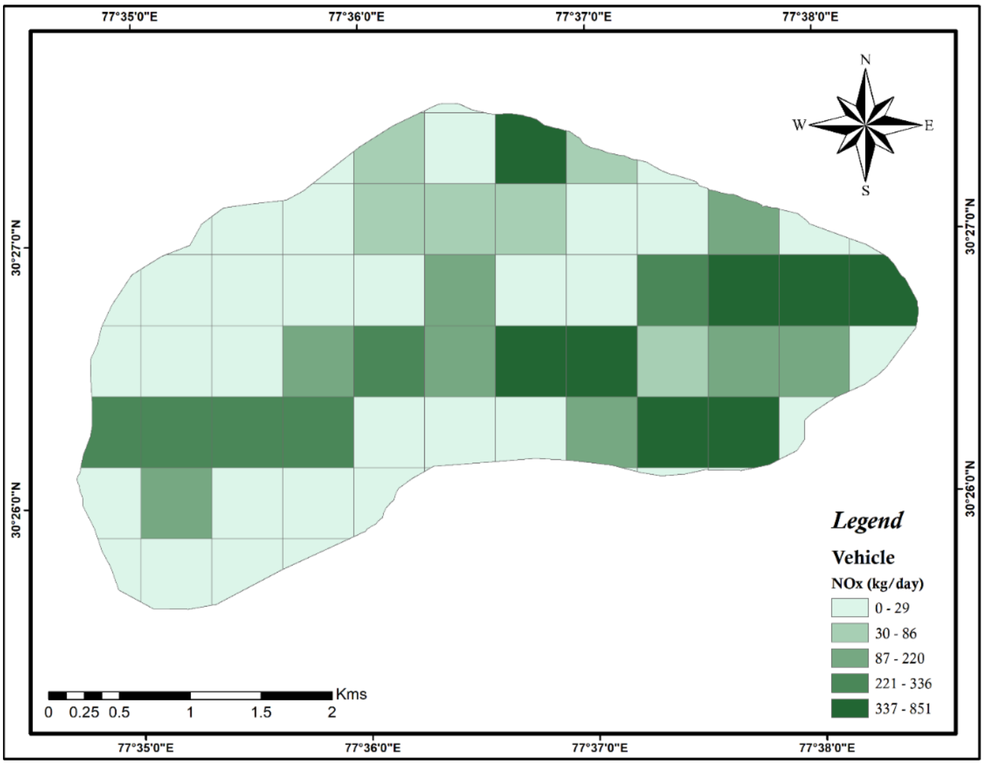


Figure 4.77: Spatial Distribution of NOx Emissions from Vehicles

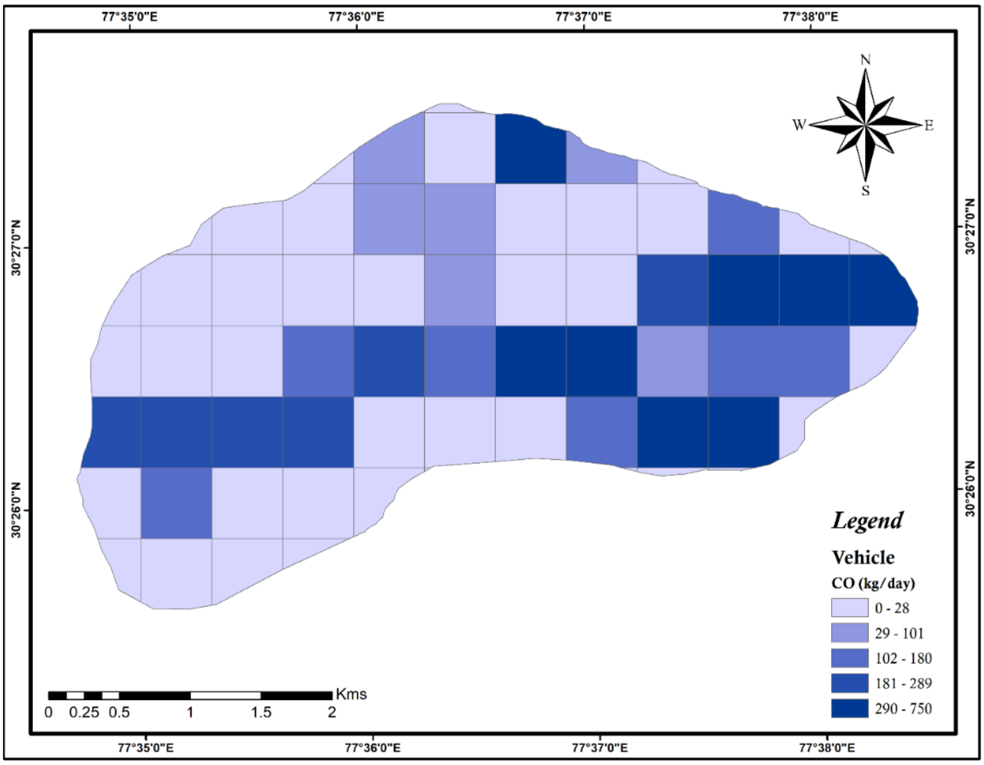


Figure 4.78: Spatial Distribution of CO Emissions from Vehicles

4.2.15 **Traffic Congestion**

The typical Traffic conditions at different locations for Paonta Sahib are given in Figure 4.79. Consequently, the major Traffic bottlenecks are mentioned in Table 4.3. The figure depicts the traffic report of Paonta Sahib for 5 traffic hotspots of the city for the 7 days of the week. The colour coding used here is Red, Orange, and Green indicating the slow traffic to fast traffic movement respectively. Ambala-Dehradun Road and main market road have been seeing a moderate amount of traffic throughout 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 Paonta Sahib

Kishanpura-Jamniwala Road	Main Market Road
Badripur Chowk	Vishwakarma Chowk
Bangran Chowk	

S.No.	Day	Kishanpura-Jamniwala Road	Badripur Chowk	Bangran Chowk	Main Market Road	Vishwakarma Chowk
1	Sunday	8am-10am	8am-10am	8am-10am	8am-10am	8am-10am
		10am-12pm	10am-12pm	10am-12pm	10am-12pm	10am-12pm
		12pm-2pm	12pm-2pm	12pm-2pm	12pm-2pm	12pm-2pm
		2pm-4pm	2pm-4pm	2pm-4pm	2pm-4pm	2pm-4pm
		4pm-6pm	4pm-6pm	4pm-6pm	4pm-6pm	4pm-6pm
		6pm-8pm	6pm-8pm	6pm-8pm	6pm-8pm	6pm-8pm
2	Monday	8am-10am	8am-10am	8am-10am	8am-10am	8am-10am
		10am-12pm	10am-12pm	10am-12pm	10am-12pm	10am-12pm
		12pm-2pm	12pm-2pm	12pm-2pm	12pm-2pm	12pm-2pm
		2pm-4pm	2pm-4pm	2pm-4pm	2pm-4pm	2pm-4pm
		4pm-6pm	4pm-6pm	4pm-6pm	4pm-6pm	4pm-6pm
		6pm-8pm	6pm-8pm	6pm-8pm	6pm-8pm	6pm-8pm
3	Tuesday	8am-10am	8am-10am	8am-10am	8am-10am	8am-10am
		10am-12pm	10am-12pm	10am-12pm	10am-12pm	10am-12pm
		12pm-2pm	12pm-2pm	12pm-2pm	12pm-2pm	12pm-2pm
		2pm-4pm	2pm-4pm	2pm-4pm	2pm-4pm	2pm-4pm
		4pm-6pm	4pm-6pm	4pm-6pm	4pm-6pm	4pm-6pm
		6pm-8pm	6pm-8pm	6pm-8pm	6pm-8pm	6pm-8pm
4	Wednesday	8am-10am	8am-10am	8am-10am	8am-10am	8am-10am
		10am-12pm	10am-12pm	10am-12pm	10am-12pm	10am-12pm
		12pm-2pm	12pm-2pm	12pm-2pm	12pm-2pm	12pm-2pm
		2pm-4pm	2pm-4pm	2pm-4pm	2pm-4pm	2pm-4pm
		4pm-6pm	4pm-6pm	4pm-6pm	4pm-6pm	4pm-6pm
		6pm-8pm	6pm-8pm	6pm-8pm	6pm-8pm	6pm-8pm
5	Thursday	8am-10am	8am-10am	8am-10am	8am-10am	8am-10am
		10am-12pm	10am-12pm	10am-12pm	10am-12pm	10am-12pm
		12pm-2pm	12pm-2pm	12pm-2pm	12pm-2pm	12pm-2pm
		2pm-4pm	2pm-4pm	2pm-4pm	2pm-4pm	2pm-4pm
		4pm-6pm	4pm-6pm	4pm-6pm	4pm-6pm	4pm-6pm
		6pm-8pm	6pm-8pm	6pm-8pm	6pm-8pm	6pm-8pm
6	Friday	8am-10am	8am-10am	8am-10am	8am-10am	8am-10am
		10am-12pm	10am-12pm	10am-12pm	10am-12pm	10am-12pm
		12pm-2pm	12pm-2pm	12pm-2pm	12pm-2pm	12pm-2pm
		2pm-4pm	2pm-4pm	2pm-4pm	2pm-4pm	2pm-4pm
		4pm-6pm	4pm-6pm	4pm-6pm	4pm-6pm	4pm-6pm
		6pm-8pm	6pm-8pm	6pm-8pm	6pm-8pm	6pm-8pm
7	Saturday	8am-10am	8am-10am	8am-10am	8am-10am	8am-10am
		10am-12pm	10am-12pm	10am-12pm	10am-12pm	10am-12pm
		12pm-2pm	12pm-2pm	12pm-2pm	12pm-2pm	12pm-2pm
		2pm-4pm	2pm-4pm	2pm-4pm	2pm-4pm	2pm-4pm
		4pm-6pm	4pm-6pm	4pm-6pm	4pm-6pm	4pm-6pm
		6pm-8pm	6pm-8pm	6pm-8pm	6pm-8pm	6pm-8pm

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

Figure 4.79: Typical Traffic conditions at different locations in Paonta Sahib

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:

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

Where

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

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

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,

N = number of days in the averaging period.

k: constant (a function of particle size) in g VKT^{-1} (Vehicle Kilometer Travel); PM_{10} = 0.62 g/VKT, $PM_{2.5}$ = 0.15 g/VKT.

The road dust sampling locations are given in Figure 4.80. 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 (4.4). 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 by using Eq (4.4). The emission load from road dust in Paonta Sahib is given in Figure 4.81 (a) & (b). The Spatial distribution of Emissions from Road Dust Re-suspension is presented in Figure 4.82 & Figure 4.83.

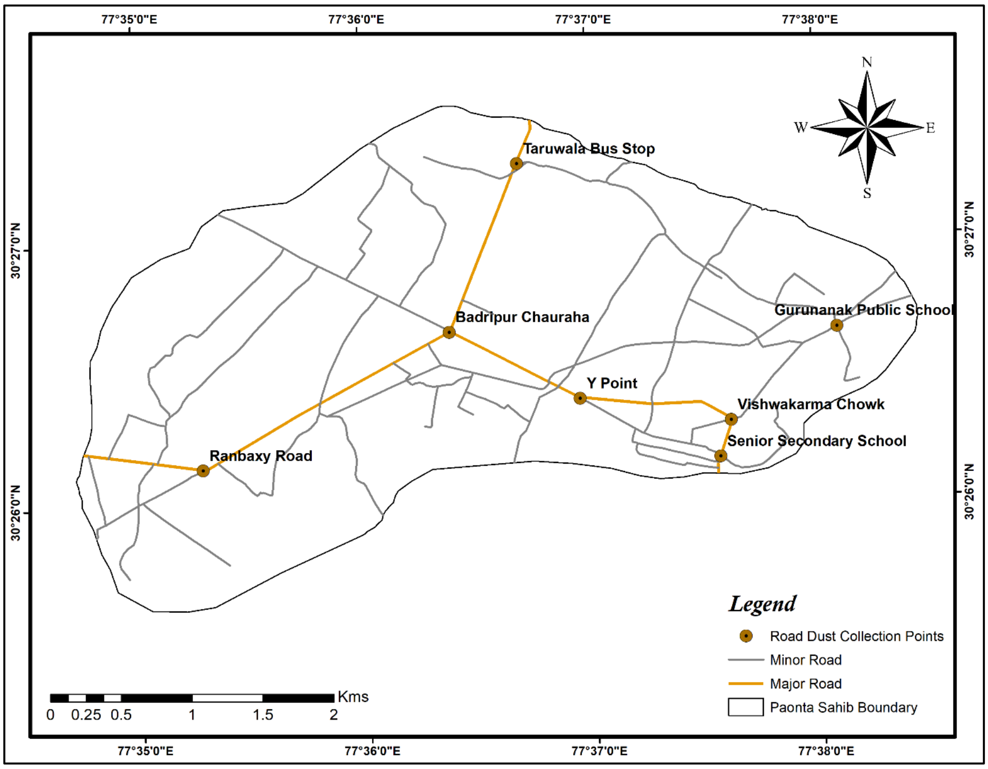
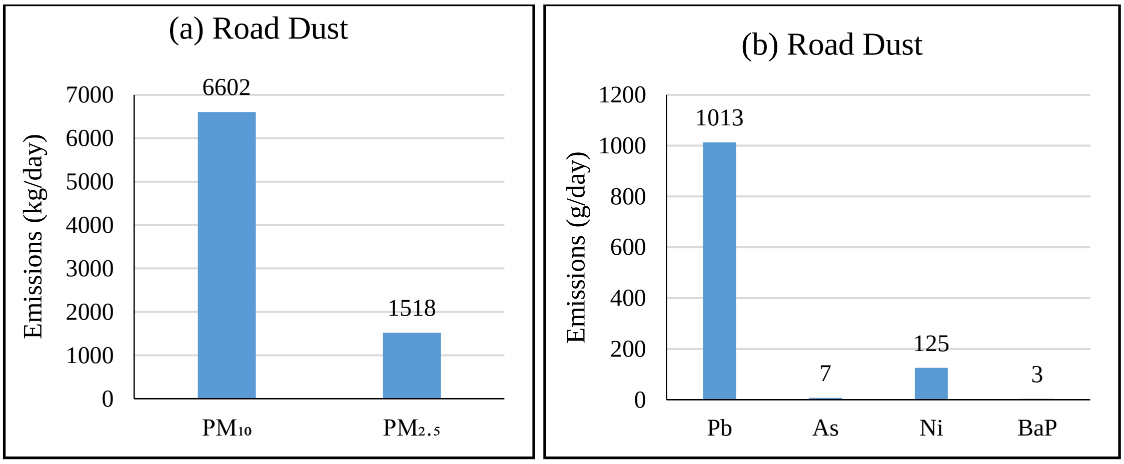


Figure 4.80: Road Dust Sampling Location



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

Figure 4.81: Emissions from road dust in Paonta Sahib city

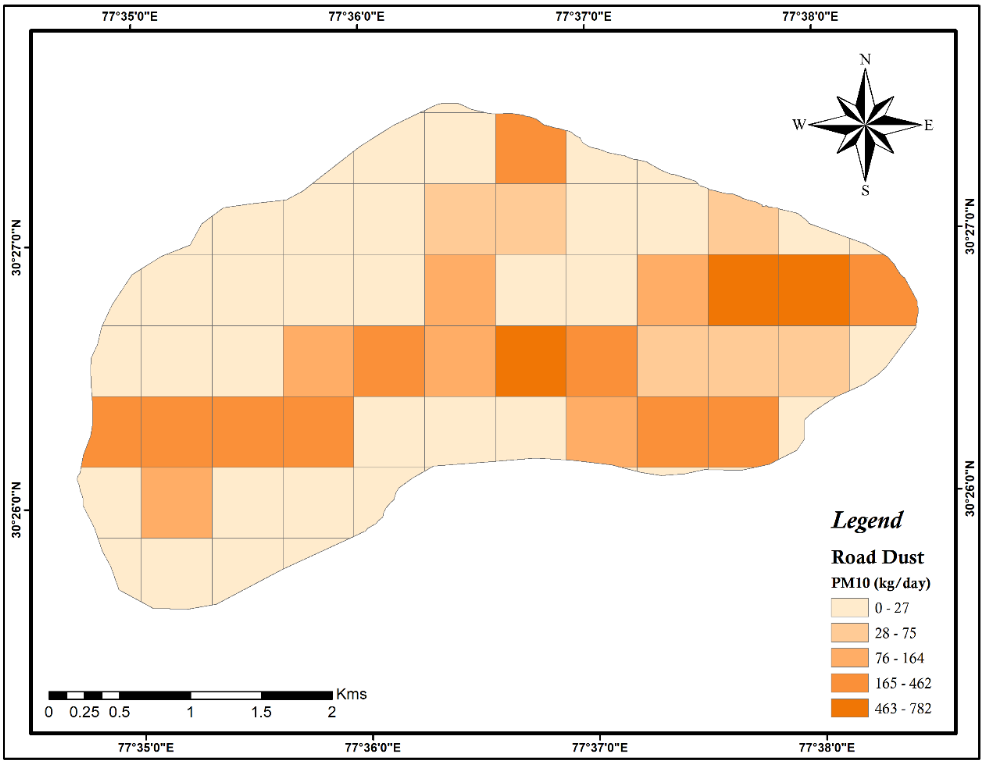


Figure 4.82: Spatial Distribution of PM_{10} Emissions from Road Dust Re-suspension

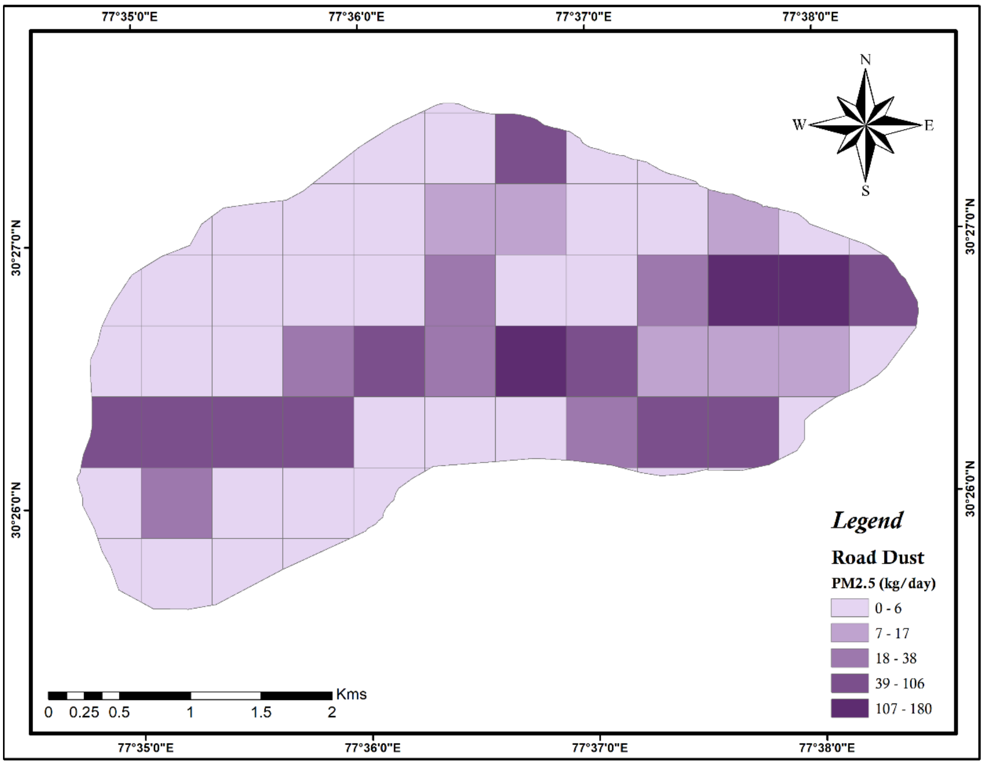


Figure 4.83: Spatial Distribution of $PM_{2.5}$ Emissions from Road Dust Re-suspension

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 4.84 to Figure 4.88. The spatial distribution of pollutant Emissions from all sources is presented in Figure 4.89 to Figure 4.93. The pollutant wise gridded emissions are provided in Annexure 2.

The total PM_{10} emission load in the city is estimated to be 9206 kg/day. The top four contributors to PM_{10} emissions are Road Dust (72%), Vehicles (13%), Industries (10%), and Brick Kilns (4%); 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 3659 kg/day. The top four contributors to $PM_{2.5}$ emissions are Road Dust (41%), Vehicular (30 %), Industries (20%), and Brick Kilns (6 %); these are based on annual emissions. Seasonal and daily emissions could be highly variable.

SO_2 emission load in the city is estimated to be 2312 kg/day. Industrial (79%), Brick Kiln (18%), and Hotels, restaurants, GHs & BHs (2%) are the top three contributors to SO_2 emissions.

NOx emissions load in the city is estimated to be 10360 kg/day. The majority of total emissions are attributed to Vehicular (79%), Industries (19%), and Brick Kilns (1%). Vehicular emissions that occur at ground level, probably making it the most important emission. NOx apart from being a pollutant itself is an important component in the formation of secondary particles (nitrates) and ozone. NOx from vehicles and industry are potential sources for controlling NOx emissions.

The estimated CO emission is about 8730 kg/day. The major contributors to CO emissions are Vehicular (81%), Brick Kilns (9%), and Industries (5%). Vehicular emissions could be the main target for controlling CO for improving air quality with respect to CO.

The estimated emissions are for benzene: 311 g/d, Pb: 1265 g/d, As: 53 g/d, Ni: 384 g/d and BaP: 26 g/d from all sources.

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

Sources	PM_{10} (kg/d)	$PM_{2.5}$ (kg/d)	SO_2 (kg/d)	NOx (kg/d)	CO (kg/d)	NH_3 (kg/d)	Benzene (g/d)	Pb (g/d)	As (g/d)	Ni (g/d)	BaP (g/d)
Brick Kilns	327	230	426	128	816		21	26	35	103	5
Domestic	34	26	8	18	147		0.2	0.6	0.8	7.7	0.1
MSW Burning	36	25	2	14	190		0	8	1.4	1.1	0.0002
Hotels, Restaurants, GHs & BHs	57	30	38	42	102		144	3	4	14	0.6
Construction & Demolition	29	7	0	0	0		0	0.9	0.3	0.5	0
Industrial DG Sets	0.9	0.8	0.8	12.7	2.7		2.67	0.08	0	0.01	0.01
Hospitals	0.09	0.08	0.09	1.32	0.28		0.28	0.01	0	0.001	0.001
Industries	909	734	1817	1967	402		144	0.8	0.04	0.07	0.2
Vehicle	1210	1089	20	8178	7070		0	213	5.2	133	17
Road Dust	6602	1518	0	0	0		0	1013	7	125	3
Livestock						1064					
Agriculture						890					
Total	**9206**	**3659**	**2312**	**10360**	**8730**	**1954**	**311**	**1265**	**53**	**384**	**26**

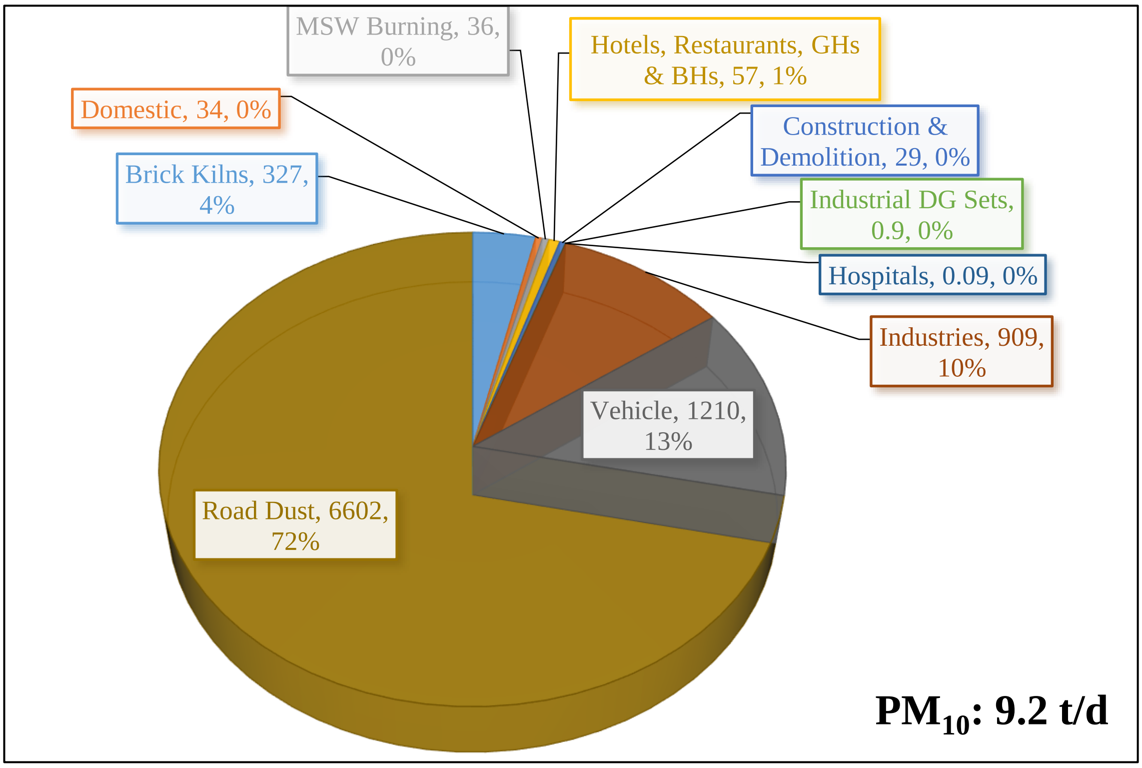


Figure 4.84: PM_{10} Emission Load Contribution of Different Sources

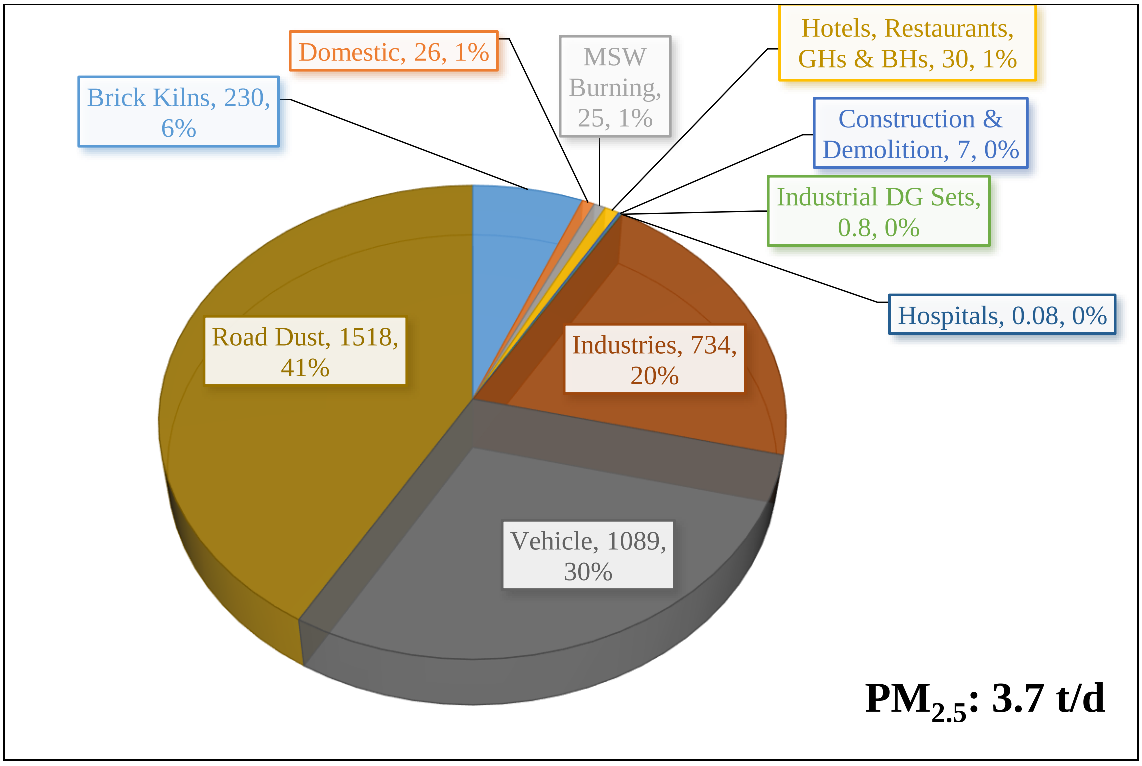


Figure 4.85: $PM_{2.5}$ Emission Load Contribution of Different Sources

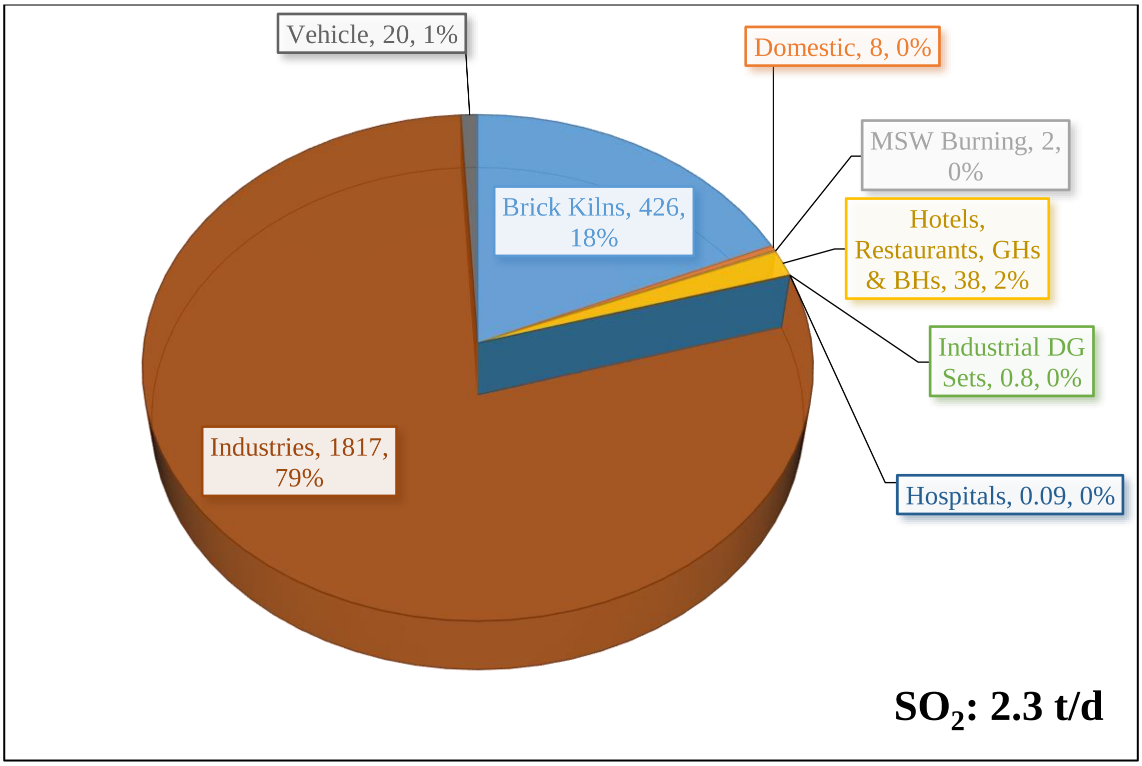


Figure 4.86: SO_2 Emission Load Contribution of Different Sources

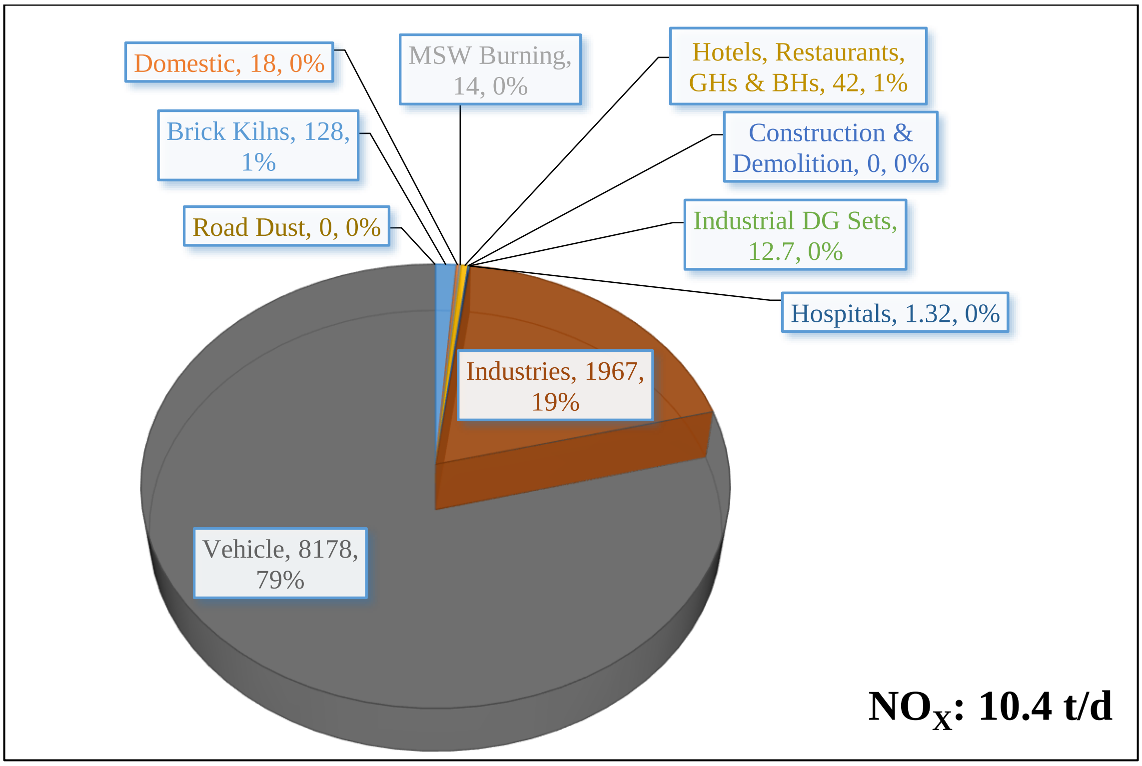


Figure 4.87: NOx Emission Load Contribution of Different Sources

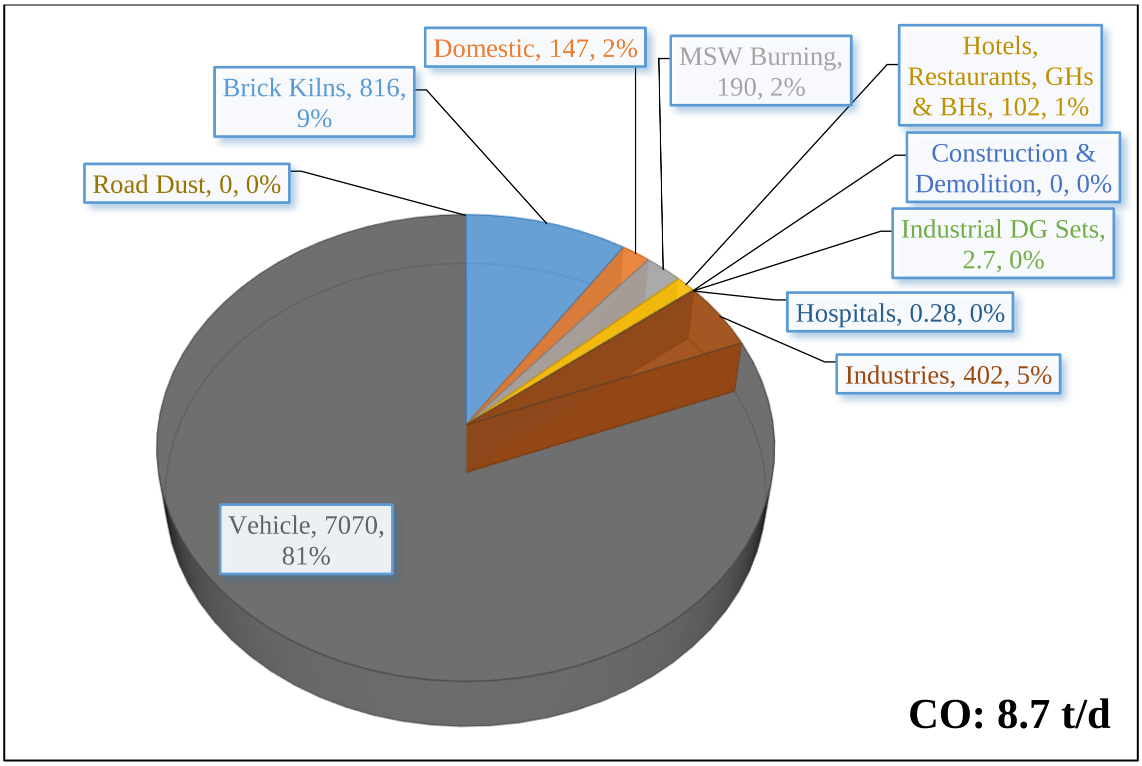


Figure 4.88: CO Emission Load Contribution of Different Sources

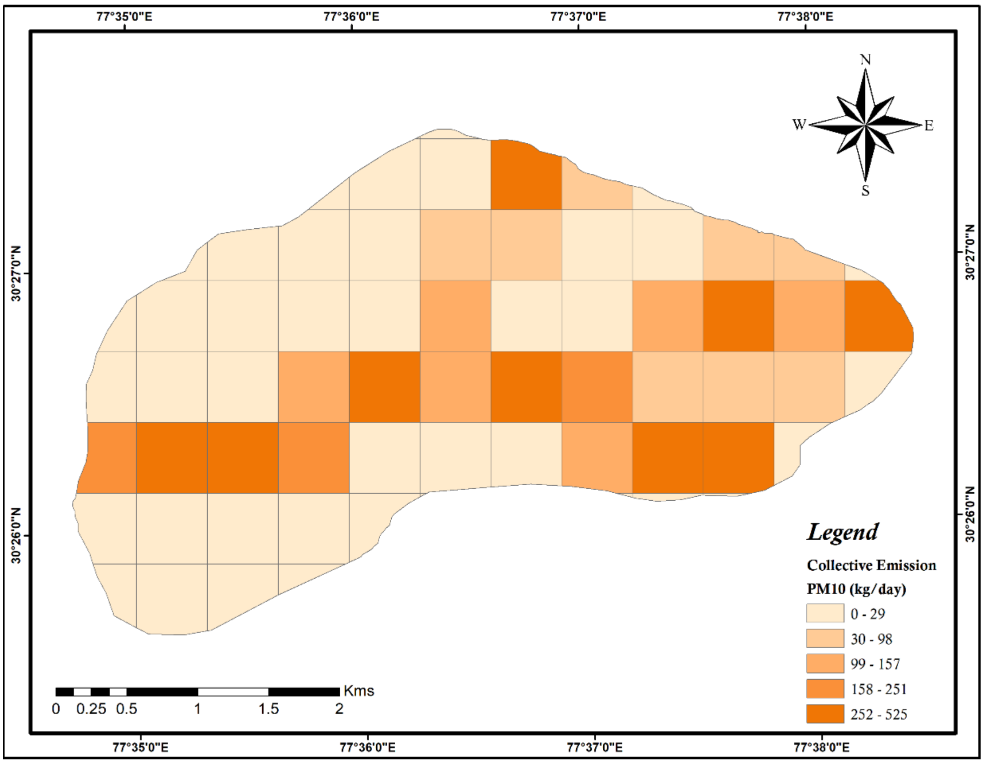


Figure 4.89: Spatial Distribution of PM_{10} Emissions in the City of Paonta Sahib

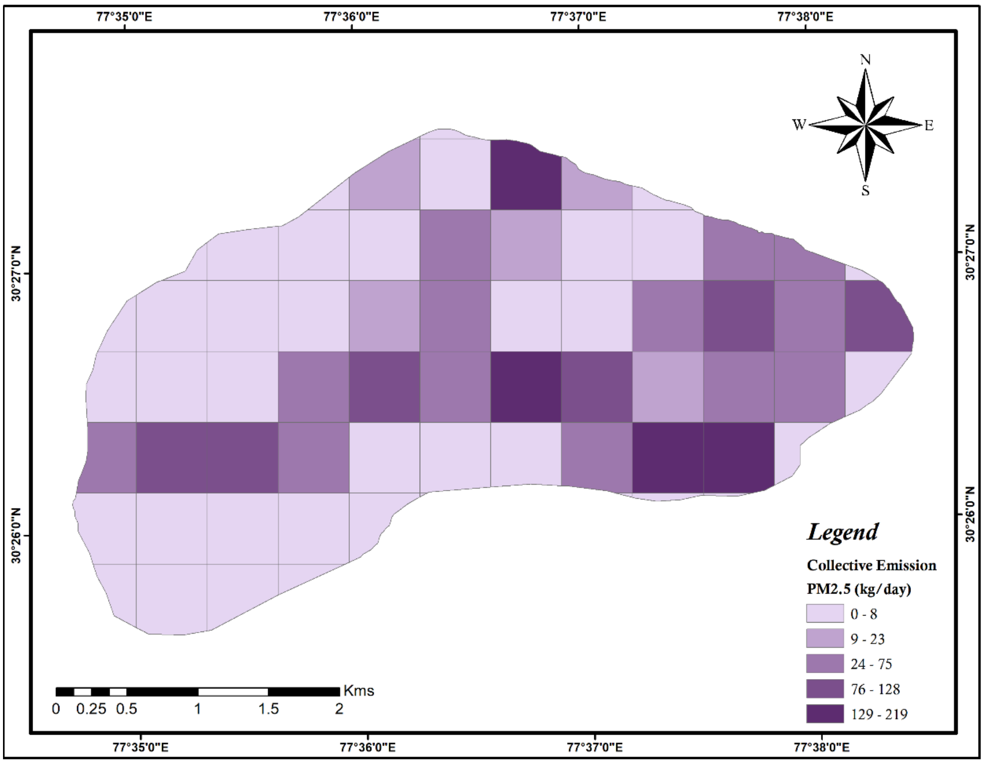


Figure 4.90: Spatial Distribution of $PM_{2.5}$ Emissions in the City of Paonta Sahib

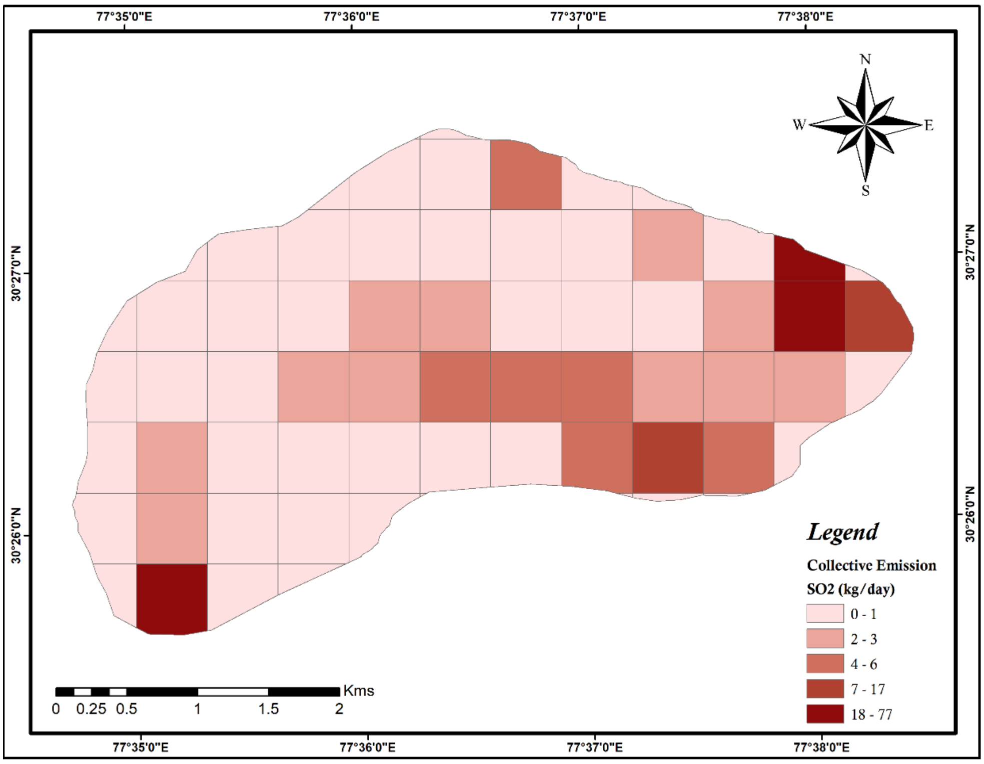


Figure 4.91: Spatial Distribution of SO_2 Emissions in the City of Paonta Sahib

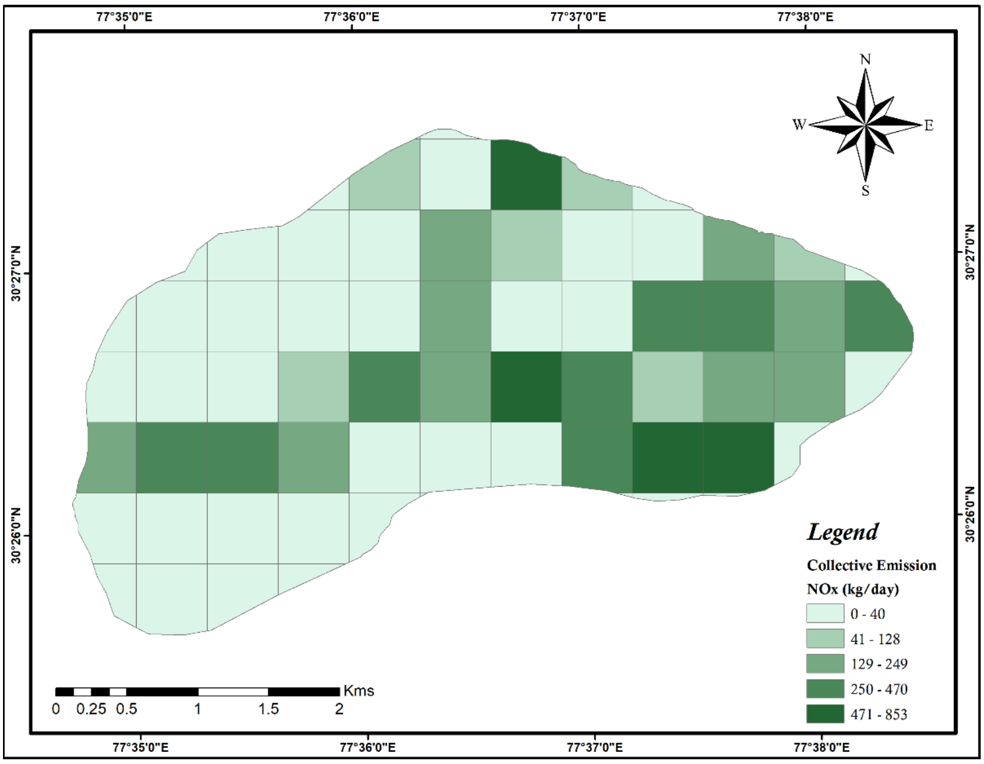


Figure 4.92: Spatial Distribution of NOx Emissions in the City of Paonta Sahib

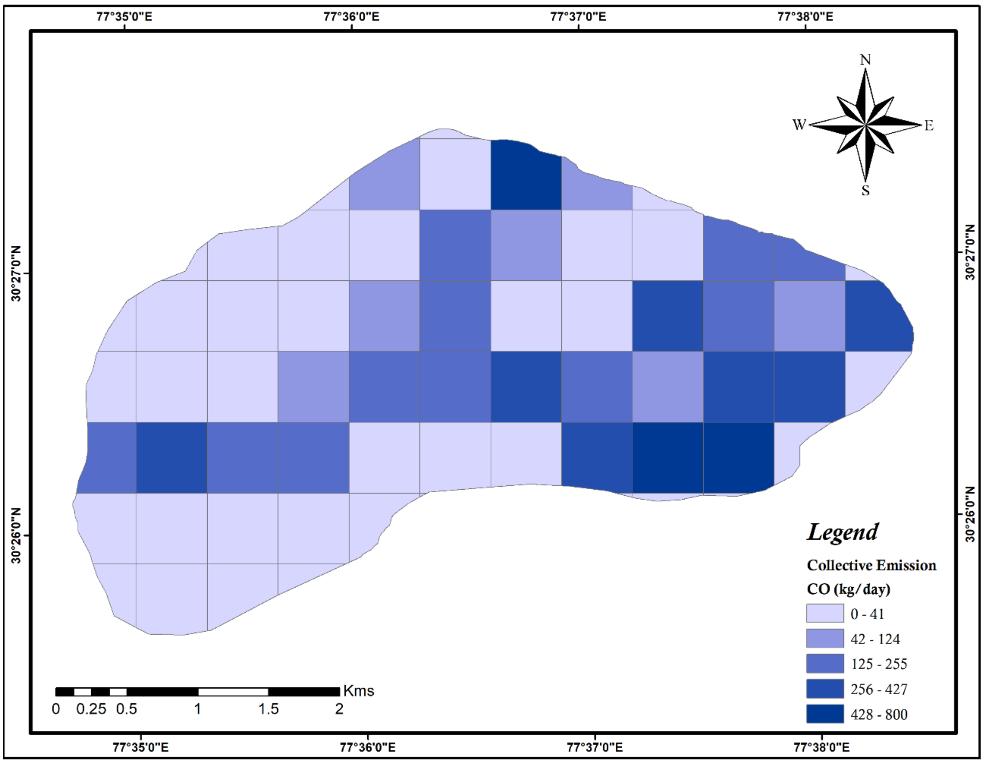


Figure 4.93: Spatial Distribution of CO Emissions in the City of Paonta Sahib

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 PM_{10} 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:

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

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 PM_{10} 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 PM_{10} and $PM_{2.5}$ observations with chemical composition were used for apportionment of sources for about 42 samples of PM_{10} and $PM_{2.5}$ (7 samples at each site for each pollutant) collected from November 29 – December 7, 2019 during winter at three sites in Paonta Sahib.

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 Paonta Sahib are described in the next section.

5.3 PMF Modeling Results and interpretation (Paonta Sahib)

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 PM_{10} and $PM_{2.5}$ are presented in Figure 5.1. The results showed the R-square was above 0.95 for both PM_{10} and $PM_{2.5}$ and the percent mass accounted was over 85%. Tables 5.1 and 5.2 presents a summary of the source concentration of PM_{10} and $PM_{2.5}$ for all the three 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 PM_{10} and $PM_{2.5}$.

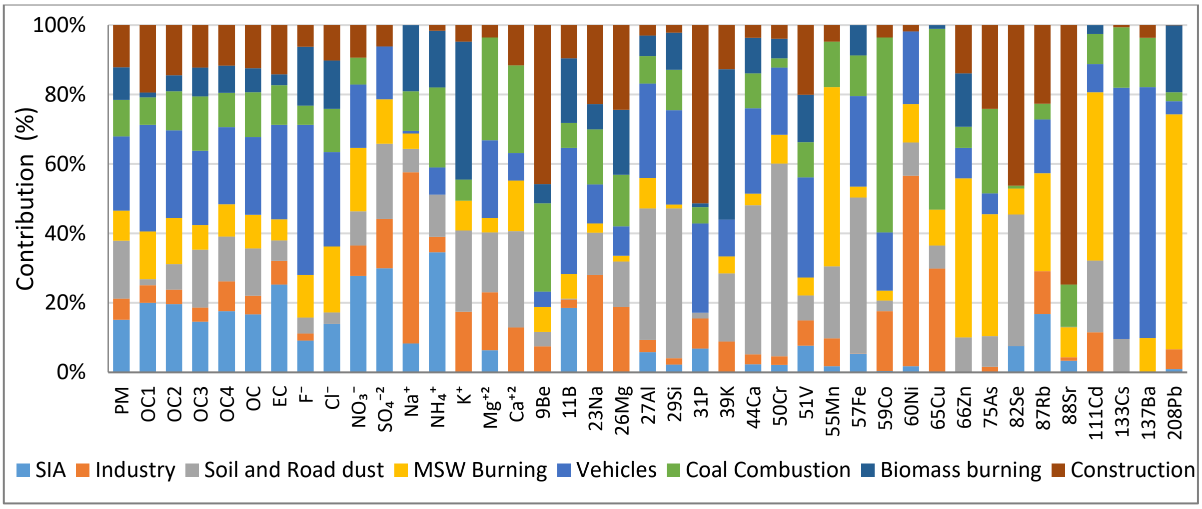
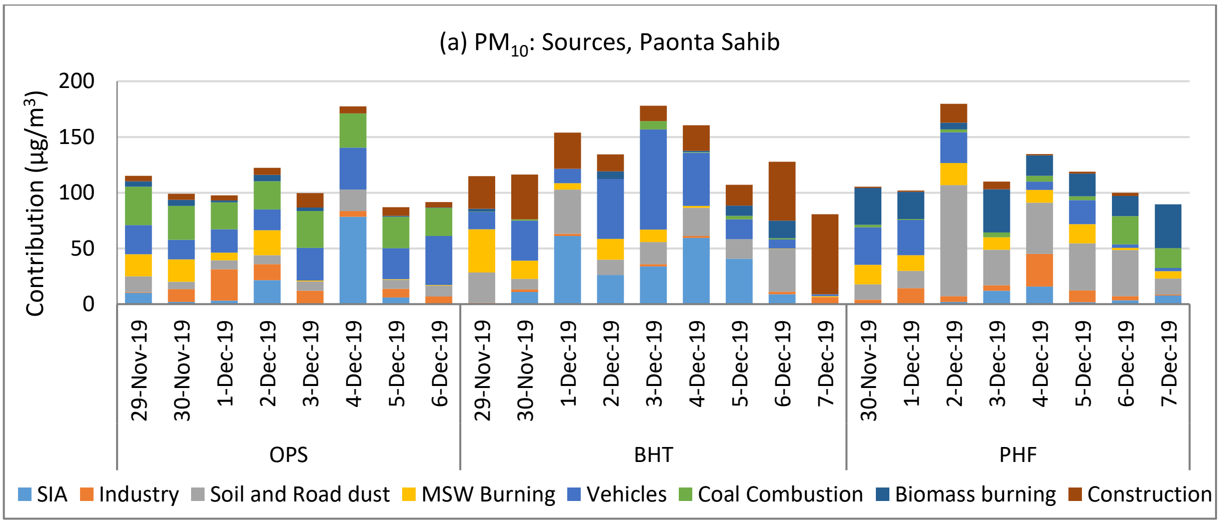


Figure 5.1: PMF-based Source profiles for PM_{10} and $PM_{2.5}$



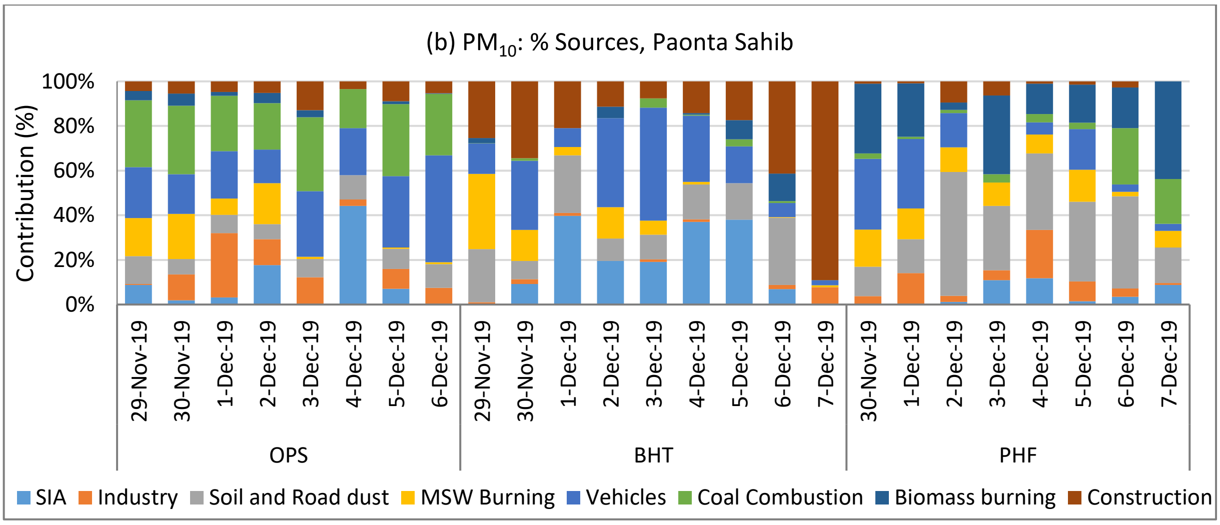


Figure 5.2: PMF modeling Results for PM_{10} at all sites

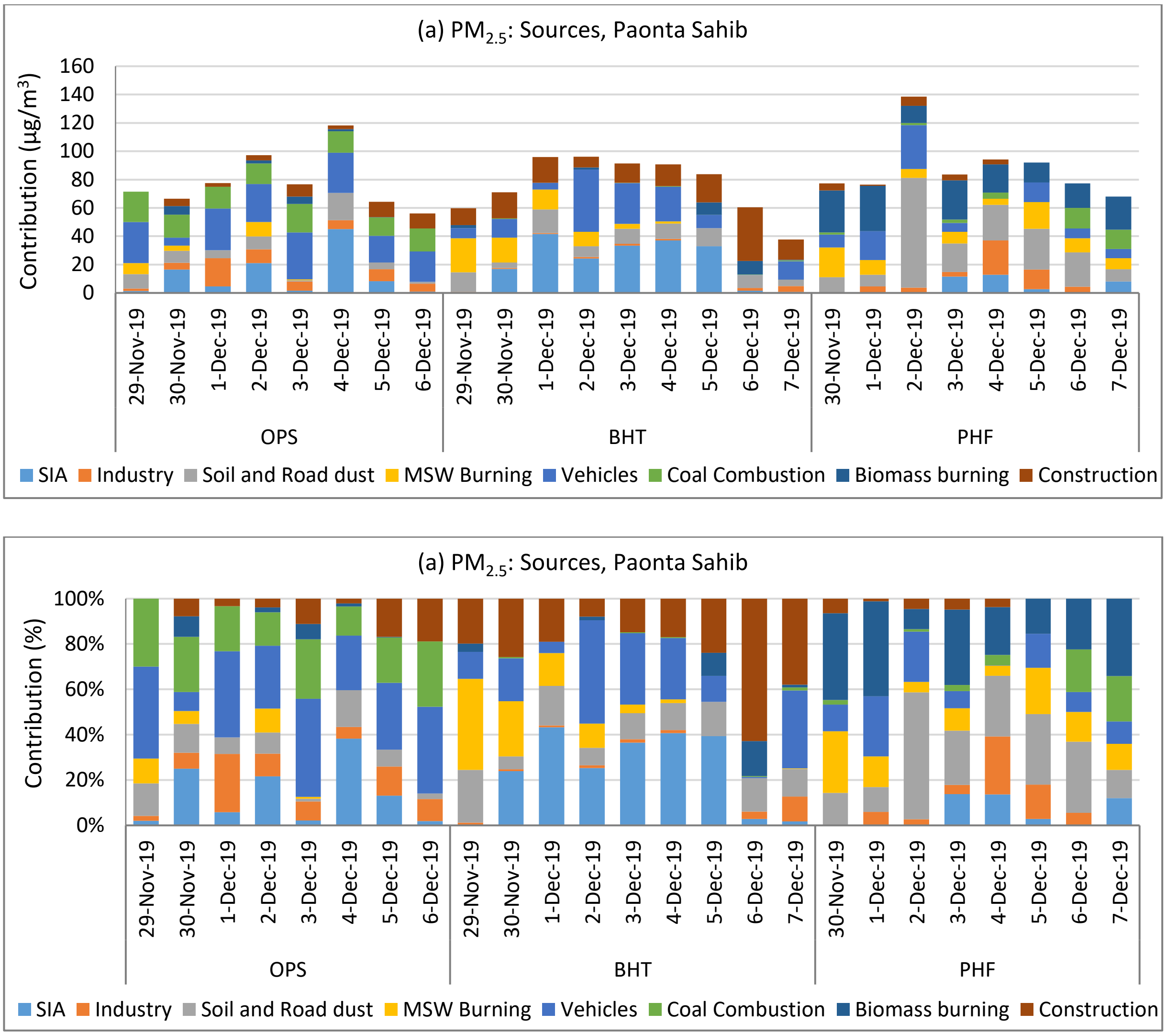


Figure 5.3: PMF modeling Results for $PM_{2.5}$ at all sites

5.3.1 OPS

PM_{10}

The average PM_{10} concentration was 113 µg/m^3. Figure 5.2 represents PM_{10} contribution of sources in terms of concentration, and percent contribution of sources at all sites (OPS represented in 1st part of the graphs). Figure 5.4(a) represents PM_{10} overall contribution in terms of the percentage of sources. It is observed that the major source contributing to PM_{10} was coal combustion (26%) followed by vehicular emission (25%). The other sources are secondary inorganic aerosol (SIA; 14%), industrial emission (10%), soil and road dust (9%), municipal solid waste (MSW) burning (8%), construction (6%) and biomass burning (2%).

$PM_{2.5}$

The average $PM_{2.5}$ concentration was 73 µg/m^3 (i.e., about 0.65 of PM_{10}). Figure 5.3 represents $PM_{2.5}$ contribution of sources in terms of concentration, and percent contribution of sources at all sites (OPS represented in 1^{st} 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 source contributing to $PM_{2.5}$ was vehicular emission (31%) followed by coal combustion (21%). The other sources are SIA (16%), industrial emission (10%), soil and road dust (9%), construction (7%), MSW burning (4%) and biomass burning (2%).

HYSPLIT back trajectories (Figure 5.5) indicate that wind is flowing mostly 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.

Inferences

- The contribution of coal combustion including flyash is most significantly high both in PM_{10} (26%) and $PM_{2.5}$ (21%). It was seen that restaurants and dhabas were using coal in the nearby areas within 200 m radius.
- Vehicle contribution is consistent in $PM_{2.5}$ (31%) and PM_{10} (25%). It could be moderate to high traffic on NH-7 and NH-107 in the nearby areas.
- The secondary particles (SIA) contribute significantly to PM_{10} (14%) and PM_{10} (16%). These particles are expected to source from precursor gases (SO_2 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.
- Soil and road dust contribution is significant in $PM_{2.5}$ (9%) and PM_{10} (9%). The high contribution in emissions during sampling period may be due to bad/unpaved roads.
- Th industrial source has a significant contribution to $PM_{2.5}$ and PM_{10} at about 10% other than coal combustion.
- The biomass and MSW burning contribution have significant. It is clearly seen that MSW burning is a major source that contributes to PM_{10} and $PM_{2.5}$. biomass and MSW burning emission are 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 and use of biomass as a solid fuel for cooking.

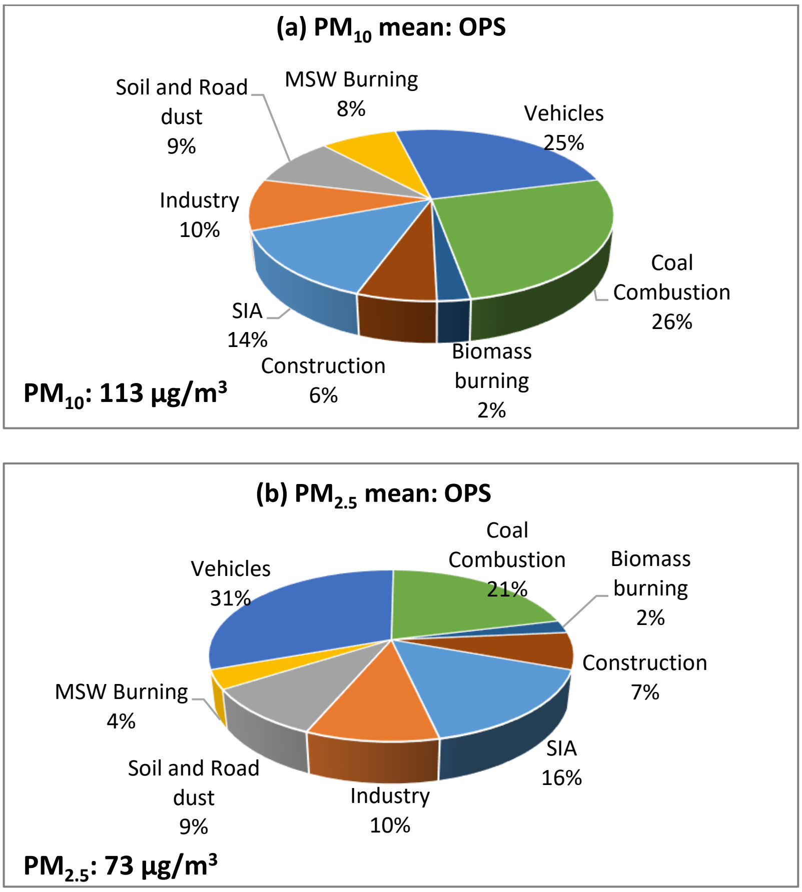


Figure 5.4: PMF modeling for (a) PM$_{10}$ and (b) PM$_{2.5}$ at OPS

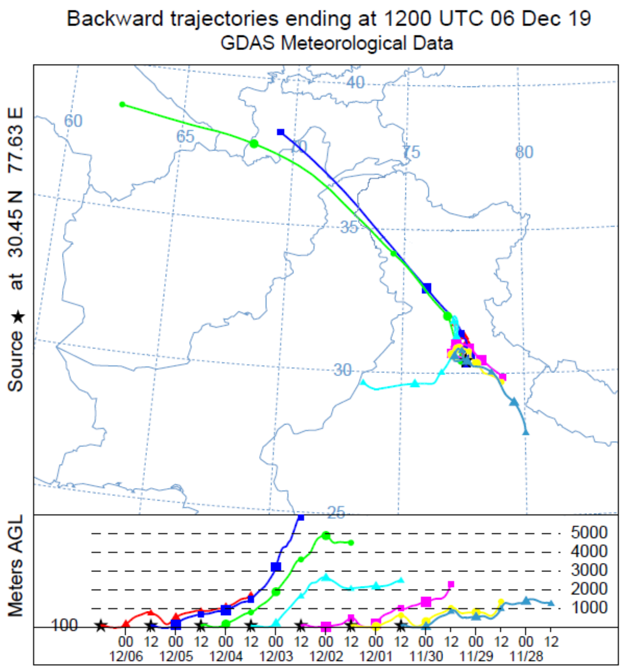


Figure 5.5: Backward trajectories at OPS

5.3.2 BHT

PM_{10}

The average PM_{10} concentration was 136 µg/m^3. Figure 5.2 represents PM_{10} contribution of sources in terms of concentration, and percent contribution of sources at all sites (BHT represented in 2nd part of the graphs). Figure 5.6(a) represents PM_{10} overall contribution in terms of the percentage of sources. It is observed that the major source contributing to PM_{10} was construction (25%) followed by vehicular emission (24%). The other sources are SIA (21%), soil and road dust (16%), MSW burning (8%), biomass burning (3%), industrial emission (2%) and coal combustion (1%).

$PM_{2.5}$

The average $PM_{2.5}$ concentration was 77 µg/m^3 (i.e., about 0.56 of PM_{10}). Figure 5.3 represents $PM_{2.5}$ contribution of sources in terms of concentration, and percent contribution of sources at all sites (BHT represented in 2nd part of the graphs). Figure 5.6(b) represents $PM_{2.5}$ overall contribution in terms of the percentage of sources. It is observed that the major source contributing to $PM_{2.5}$ was SIA (28%), followed by construction (23%). The other sources are vehicular emission (21%), soil and road dust (13%), MSW burning (10%), biomass burning (3%), industrial emission (2%) and coal combustion (<1%).

HYSPLIT back trajectories (Figure 5.7) 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.

Inferences

Construction and soil and road dust are the most significant sources contributing about 36% in $PM_{2.5}$ and 41% in PM_{10}. It indicates use of construction activities (i.e., repairing works in the commercial establishments) in nearby areas. Vehicles contribute about 21% in $PM_{2.5}$ and 24% in PM_{10}. SIA contribution also significantly high at 21% in PM_{10} and 28% in $PM_{2.5}$. MSW burning contributes about 8% in PM_{10} and 10% in $PM_{2.5}$.

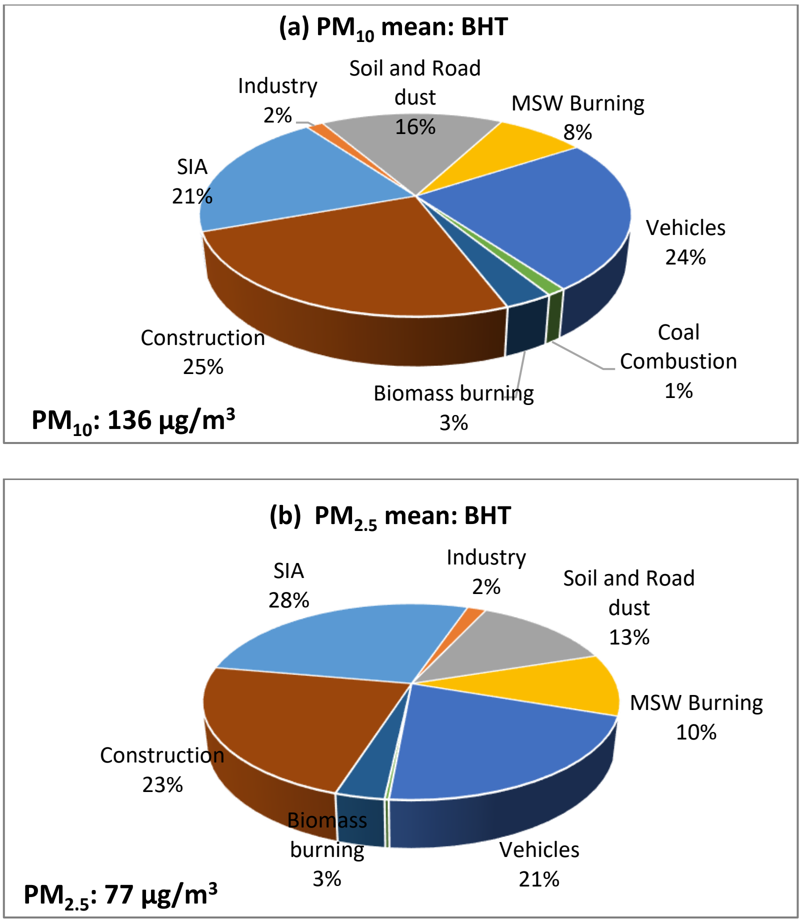


Figure 5.6: PMF modeling for (a) PM_{10} and (b) $PM_{2.5}$ at BHT

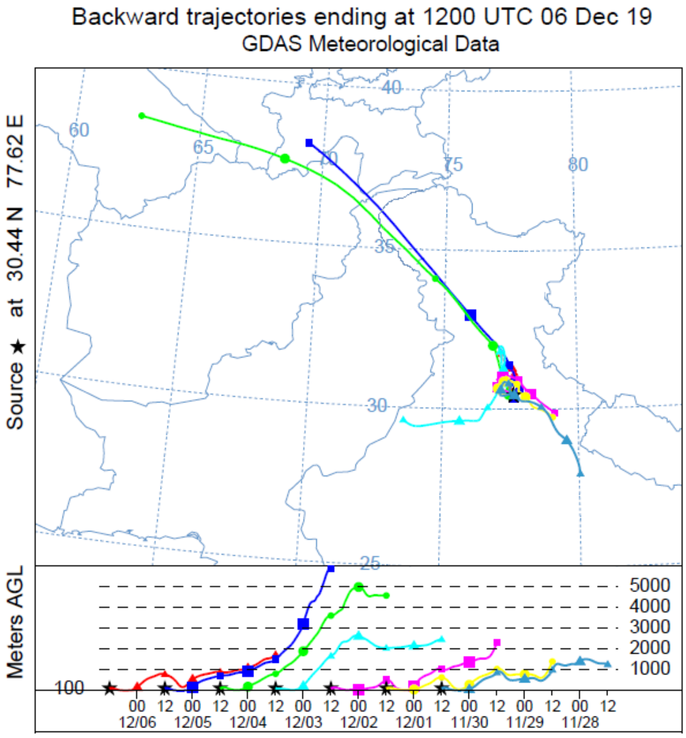


Figure 5.7: Backward trajectories at BHT

5.3.3 PHF

PM_{10}

The average PM_{10} concentration was 116 µg/m^3. Figure 5.2 represents PM_{10} contribution of sources in terms of concentration, and percent contribution of sources at all sites (PHF represented in 3rd part of the graphs). Figure 5.8(a) represents PM_{10} overall contribution in terms of the percentage of sources. It is observed that the major source contributing to PM_{10} was soil and road dust (32%) followed by biomass burning (21%). The other major sources are vehicular emission (14%), MSW burning (11%) industrial emission (8%), coal combustion (6%), SIA (5%), and construction (3%).

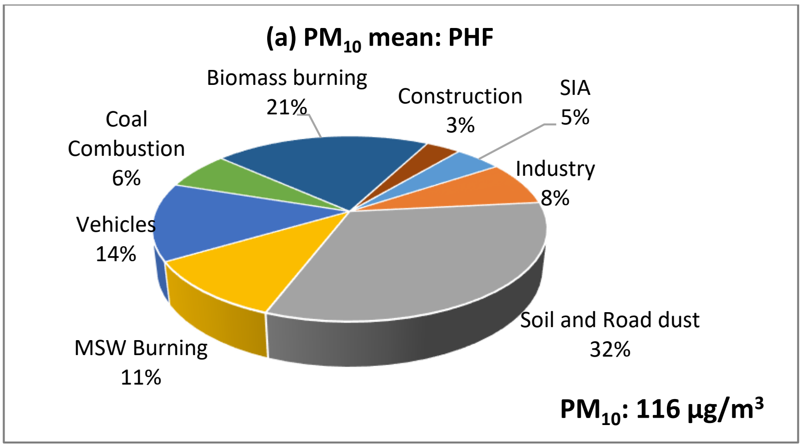
$PM_{2.5}$

The average $PM_{2.5}$ concentration was 86 µg/m^3 (i.e., about 0.74 of PM_{10}). Figure 5.3 represents $PM_{2.5}$ contribution of sources in terms of concentration, and percent contribution of sources at all sites (PHF represented in 3rd part of the graphs). Figure 5.8(b) represents $PM_{2.5}$ overall contribution in terms of the percentage of sources. It is observed that the major source contributing to $PM_{2.5}$ was soil and road dust (29%) followed by biomass burning (25%). The other major sources are vehicular emission (13%), MSW burning (12%), industrial emission (8%), coal combustion (5%), SIA (5%) and construction (3%).

HYSPLIT back trajectories (Figure 5.9) 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.

Inferences

soil and road dust are the most significant source contributing about 32% in $PM_{2.5}$ and 29% in PM_{10}. Biomass burning contribution was very high at 21% in PM_{10} and 25% in $PM_{2.5}$. Sources of SIA contribute about 5% in PM_{10} and $PM_{2.5}$. Coal combustion (including flyash) contribution was very high at 19% in PM_{10} and 26% in $PM_{2.5}$. It could be due to the use of coal in industries and cement in construction activities. vehicles contribution is also high in PM_{10} and $PM_{2.5}$.



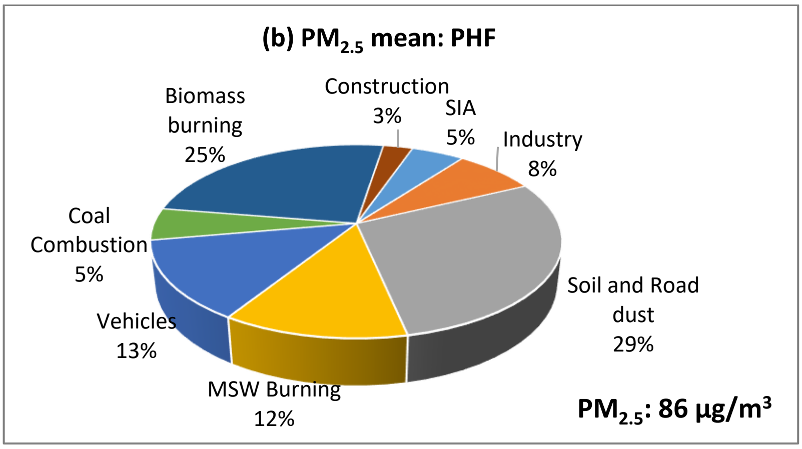


Figure 5.8: PMF modeling for (a) PM_{10} and (b) $PM_{2.5}$ at PHF

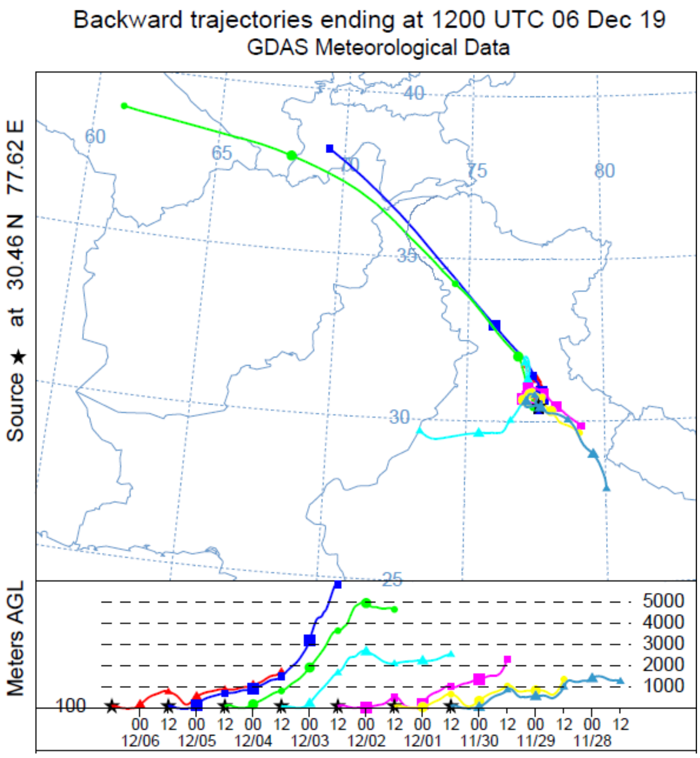


Figure 5.9: Backward trajectories at PHF

5.3.4 Overall

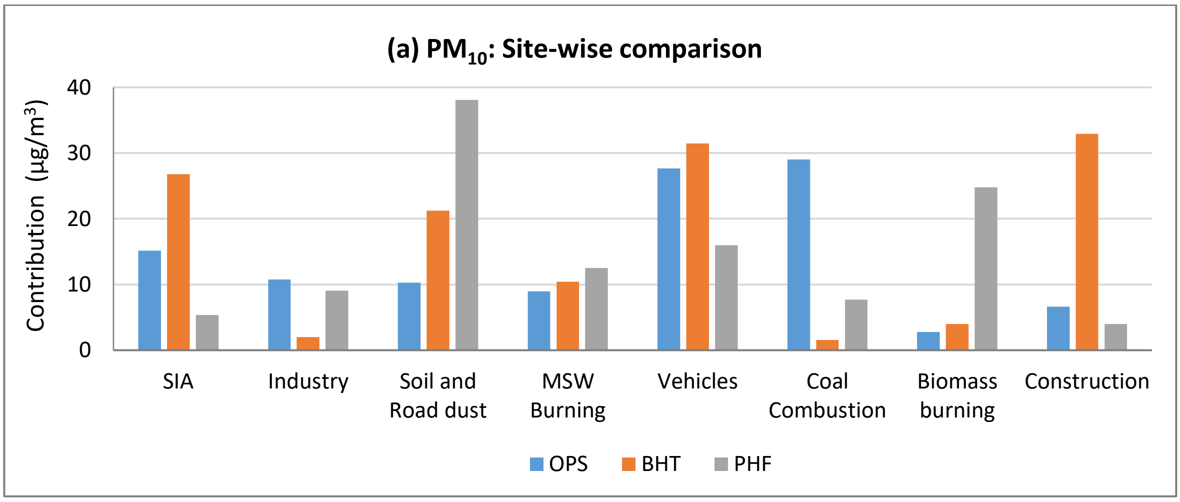
The overall summary of PMF modeling results is shown in Figures 5.10 – 5.11. Tables 5.1 – 5.2 provide a summary of overall statistics.

PM_{10}

The average PM_{10} concentration was 123 μg/m^3. Figure 5.10(a) represents a site-wise comparison of PM_{10} contributing sources and Figure 5.11(a) represents the overall contribution in terms of concentration and percentage of sources for the Paonta Sahib city. It is observed that the major source contributing to PM_{10} was vehicular emission (25 μg/m^3 ~ 21%) followed by soil and road dust (23 μg/m^3 ~ 19%). The other major sources are SIA (16 μg/m^3 ~ 13%), construction (15 μg/m^3 ~ 12%), coal combustion (13 μg/m^3 ~ 11%), MSW burning (11 μg/m^3 ~ 9%), biomass burning (11 μg/m^3 ~ 9%) and industrial emission (7 μg/m^3 ~ 6%).

$PM_{2.5}$

The average $PM_{2.5}$ concentration was 78 μg/m^3 (i.e., about 0.63 of PM_{10}). Figure 5.10(b) represents a site-wise comparison of $PM_{2.5}$ contributing sources. Figure 5.11(b) represents the overall contribution in terms of concentration and percentage of sources for the city. It is observed that the major source contributing to $PM_{2.5}$ was vehicular emission (17 μg/m^3 ~ 21%) followed by soil and road dust (14 μg/m^3 ~ 19%). The other major sources are SIA (13 μg/m^3 ~ 16%), construction (8 μg/m^3 ~ 10%), biomass burning (9 μg/m^3 ~ 11%), MSW burning (7 μg/m^3 ~ 9%), coal combustion (7 μg/m^3 ~ 9%) and industrial emission (5 μg/m^3 ~ 6%).



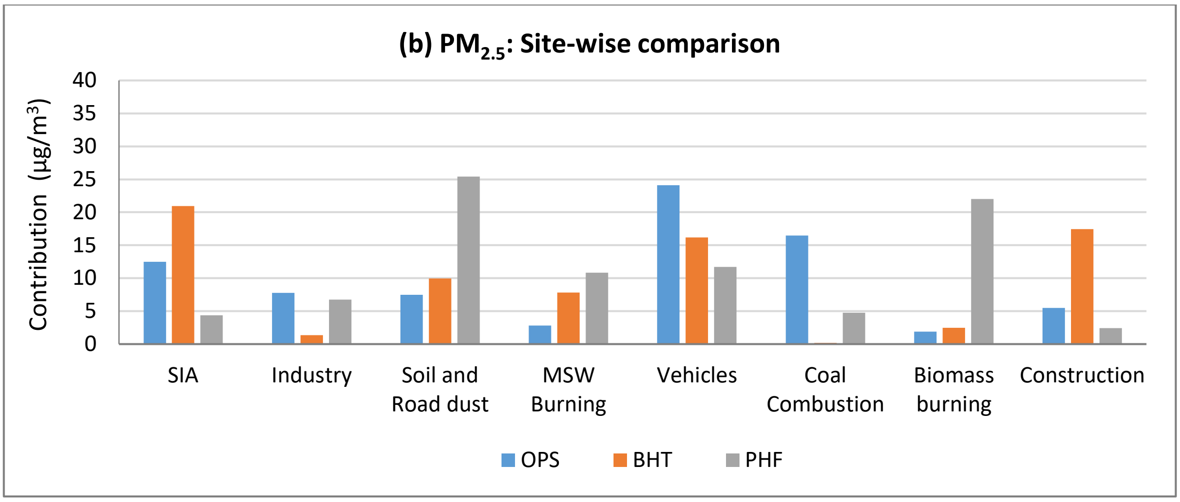
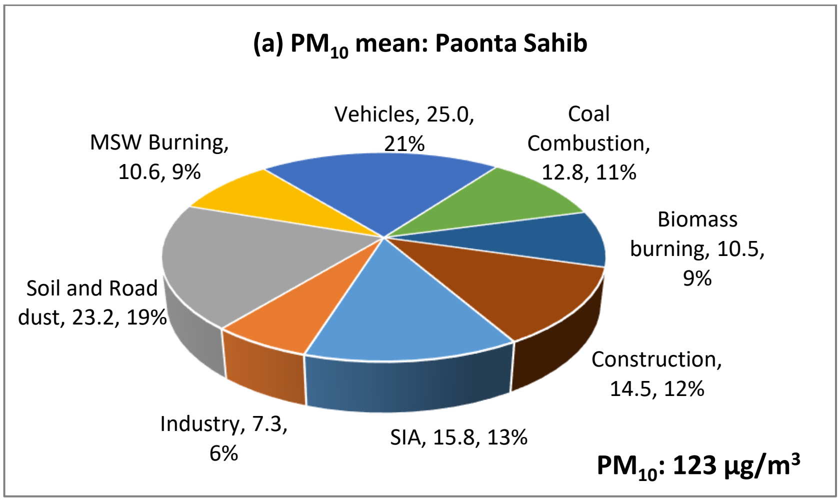


Figure 5.10: source concentration comparison at sites for (a) PM_{10} and (b) $PM_{2.5}$ at all sites



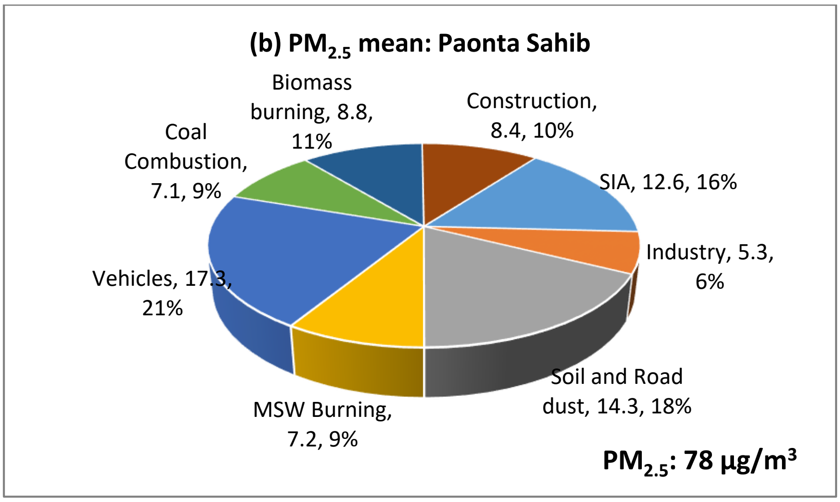


Figure 5.11: PMF modeling for (a) PM_{10} and (b) $PM_{2.5}$

Table 5.1: Summary of source concentration of PM_{10}: Paonta Sahib

Site	Parameter	Measured PM_{10}	Calculated PM_{10}	% Mass	% Source Contribution							
					SIA	Industry	Soil + Road Dust	MSW Burning	Vehicles	Coal Combustion	Biomass Burning	Construction
OPS	Mean	115.2	113.3	98.1	10.17	9.38	10.68	9.48	26.40	19.69	1.67	12.54
	SD	25.3	26.9	4.4	14.07	8.35	5.11	11.21	10.40	12.03	1.56	10.66
BHT	Mean	134.1	127.7	94.8	17.81	3.44	15.29	6.31	24.05	1.32	9.13	22.66
	SD	27.9	30.1	6.6	16.10	4.39	8.27	6.32	15.62	1.45	10.83	26.15
PHF	Mean	119.8	122.1	101.6	6.25	7.07	35.22	8.99	7.57	9.50	21.90	3.51
	SD	26.0	29.5	2.7	4.39	6.95	11.95	3.81	6.72	9.42	13.61	3.32
OVERALL	Mean	123.8	121.3	97.7	12.14	6.45	18.88	8.11	20.57	9.84	9.87	14.14
	SD	28.5	30.2	5.9	14.40	7.30	13.38	8.26	14.66	11.94	12.79	19.64
	CV	0.23	0.25	0.06	1.19	1.13	0.71	1.02	0.71	1.21	1.30	1.39
	MAX	180.5	179.9	106.0	44.18	28.81	55.40	33.72	50.57	33.07	43.76	89.08
	MIN	89.1	80.7	78.3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 5.2: Summary of source concentration of $PM_{2.5}$: Paonta Sahib

Site	Parameter	Measured $PM_{2.5}$	Calculated $PM_{2.5}$	% Mass	% Source Contribution							
					SIA	Industry	Soil + Road Dust	MSW Burning	Vehicles	Coal Combustion	Biomass Burning	Construction
OPS	Mean	73.3	78.5	108.0	13.73	10.15	8.88	3.50	31.21	22.12	2.46	7.95
	SD	19.6	18.8	6.1	12.57	6.62	5.03	4.55	10.69	5.90	3.30	6.53
BHT	Mean	76.7	76.3	99.1	23.73	2.35	13.28	10.59	20.72	0.34	3.58	25.40
	SD	17.9	19.2	9.1	16.88	3.13	4.92	13.07	14.05	0.42	5.22	15.33
PHF	Mean	85.7	88.4	103.4	5.29	7.39	25.85	13.08	12.73	6.17	26.94	2.56
	SD	19.2	20.6	6.4	6.18	8.21	13.73	7.18	7.89	7.77	10.96	2.42
OVERALL	Mean	78.5	80.9	103.3	14.63	6.46	15.89	9.12	21.52	9.18	10.70	12.51
	SD	19.9	20.6	8.4	15.25	7.21	11.50	10.23	13.79	10.95	13.54	14.37
	CV	0.25	0.26	0.08	1.04	1.12	0.72	1.12	0.64	1.19	1.27	1.15
	MAX	127.9	138.5	115.5	43.33	25.72	55.99	40.12	45.59	30.00	41.92	62.76
	MIN	46.7	37.6	80.6	0.00	0.00	1.27	0.00	0.05	0.00	0.00	0.00

5.4 Interpretations and Inferences

Based on the PMF modeling results (Figures 5.10 and 5.11) 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 PM_{10} and $PM_{2.5}$, and these tables are frequently referred to bring the important inferences to the fore.

- 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 vehicles (21 – 22%), soil and road dust (19 – 16%), secondary inorganic aerosol (SIA) (12 – 15%), construction activities (14 – 13%), biomass burning (10 – 9%), MSW burning (8 – 9%), coal combustion and flyash (10 – 9%) and industrial emission (6 – 6%).
- The most consistent sources for PM_{10} and $PM_{2.5}$ are vehicles and soil and road dust. On average, the other sources may contribute more (or less), but their contributions vary from day to day. The most variable source was construction activities followed by biomass burning and coal combustion.
- Vehicles' contribution is most significant and consistent in PM_{10} (21%) and $PM_{2.5}$ (22%) in the city.
- Soil and road dust is the second most contributor in PM_{10} (19%) and $PM_{2.5}$ (16%), showing high variability, 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.
- Coal and flyash contribute 10% in PM_{10} and 9% in $PM_{2.5}$. It could be due to uses in industries, hotels and restaurants and as a part of cement used for construction activities.
- Secondary inorganic aerosol is significantly high contribution in both PM_{10} (12%) and $PM_{2.5}$ (15%).
- 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} (8%) and $PM_{2.5}$ (9%). This emission is expected to be large in the regions of economically lower strata of the society and commercial places, which do not have proper infrastructure for collection and disposal of MSW.

- PHF site was in the industrial area having major polluting industries. Therefore, it has the movement of large trucks ferrying raw material and finished products. The dumping and burning of MSW and plastic waste along the roadsides were a routine practice. The MSW/plastic burning contribution is high both in PM_{10} (9%) and $PM_{2.5}$ (13%) that indicating improper management of waste generated in the industrial area.

- Industrial contribution in the city is reasonable for both PM_{10} (6%) and $PM_{2.5}$ (6%) 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 6% of PM_{10} and 6% of $PM_{2.5}$, and their contribution is significant at the breathing level.
- The contribution of biomass burning is significant among all sources at 10% (for PM_{10}) and 11% (for $PM_{2.5}$). Sizeable biomass is consistent in PM, indicating local sources present in Paonta Sahib city and nearby areas. Biomass burning is because of arboriculture activities, agricultural residue burning, high energy crop burning for fuel, etc.

Directions for PM control

- Industrial and combustion sources

  The industrial units in the Paonta Sahib must comply with the norms notified by the HPSPCB. There might be some unauthorized industries in Paonta Sahib 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.

- Construction, Soil and road dust

  These sources contribute about 19% to PM_{10}. The silt load on some of the road is very high and silt can become airborne with the movement of vehicles. The estimated PM_{10} emission from road dust is over 6 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. Industries must follow the standard protocols for disposing-off the waste material and dumping on roadsides completely stopped.

- Coal combustion

Coal combustion (including flyash) contributes 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, dhabas and tandoors also cause large emissions and requires better housekeeping and flyash disposal.

- Secondary particles

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 19%) 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 Paonta Sahib

The city of Paonta Sahib 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 are generally the same. The sources (% contribution given in parenthesis for PM_{10} - $PM_{2.5}$ to the ambient air levels) include vehicles (21 – 22%), soil and road dust (19 – 16%), secondary inorganic aerosol (SIA) (12 – 15%), construction activities (14 – 13%), biomass burning (10 – 9%), MSW burning (8 – 9%), coal combustion and flyash (10 – 9%) and industrial emission (6 – 6%).

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 58, mainly situated in the central part of the city and along with the National Highway-7 and 107. 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 Paonta Sahib City.

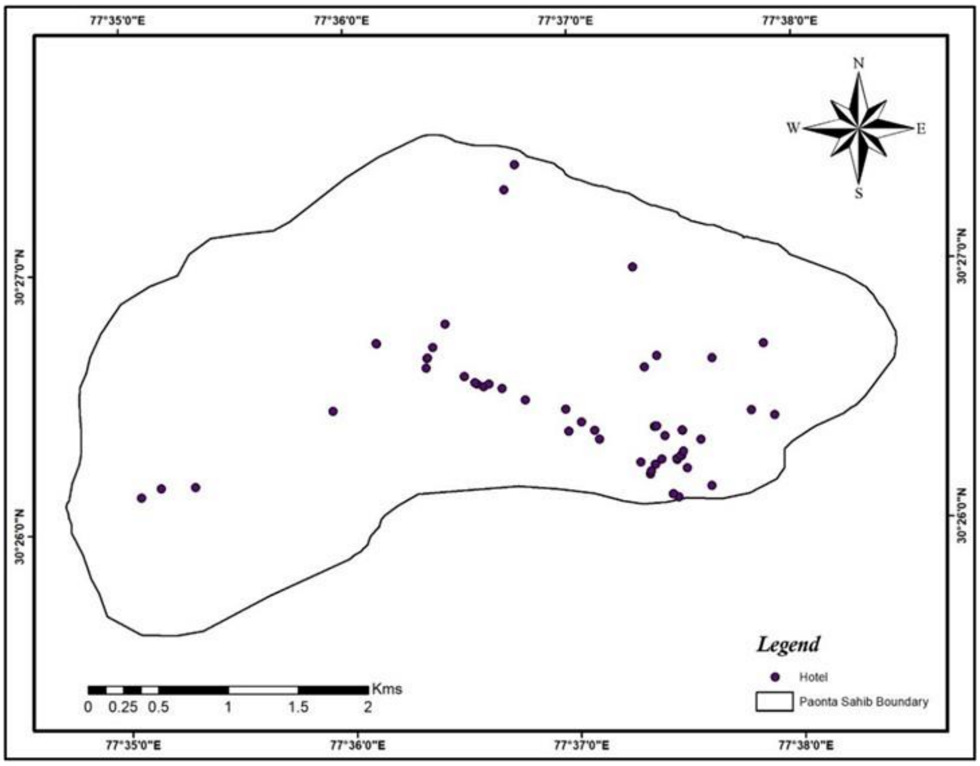


Figure 6.1: Location of Hotels, Restaurants, GHs and BHs in Paonta Sahib City

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 Paonta Sahib 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 Paonta Sahib, Department of Food, Civil Supplies and Consumer Affairs, and oil companies (Indian Oil, HP, etc.). A 70% reduction of PM_{10} (40 kg/d) and $PM_{2.5}$ (21 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 15 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 others residue burning are rampant in Paonta Sahib (Figure 6.2). In winter, the overall source contribution from MSW burning is 8% in PM_{10} and 9% in $PM_{2.5}$ (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, Paonta Sahib 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.

Figure 6.2: MSW Burning in several parts in Paonta Sahib City

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 Main Market, Shamsherpur near ITI college, Badripur Chowk. Major residential areas (having high density) were Shanti colony, Badripur Chowk, Subh Khera, Nav Vihar Colony, Taruwala and Yamuna Vihar Colony.

Desilting and cleaning of municipal drains by Municipal Council, Paonta Sahib 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.

In Paonta Sahib, ‘treatment, storage, and disposal facility (TSDF)’ is not available for MSW management. A 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, Paonta Sahib 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.

It is recommended to develop an Integrated TSDF along with provision of electricity connection and necessary water connection. 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, Paonta Sahib, HPSPCB, NGOs and municipal corporators.

The banning of MSW waste burning can reduce the emissions by 100% of PM_{10} (36 kg/d) and $PM_{2.5}$ (25 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 Paonta Sahib. 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 8 brick kilns present in Paonta Sahib (Figure 6.3). 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 196 kg/d for PM_{10} and 138 kg/d for $PM_{2.5}$.

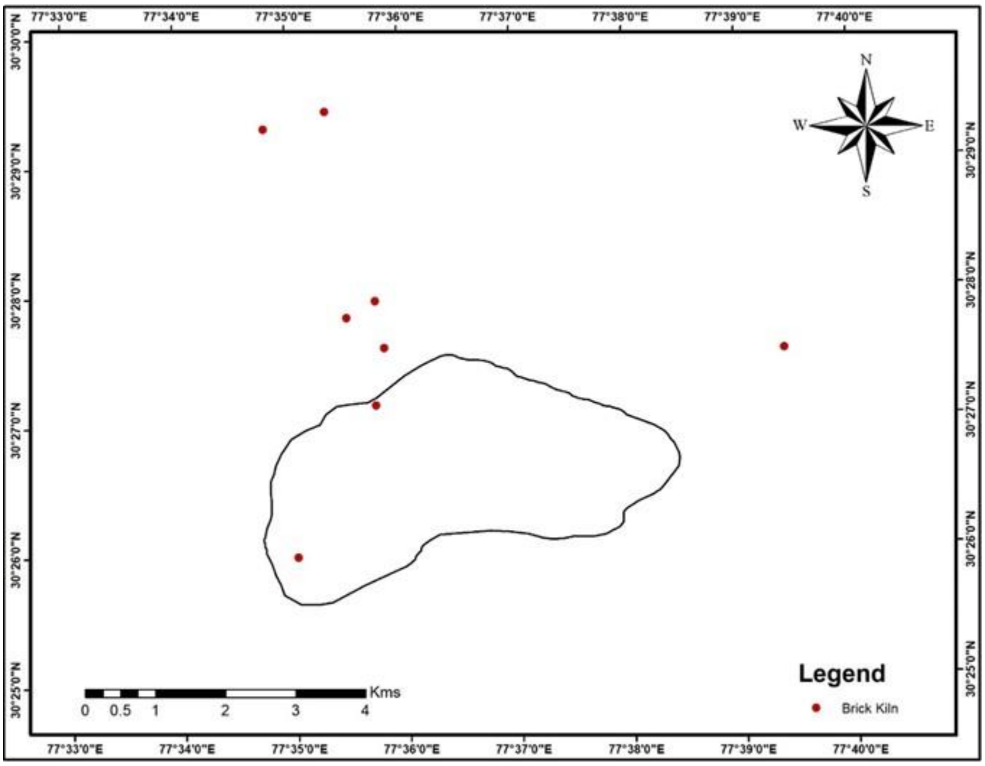


Figure 6.3: Location of Brick Kilns in Paonta Sahib City

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 6.4).

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 Paonta Sahib Development Authority, Himachal Pradesh Housing Board, Municipal Council, Paonta Sahib, Urban Development Department, PWD, and HPSPCB.

Figure 6.4: Construction material and debris near construction sites

The suggested control measures will reduce the emission by 50% in PM_{10} (15 kg/day) and 72% in $PM_{2.5}$ (5 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 Paonta Sahib city for the year 2020 is approximately 34,000 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 (PPAC, MoPNG, 2016), 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-fueled. 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. A sizable floating population working in industries must also have an LPG supply.

This action is expected to reduce 82% of PM_{10} (28 kg/day) and 81% of $PM_{2.5}$ (21 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 PM_{10} and $PM_{2.5}$ emissions. The silt load, an important factor in PM emissions from the road varied from 1.5 to 4 g/m^2 which is slightly high (typical load in developed countries is less than 1 g/m^2). 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 50% 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% (PM_{10} = 2773 kg/day and $PM_{2.5}$ = 638 kg/day).

3. If the silt road is greater than 3 gm/m^2, 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/m^2.
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 (Main Market, Badripur Chowk, Vishwakarma Chowk 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 above control measures should be coordinated and supervised by Paonta Sahib Development Authority, Himachal Pradesh Housing Board, Municipal Council Paonta Sahib, 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/m^3 and interlocked concrete shoulder undertaken at Hyderabad can be seen and employed in Paonta Sahib (Figure 6.5).

❑ Construction of Foot Paths

❑ End to End Development of Roads

Figure 6.5: Quality of dust-free Roads, footpaths and dividers with dust control (Courtesy Greater Hyderabad Municipal Corporation)

6.2.7 Vehicle Emission Control, Congestion and Traffic Management

The vehicle emission contribution is significant for CO, NOx, PM_{10}, and $PM_{2.5}$. There is a relatively large contribution of diesel vehicles (trucks, buses, LCVs, cars, etc.) to PM_{10}, $PM_{2.5}$ and NOx. The source apportionment results show that OPS site have very large vehicle contributions (31% in $PM_{2.5}$ and 26% in PM_{10}; Figure 5.11, Chapter 5) with an overall contribution of vehicles in the city is 22% in $PM_{2.5}$ and 21% in PM_{10} in winter months. Out of about 1089 kg/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 2030, 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, MoPG), 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 Paonta Sahib are 7 *(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 Paonta Sahib 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 Paonta Sahib 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 maundering 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. Information Transmission (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 Paonta Sahib 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

Paonta Sahib is a municipal council in Sirmaur district of Himachal Pradesh. It is an industrial town. It is the one of the main centre of commercial and industrial activities in the state. A chaotic, undisciplined, and poorly managed traffic is normal on Badripur chowk and Main Bazar, Court 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 Ambala-Dehradun-Rishikesh Road, Paonta Sahib-Purwala-Bharli road and Ambala Paonta Sahib-Dehradun 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 at some of the areas where these unorganized shops on Ambala-Paonta Sahib-Dehradun Road in main market.
- Heavy-duty vehicles and buses which are destined for other cities pass through major roads within Paonta Sahib city and create heavy congestion. The important points of congestions are Kishanpura-Jamniwala Road, Main Market Road, Badripur Chowk, Vishwakarma Chowk, Bangran Chowk and Main Market. The city main road is Ambala-Dehradun Road and this having mostly traffic; As a result, these routes within the city will also be congested.
- Areas that are adjacent to the market centers like Main Market, Court Road, Ramghat Road, Badripur and Shamsherpur 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 6.6).

Table 6.1: Major Traffic Bottleneck at Paonta Sahib City

Kishanpura-Jamniwala Road	Main Market Road
Badripur Chowk	Vishwakarma Chowk
Bangran Chowk	Main Market

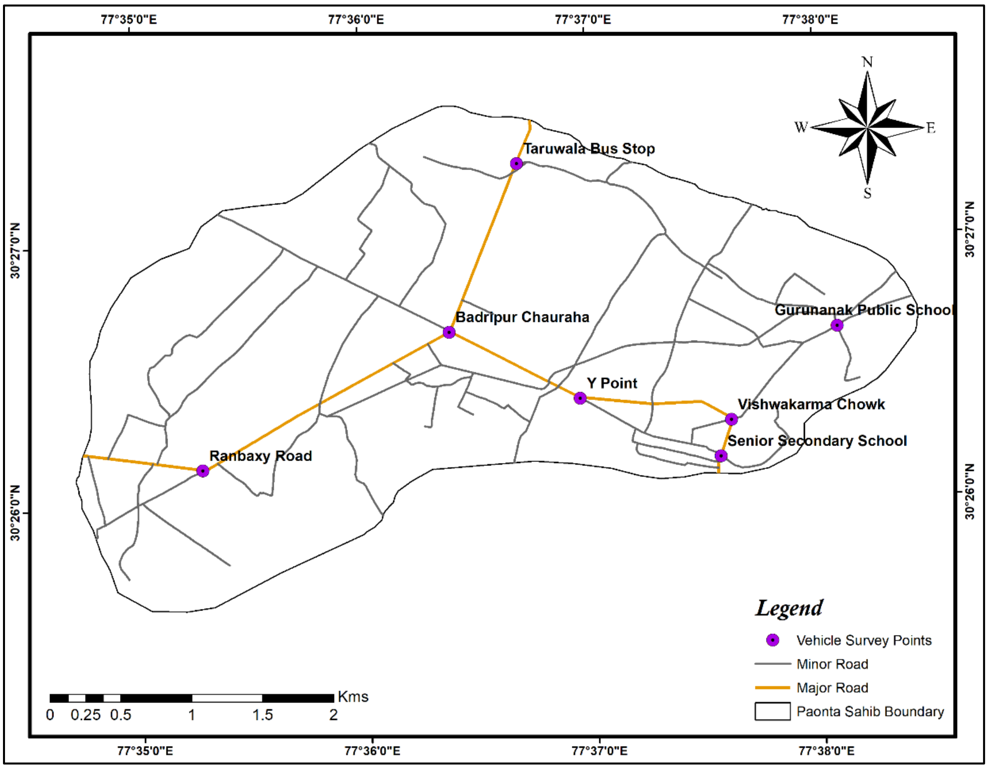


Figure 6.6: Location of traffic bottlenecks

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 6.7) 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.

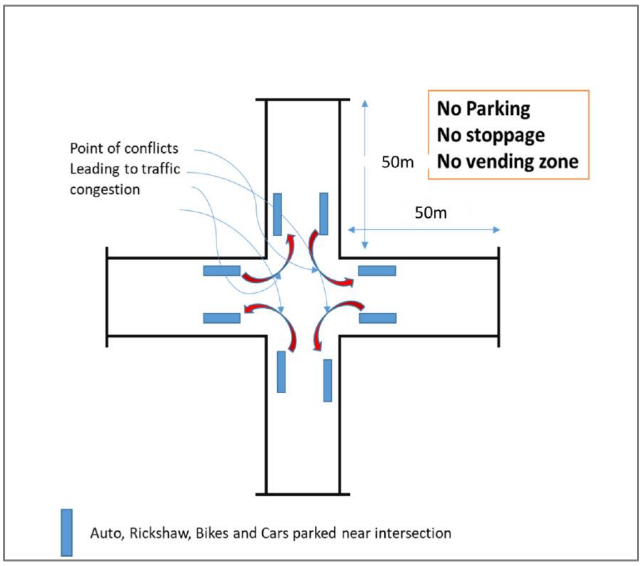


Figure 6.7: Conflicts due to on-street parking near intersections

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 6.8). 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.

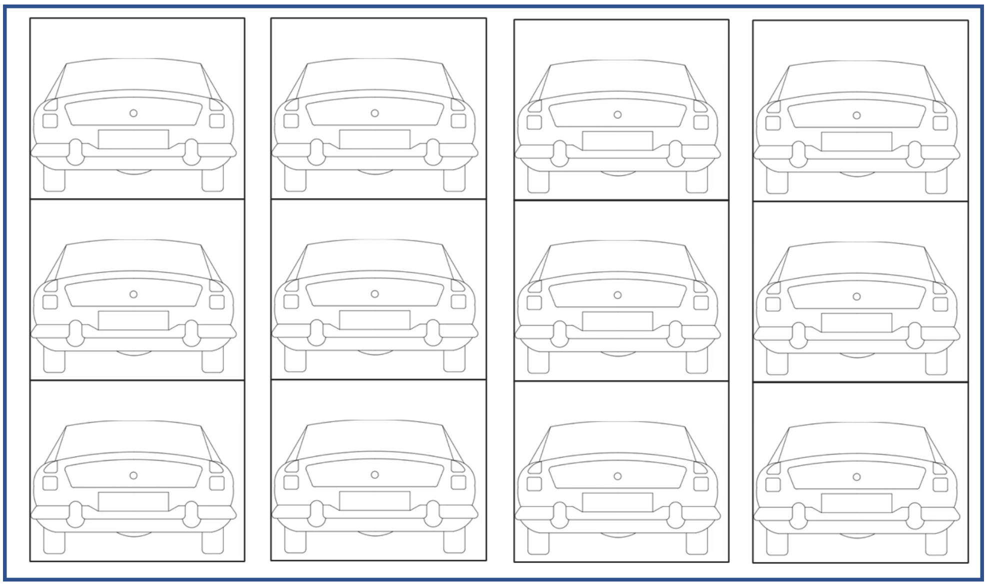


Figure 6.8: Multi-level car parking (example)

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.

6.2.8 Industries

Besides PM pollution (discussed later), ambient air samples collected in the industrial area during the winter months show high levels of PM_{10} and $PM_{2.5}$; these levels are not acceptable. There are more than 9 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., PSDA) 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 Paonta Sahib. 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 6.9 – 6.11) is far more effective than top suction, which interferes with the movement of the crane.

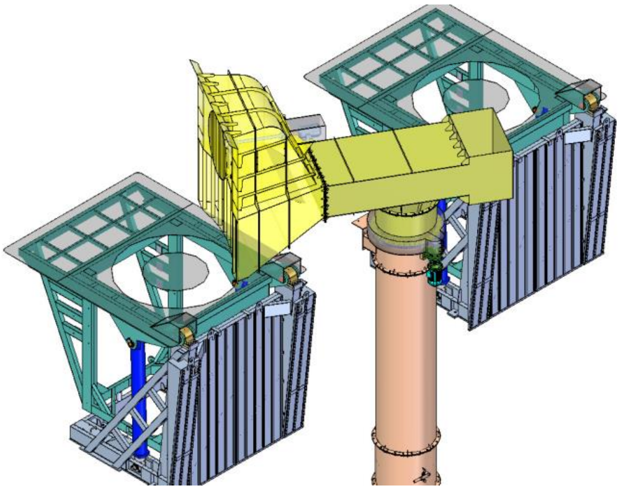


Figure 6.9: Proposed Suction Hood (Pic courtesy: Electrotherm)

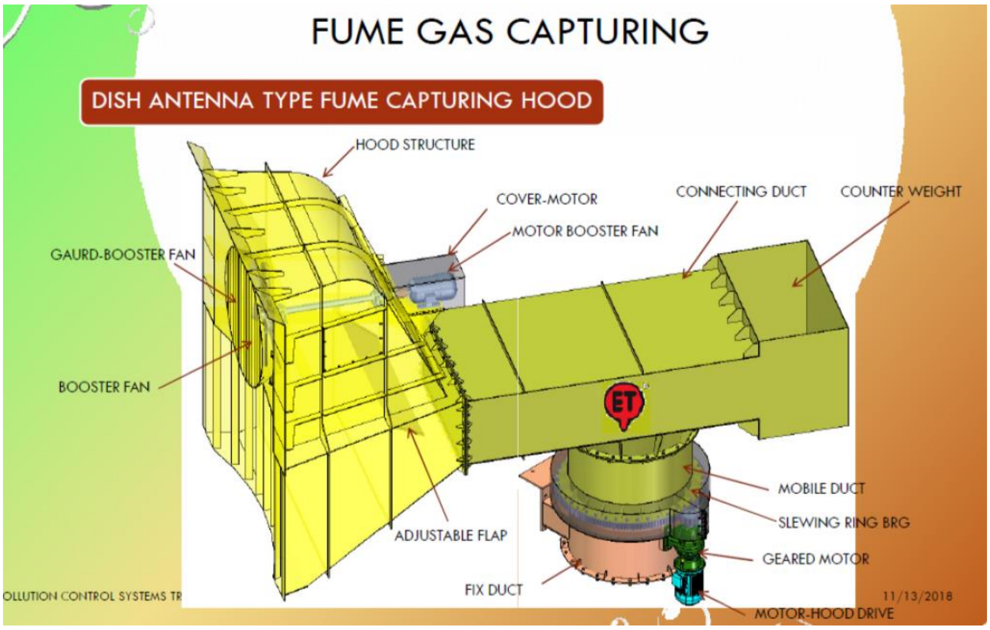


Figure 6.10: Side-based Suction Hood (Pic courtesy: Electrotherm)

Figure 6.11: 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 (Ganguwala, Gondpur, and Jawalpur). Hazardous waste (oil, grease, paint, packaging material etc.) is dumped and burned on the roads in the areas like Ambala-Dehradoon Road, where the trucks are being parked/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, Paonta Sahib 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 PM_{10}.

6.4 Strengthening of HPSPCB Paonta Sahib, 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 their personnel
- Laboratory up-gradation

Table 6.2: A Glance of Control Options and Action Plan for City of Paonta Sahib (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 15 persons) appliances.	Municipal Council, Paonta Sahib	1 year
	Link Commercial license to clean fuel	Municipal Council, Paonta Sahib, 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, Paonta Sahib	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 cooking (common in western countries) or PNG at the	Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian	10 years

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
	minimum	Oil/HP, etc.)	
Municipal Solid Waste (MSW) Burning	Develop an Integrated treatment, storage and disposal facility (TSDF)	Municipal Council, Paonta Sahib, HPSPCB, PSDA	One year
	Any type of garbage burning should be strictly stopped. Current waste collection and surveillance are poor.	Municipal Council, Paonta Sahib	Immediate
	Surveillance is required that hazardous waste goes to TSDF.	Municipal Council, Paonta Sahib, HPSPCB, Paonta Sahib Development Authority (PSDA)	
	Desilting and cleaning of municipal drains	Municipal Council, Paonta Sahib	
	Waste burning in Industrial areas should be stopped.	HPSIDC, HPSPCB	
	Daily, Monthly mass balance of MSW generation and disposal	Municipal Council, Paonta Sahib	
	Sensitize people and media through workshops and literature distribution so as not to burn the waste.	Municipal Council, Paonta Sahib, HPSPCB, and NGO	
Construction and Demolition	Wet suppression	PSDA, Municipal Council, Paonta Sahib, Urban Development Department, PWD	Immediate
	Wind speed reduction (for large construction sites)	PSDA, Municipal Council, Paonta Sahib, Urban Development Department, PWD	
	Enforcement of C&D Waste Management Rules. The	PSDA, Municipal Council, Paonta Sahib,	Immediate

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
	waste should be sent to a construction and demolition processing facility	Urban Development Department, PWD	
	Proper handling and storage of raw material: covered the storage and provide the windbreakers.	PSDA, Municipal Council, Paonta Sahib, Urban Development Department, PWD	
	Vehicle cleaning and specific fixed wheel washing on leaving the site and damping down of haul routes.	PSDA, Municipal Council, Paonta Sahib, Urban Development Department, PWD	
	The actual construction area should be covered by a fine screen.	PSDA, Municipal Council, Paonta Sahib, 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)	PSDA, Municipal Council, Paonta Sahib, Urban Development Department, PWD	
	Builders should leave 25% area for green belt in residential colonies to be made mandatory.	PSDA, Municipal Council, Paonta Sahib, Urban Development Department, PWD	
	Sensitize construction workers and contract agencies through workshops.	PSDA, Municipal Council, Paonta Sahib, Urban Development Department, PWD, HPSPCB, and NGO	
Road Dust	The silt load in Paonta Sahib varies from 1.5 to 4 g/m^2. The silt load on each road should be reduced to	PSDA, Municipal Council, Paonta Sahib, National Highway Authority, PWD, HPSPCB	Immediate

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
	under 2 gm/m^2. Regular vacuum sweeping should be done on the road having a silt load above 2 $gm/m^{2.}$	(for silt load compliance)	
	Convert unpaved roads to paved roads. Maintain pothole-free roads.	PSDA, Municipal Council, Paonta Sahib, 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.	PSDA, Municipal Council, Paonta Sahib, National Highway Authority, PWD	
	Increase green cover and plantation. Undertake the green of open areas, community places, schools, and housing societies.	PSDA, Municipal Council, Paonta Sahib, National Highway Authority, State Forest Department, PWD	
	vacuum-assisted sweeping is carried out four times a month on major roads with road washing.	PSDA, Municipal Council, Paonta Sahib, 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	Industrial Associations and State transport Department	Immediate

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
	finished products		
	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 Paonta Sahib.	Transport Department, Traffic Police, Paonta Sahib, 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 Paonta Sahib	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 Paonta Sahib	1year
	Enforcement of bus lanes and keeping them free from obstruction and encroachment.	Municipal Council, Paonta Sahib, ARTO Paonta Sahib	1 year

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
	Route rationalization: Improvement of availability by rationalizing routes and fleet enhancement with requisite modification.	PSDA, ARTO Paonta Sahib, Traffic Police, Paonta Sahib	1 year
	IT systems in buses, bus stops, control centers, and passenger information systems for the reliability of bus services and monitoring.	PSDA, ARTO Paonta Sahib, Traffic Police, Paonta Sahib	1 year
	Movement of materials (raw and product) within the city should be allowed between 10 PM to 5 AM.	PSDA, ARTO Paonta Sahib, Traffic Police, Paonta Sahib	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	
	There should be separate Treatment, Storage, and Disposal Facilities (TSDFs) for hazardous waste.	Industrial Associations, PSDA, 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

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
	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 5 boilers, Heater and furnaces in Paonta Sahib 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. 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	State Energy Department, HPSEBL	2 years

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
	power supply to the industries.		
	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.	PSDA, Municipal Council, Paonta Sahibs, ARTO Paonta Sahib, Traffic Police, Paonta Sahib	6 months
	Disciplined Public transport (designate one lane stop).	ARTO Paonta Sahib., Traffic Police, Paonta Sahib	
	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.	PSDA, Municipal Council, Paonta Sahib, ARTO Paonta Sahib, Traffic Police, Paonta Sahib	
	Examine the existing framework for removing broken vehicles from roads and create a system for speedy removal and ensure minimal disruption to traffic.	PSDA, ARTO Paonta Sahib, NHAI, Traffic Police, Paonta Sahib	
	Synchronize traffic movements or introduce intelligent traffic systems for lane-driving.	PSDA, ARTO Paonta Sahib, NHAI, Traffic Police, Paonta Sahib	
	Mechanized multi-story parking at bus stands, and big commercial areas.	PSDA, ARTO Paonta Sahib, Municipal Council, Paonta Sahib, NHAI, Traffic Police,	

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
	Remove at least 50 percent of on-street parking in the city.	Paonta Sahib	
	Identify traffic bottleneck intersections and develop a smooth traffic plan. For example, Kishanpura-Jamniwala Road, Main Market Road, Badripur Chowk, Vishwakarma Chowk, Bangran Chowk and Main Market are the main bottlenecks for traffic.	PSDA, ARTO Paonta Sahib, Municipal Council, Paonta Sahib, Traffic Police, Paonta Sahib	
	Parking policy in congestion areas (high parking cost, at city centers, only parking is limited for physically challenged people, etc).	PSDA, ARTO Paonta Sahib, Municipal Council, Paonta Sahib, NHAI, Traffic Police, Paonta Sahib	
	The important point of congestion is Main Market. Parking in Main Market parking should be strictly prohibited.	ARTO Paonta Sahib, Traffic Police	2 years
*The above steps should not only be implemented in Paonta Sahib municipal limits rather these should be extended up to at least 10 km beyond the boundary. This will need support from the central government and adjacent city administration.			

References

Anchal Sharma, Ashok Kumar Gupta, Rajiv Ganguly. "Impact of open dumping of municipal solid waste on soil properties in mountainous region." *Journal of Rock Mechanics and Geotechnical Engineering*, 2018: 725-739.

PPAC, MoPNG (2016) "Assessment Report: Primary survey on household cooking fuel usage and willingness to convert to LPG", *Petroleum Planning & Analysis Cell, Ministry of Petroleum and Natural Gas, Government of India*. (https://www.ppac.gov.in/WriteReadData/Reports/201710310449342512219PrimarySurveyReportPPAC.pdf).

NGT CELL and Waste Management Division, HPSPCB.

Census-India, (2012). Census of India, 2011. *The Government of India*, New Delhi, India. (http://censusindia.gov.in/)

ARAI, (2009), Air Quality Monitoring Project-Indian Clean Air Programme (ICAP): 'SOURCE PROFILING FOR VEHICULAR EMISSIONS' as a part of Ambient Air Quality Monitoring and Emission Source Apportionment Studies. *Central Pollution Control Board*, Government of India, Delhi, India, Report No. ARAI/VSP-III/SP/RD/08-09/60

ARAI, (2011), Indian Emissions Regulations: Limits, Regulations and Measurement of Exhuast Emissions and Calculation of Fuel Consumption. *The Automotive Research Association of India*, Pune, India

Cooper, J.A. and Watson J.G., (1980), Receptor oriented methods of air particulate source apportionment. *JAPCA*, 30(10): 1116-1125.

Javitz, H.S., Watson, J.G. and Robinson, N.F., (1988). Performance of the chemical mass balance model with simulated local-scale aerosols. *Atmos. Environ*., 22(10): 2309-2322.

NOAA, (2013), Real-time Environmental Applications and Display sYstem: Providing a Unique Web-based System for Displaying Meteorological Data. National Oceanic and Atmospheric Administration, *Air Resources Laboratory*, College Park, MD 20740.

Sharma M, (2020), Air Quality Assessment, Trend Analysis, Emission Inventory and Source Apportionment Study in Jaipur City, (Final Report), IIT Kanpur submitted to Rajasthan State Pollution Control Board, Jaipur.

USEPA (2014), EPA Positive Matrix Factorization (PMF) 5.0 Fundamentals and User Guide Air Quality Modeling Group. *U.S. Environmental Protection Agency*, NC., EPA/600/R-14/108

USEPA, (1991), Receptor model technical series, Vol. 1: Overview of receptor model application to particulate source apportionment. *Office of Air Quality Planning and Standards Research Triangle Park*, North Carolina, EPA- 450/4-81-061

USEPA, (1999a), Compendium of Methods for the determination of Inorganic Compounds in Ambient Air, Compendium Method IO-4.2: Determination of Reactive Acidic and Basic Gases and Strong Acidity of Atmospheric Fine Particles (<2.5μm) in Ambient Air. Center for Environmental Research Information Office of Research and Development, *U.S. Environmental Protection Agency*, Cincinnati, OH 45268, EPA/625/R-96/010a1999.

USEPA, (1999b), Compendium of Methods for the determination of Inorganic Compounds in Ambient Air, Compendium Method IO – 3.1: Selection, Preparation and Extraction of filter material. Center for Environmental Research Information Office of Research and Development, *U.S. Environmental Protection Agency*, Cincinnati, OH 45268, EPA/625/R-96/010a.

USEPA, (1999c), Compendium of Methods for the determination of Inorganic Compounds in Ambient Air, Compendium Method IO-3.4: Determination of Metals in Ambient Particulate Matter using Inductively Coupled Plasma (ICP) Spectroscopy. Center for Environmental Research Information Office of Research and Development, *U.S. Environmental Protection Agency*, Cincinnati, OH 45268, EPA/625/R-96/010a.

USEPA, (1999d), Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air, Compendium Method TO-13A: Determination of Polycyclic Aromatic Hydrocarbons (PAHs) in Ambient Air Using Gas Chromatographic/Mass Spectrometry (GC/MS). Center for Environmental Research Information Office of Research and Development, *U.S. Environmental Protection Agency*, Cincinnati, OH 45268, EPA/625/R-96/010b.

USEPA, (2000), AP 42, Fifth Edition, Compilation of Air Pollutant Emission Factors. http://www3.epa.gov/ttnchie1/ap42/ <last retrieved on November 05, 2015>

USEPA, (2006), SPECIATE-4.0-Speciation Database Development Documentation, U.S. *Environmental Protection Agency*, NC, EPA/ 600/ R-06/161

USEPA, (2015), AERMOD View, Gaussian Plume Air Dispersion Model – AERMOD, Version 9.0 *Lakes Environmental* Software

USEPA, 2000. AP 42, fifth edition, Compilation of Air Pollutant Emission Factors, USEPA

Watson, J.G. (1984), Overview of receptor model principles. JAPCA, 34: 619-623.

Watson, J.G., Chow, J.C., Lu, Z., Fujita, E.M., Lowenthal, D.H., Lawson, D.R., and Ashbaugh L.L., (1994), Chemical Mass Balance Source Apportionment of PM_{10} during the Southern California Air Quality Study. *Aerosol Sci. Technol*., 21(1): 1-36.

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	NOx	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 =500 ppm (wt/wt).

Annexure 2

Gridded Emissions for Paonta Sahib city are represented below.

GRID	PM_{10}	$PM_{2.5}$	SO_2	NO_X	CO
P1	0.72	0.52	0.11	0.27	3.38
P2	4.08	3.61	76.22	39.05	5.96
P3	0.13	0.00	0.00	0.00	0.00
P4	0.07	0.00	0.00	0.00	0.00
P5	0.00	0.00	0.00	0.00	0.00
P6	0.00	0.00	0.00	0.00	0.00
P7	0.00	0.00	0.00	0.00	0.00
P8	0.00	0.00	0.00	0.00	0.00
P9	0.00	0.00	0.00	0.00	0.00
P10	0.00	0.00	0.00	0.00	0.00
P11	0.00	0.00	0.00	0.00	0.00
P12	0.00	0.00	0.00	0.00	0.00
P13	0.00	0.00	0.00	0.00	0.00
P14	1.70	1.22	0.25	0.64	7.94
P15	12.17	4.59	1.31	11.80	14.27
P16	1.71	0.83	0.14	0.35	4.35
P17	0.20	0.06	0.01	0.02	0.19
P18	0.87	0.62	0.13	0.33	4.07
P19	0.00	0.00	0.00	0.00	0.00
P20	0.00	0.00	0.00	0.00	0.00
P21	0.01	0.00	0.00	0.00	0.01
P22	1.43	0.79	0.81	0.46	3.18
P23	10.14	3.28	0.25	10.75	7.50
P24	0.00	0.00	0.00	0.00	0.00
P25	0.00	0.00	0.00	0.00	0.00
P26	0.00	0.00	0.00	0.00	0.00
P27	233.87	75.21	0.49	248.70	169.11
P28	360.62	124.70	1.92	469.79	343.85
P29	335.44	107.81	0.34	356.82	241.98
P30	210.94	68.06	0.59	223.95	154.77
P31	2.67	0.85	0.08	0.21	2.62
P32	3.14	1.18	0.14	0.37	4.55
P33	5.11	1.84	0.20	0.52	6.42
P34	145.34	72.68	4.25	338.06	369.67
P35	327.42	159.95	13.49	728.90	773.62
P36	328.39	152.68	3.19	679.00	702.73

GRID	PM_{10}	$PM_{2.5}$	SO_2	NO_X	CO
P37	1.74	0.95	0.16	0.42	5.23
P38	0.00	0.00	0.00	0.00	0.00
P39	0.00	0.00	0.00	0.00	0.00
P40	0.03	0.02	0.00	0.01	0.10
P41	14.49	8.09	0.27	38.53	41.45
P42	0.41	0.29	0.06	0.15	1.91
P43	121.77	39.49	1.71	128.45	90.22
P44	329.94	106.35	1.47	350.11	241.07
P45	137.48	55.32	5.64	194.38	172.25
P46	449.49	153.27	5.35	567.87	427.18
P47	251.04	86.32	3.17	328.48	247.69
P48	39.68	19.29	2.41	92.46	95.97
P49	78.19	47.45	2.51	210.39	301.84
P50	83.53	50.60	1.21	233.49	324.53
P51	1.59	0.58	0.07	0.18	2.18
P52	0.00	0.00	0.00	0.00	0.00
P53	0.01	0.00	0.00	0.00	0.00
P54	1.17	0.65	0.08	2.91	3.25
P55	12.00	6.71	0.20	28.55	34.36
P56	8.33	4.74	0.23	18.77	24.79
P57	23.18	12.09	2.00	39.97	57.63
P58	132.01	56.49	2.23	192.30	184.19
P59	0.77	0.54	0.11	0.28	3.53
P60	0.71	0.51	0.10	0.27	3.35
P61	137.02	64.09	0.87	329.35	320.03
P62	333.02	97.13	1.19	331.96	212.06
P63	157.37	52.04	77.47	195.42	120.32
P64	394.97	128.06	17.19	436.74	374.69
P65	0.00	0.00	0.00	0.00	0.00
P66	0.00	0.00	0.00	0.00	0.00
P67	0.00	0.00	0.00	0.00	0.00
P68	1.54	0.87	0.11	3.48	4.56
P69	2.73	1.45	0.10	6.19	7.41
P70	9.65	5.39	0.36	22.98	27.58
P71	91.88	40.60	0.52	157.15	154.67
P72	46.62	18.53	0.47	63.29	57.93
P73	0.50	0.36	0.07	0.19	2.35
P74	14.57	8.49	1.06	1.11	11.28
P75	98.27	45.82	0.73	237.72	228.15
P76	58.90	52.39	76.41	90.63	255.03
P77	0.02	0.02	0.00	0.01	0.11
P78	0.00	0.00	0.00	0.00	0.00
P79	0.00	0.00	0.00	0.00	0.00

GRID	PM_{10}	$PM_{2.5}$	SO_2	NO_X	CO
P80	0.00	0.00	0.00	0.00	0.00
P81	0.00	0.00	0.00	0.00	0.00
P82	0.05	0.03	0.01	0.02	0.20
P83	28.88	15.81	0.47	68.17	79.63
P84	0.92	0.56	0.11	0.29	3.56
P85	525.45	219.18	3.00	852.89	800.22
P86	41.81	23.14	0.50	105.93	124.16
P87	0.05	0.03	0.01	0.02	0.22
P88	0.00	0.00	0.00	0.00	0.00
P89	0.00	0.00	0.00	0.00	0.00
P90	0.00	0.00	0.00	0.00	0.00
P91	0.00	0.00	0.00	0.00	0.00
P92	0.00	0.00	0.00	0.00	0.00
P93	0.00	0.00	0.00	0.00	0.00
P94	0.00	0.00	0.00	0.00	0.00
P95	0.00	0.00	0.00	0.00	0.00
P96	0.00	0.00	0.00	0.00	0.00
P97	0.01	0.00	0.00	0.00	0.00
P98	0.00	0.00	0.00	0.00	0.00
P99	0.00	0.00	0.00	0.00	0.00
P100	0.00	0.00	0.00	0.00	0.00
P101	0.00	0.00	0.00	0.00	0.00
P102	0.00	0.00	0.00	0.00	0.00
P103	0.00	0.00	0.00	0.00	0.00
P104	0.00	0.00	0.00	0.00	0.00
P105	0.00	0.00	0.00	0.00	0.00
P106	0.00	0.00	0.00	0.00	0.00
P107	0.00	0.00	0.00	0.00	0.00