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: Sunder Nagar

(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 Sunder Nagar 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 Sunder Nagar;
- 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 (January 31 - February 06, 2020).

Table 1: Description of sampling sites in Sunder Nagar

S. No.	Sampling Site	Site Code	Description of the site	Type of sources
1.	BBMB Rest House	**BRH**	Residential	Domestic cooking, vehicles, road dust, garbage/MSW burning, biomass
2.	Govt. Dental College	**GDC**	Commercial and institutional	DG sets, vehicles, road dust, garbage/waste burning, hotels, restaurants, coal uses
3.	Surya Hotel Naulakha	**SHN**	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 59 – 108 µg/m^3 and the mean $PM_{2.5}$ levels were 44 – 69 µg/m^3.
- PM_{10} and $PM_{2.5}$ levels are about to meet the national air quality standards except at SHN, an industrial area in Naulakha. However, particulate pollution is the main concern in the city. It is observed that the air quality in terms of PM_{10} and $PM_{2.5}$ falls in the satisfactory to moderate 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 86±20 μg/m^3 against the acceptable level of 100 μg/m^3. The highest levels were observed at SHN and the lowest at BRH.

The important components are the secondary particles (NO_3^- + SO_4^{2-} + NH_4^+), which account for about 19% of total PM_{10}, and combustion-related total carbon (TC = EC + OC) accounts for about 29%; both fractions of secondary particles and combustion-related carbons account for 48% of PM_{10} in winter months.

The crustal component (Si + Al + Fe + Ca) accounts for about seven percent in PM_{10}. This suggests soil and road dust have less significant contributions. The coefficient of variation (CV) is about 0.41 (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 4 – 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 SHN at 10 μg/m^3 compared to the overall city level of 6.7 μg/m^3. The high level at SHN signifies some local burning of waste in as a means of disposal of solid waste.

$PM_{2.5}$

The overall average concentration of $PM_{2.5}$ in winter is 60±11 μg/m^3 against the acceptable level of 60 μg/m^3. The highest levels are observed at GDC and the lowest at BRH.

The important components are the secondary particles (NO_3^- + SO_4^{2-} + NH_4^+), which account for about 21% of total $PM_{2.5}$ and combustion-related total carbon (TC = EC + OC) accounts for about 31%; 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 SHN (25%) and TC at GDC (34%).

The Cl^- content in $PM_{2.5}$ is consistent and varies between 5 – 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 SHN with some high peaks. SHN was a industrial site having uses of coal in industries 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 GDC. The annual benzene levels are expected to be well below the NAQS of 5 $\mu g/m^3$ and in the safe limit in the city.

The mean 8-hourly ozone and CO levels are within the acceptable limits of NAQS (8-hourly O_3: 100 $\mu g/m^3$; CO: 2 mg/m^3). The diurnal pattern of CO and ozone are consistent as expected.

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 Sunder Nagar.

Total PAH levels (17 compounds; particulate phase) had high variability in the range of 2.9 to 20.2 and B(a)P at 1.02 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 BRH.

The concentrations of molecular markers in $PM_{2.5}$ (a total of 6 compounds) vary in the range of 20 to 85 $ng/m^{3,}$ 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 (2012-2019) temporal PM_{10} and NO_2 levels were analyzed for annual and monthly variations and trends. The air quality data were obtained for 2012–2019 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} and NO_x in Sunder Nagar as most of months show no trend and few months indicate decreasing or decreasing trend. The annual levels of PM_{10} and NO_x also show no trend at Station I and Station II.

Emission Inventory

Emission inventory (EI) is a basic necessity for planning air pollution control activities. The overall baseline EI for Sunder Nagar 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 1976 kg/day. The top three contributors to PM_{10} emissions are Road Dust (69%), Vehicles (18%), and Construction & Demolition (7 %); these are based on annual emissions. Seasonal and daily emissions could be highly variable. The estimated emission suggests that industrial emissions is a major source 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 738 kg/day. The top three contributors to $PM_{2.5}$ emissions are Vehicles (43%), Road Dust (43%), and Construction & Demolition (5%); 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 81 kg/day. The majority of sources which contribute for SO_2 emissions are Industries (38%) and Hotels, Restaurants, GHs & BHs (30%).

NOx emissions load in the city is estimated to be 2544 kg/day. Majority of total emissions are attributed to Vehicles (96%), Hotels, Restaurants, GHs & BHs (2%), and Domestic (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 3075 kg/day. The major contributors to CO emissions are Vehicles (87%), MSW Burning (6%), Domestic (5%). Vehicles could be the main target for controlling CO for improving air quality concerning CO.

The estimated emissions are for benzene: 93 g/d, Pb: 295 g/d, As: 9 g/d, Ni: 96 g/d and BaP: 6 g/d from all sources.

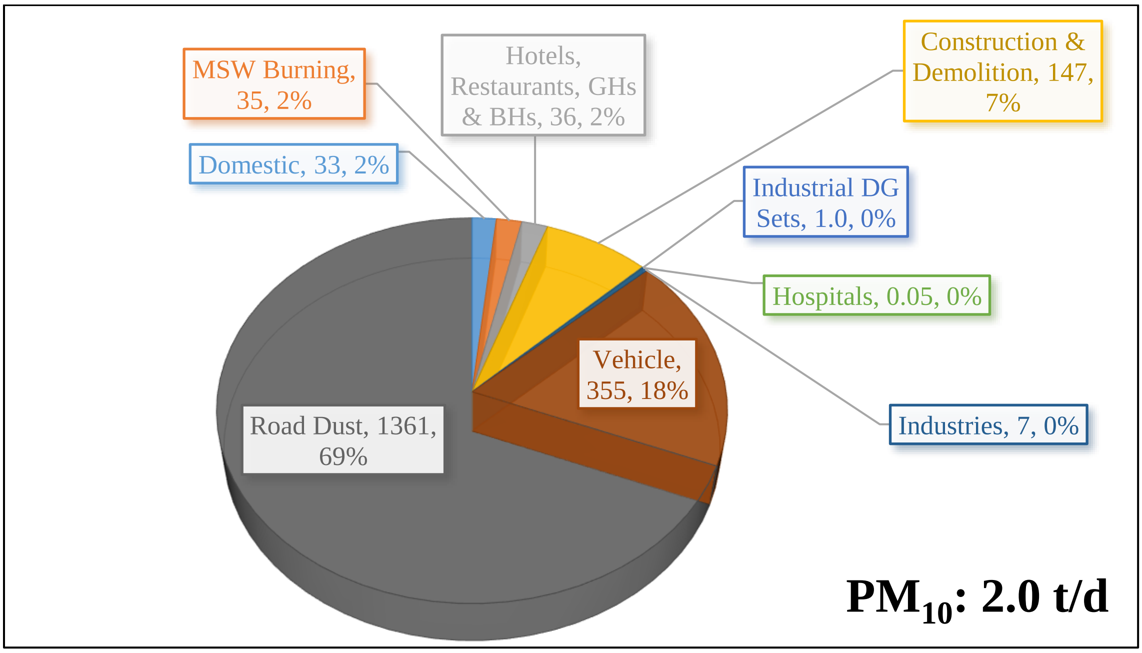

Figure 1: PM_{10} emission Inventory of different sources in Sunder Nagar (kg/d)

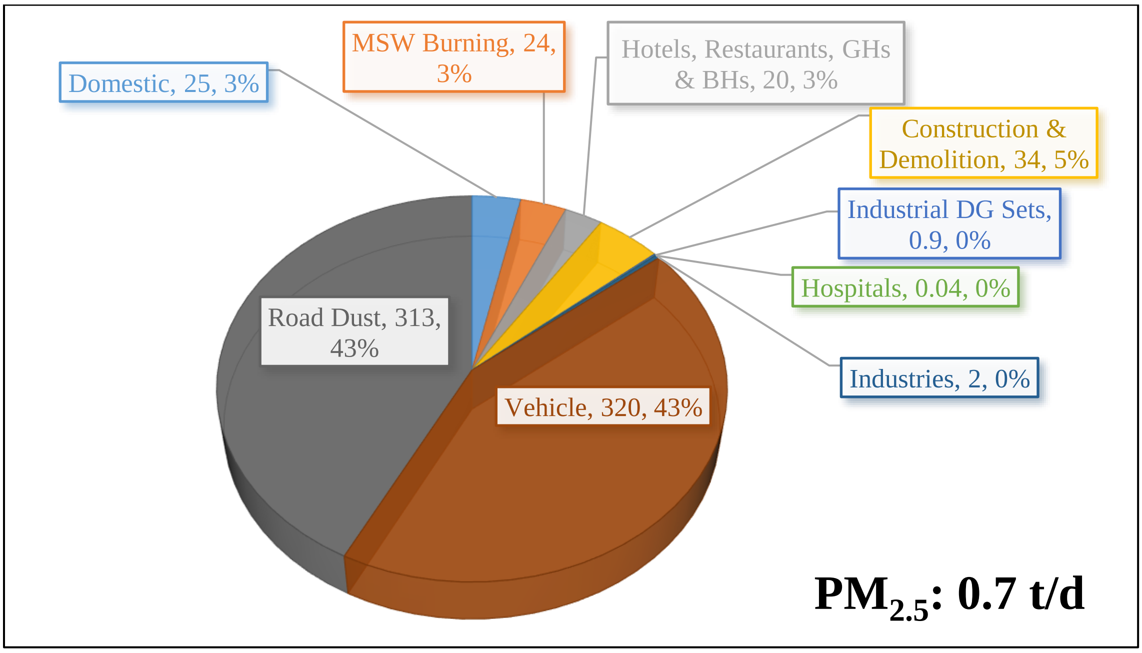

Figure 2: $PM_{2.5}$ emission load of different sources in Sunder Nagar (kg/d)

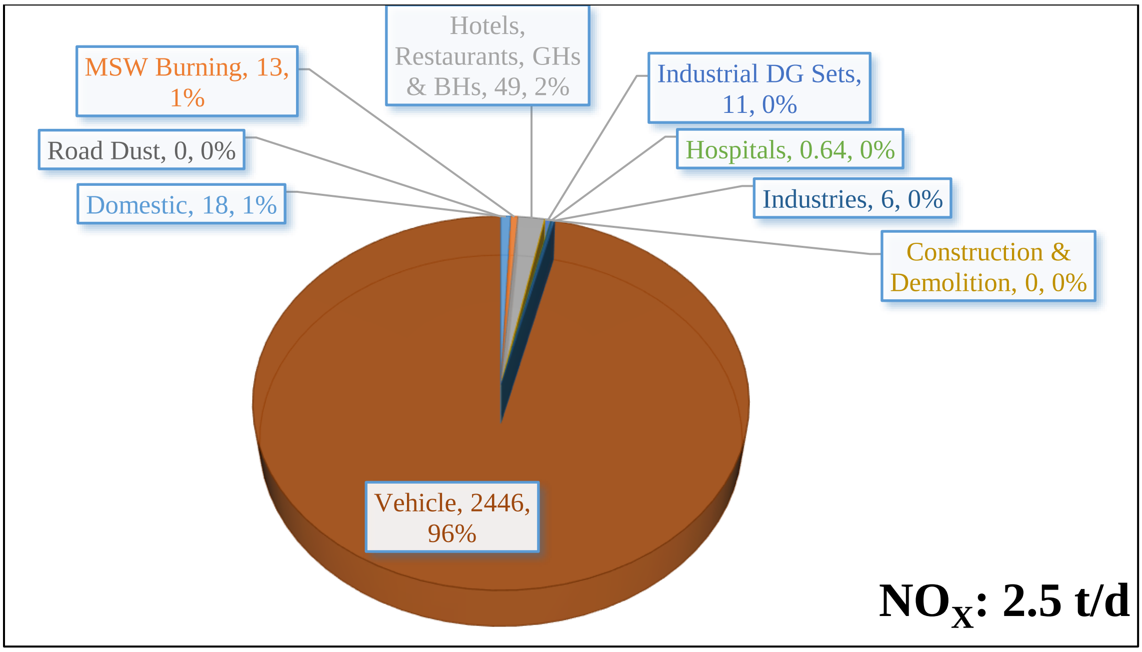

Figure 3: NO_x emission load of different sources in Sunder Nagar (Kg/d)

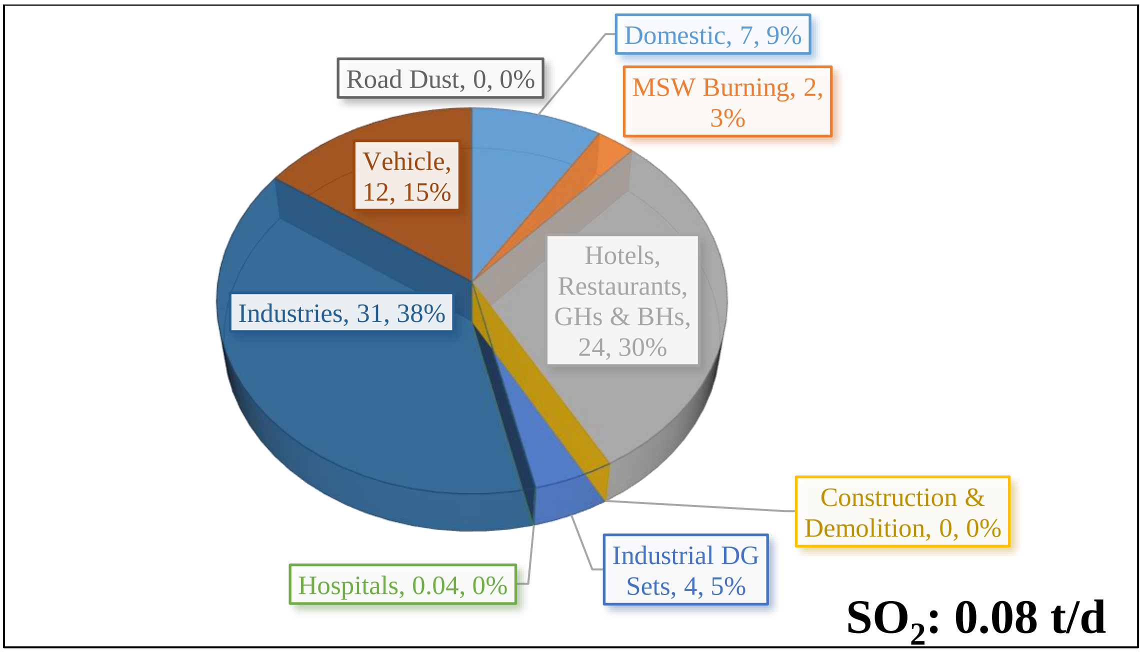

Figure 4: SO_2 emission load of different sources in Sunder Nagar (kg/d)

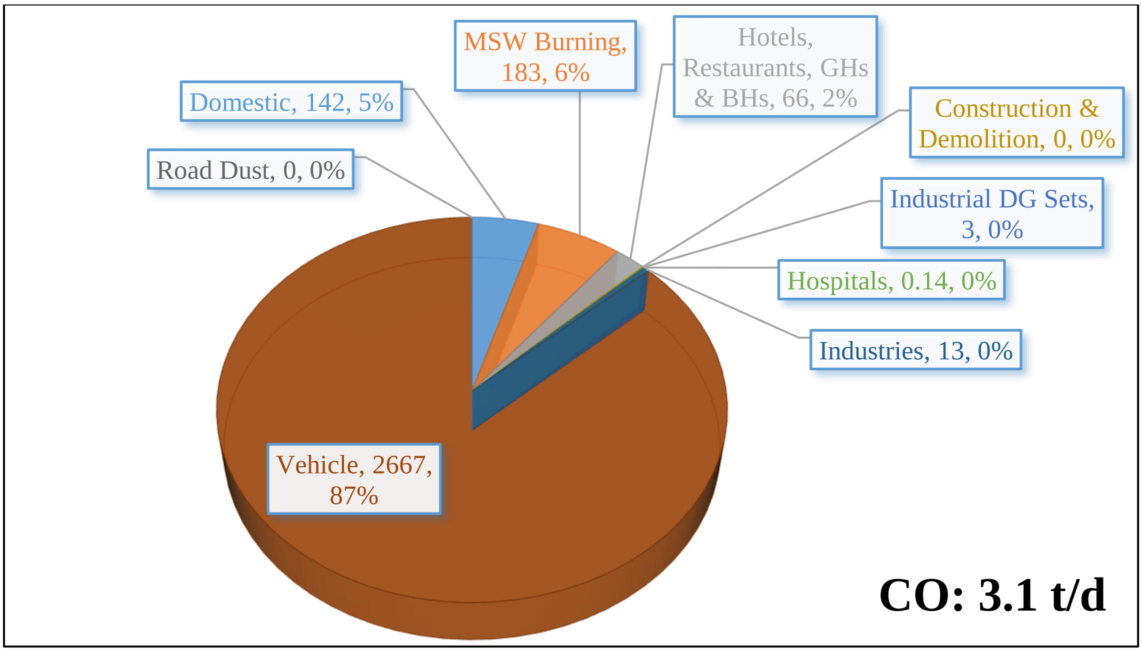

Figure 5: CO emission load of different sources in Sunder Nagar (kg/d)

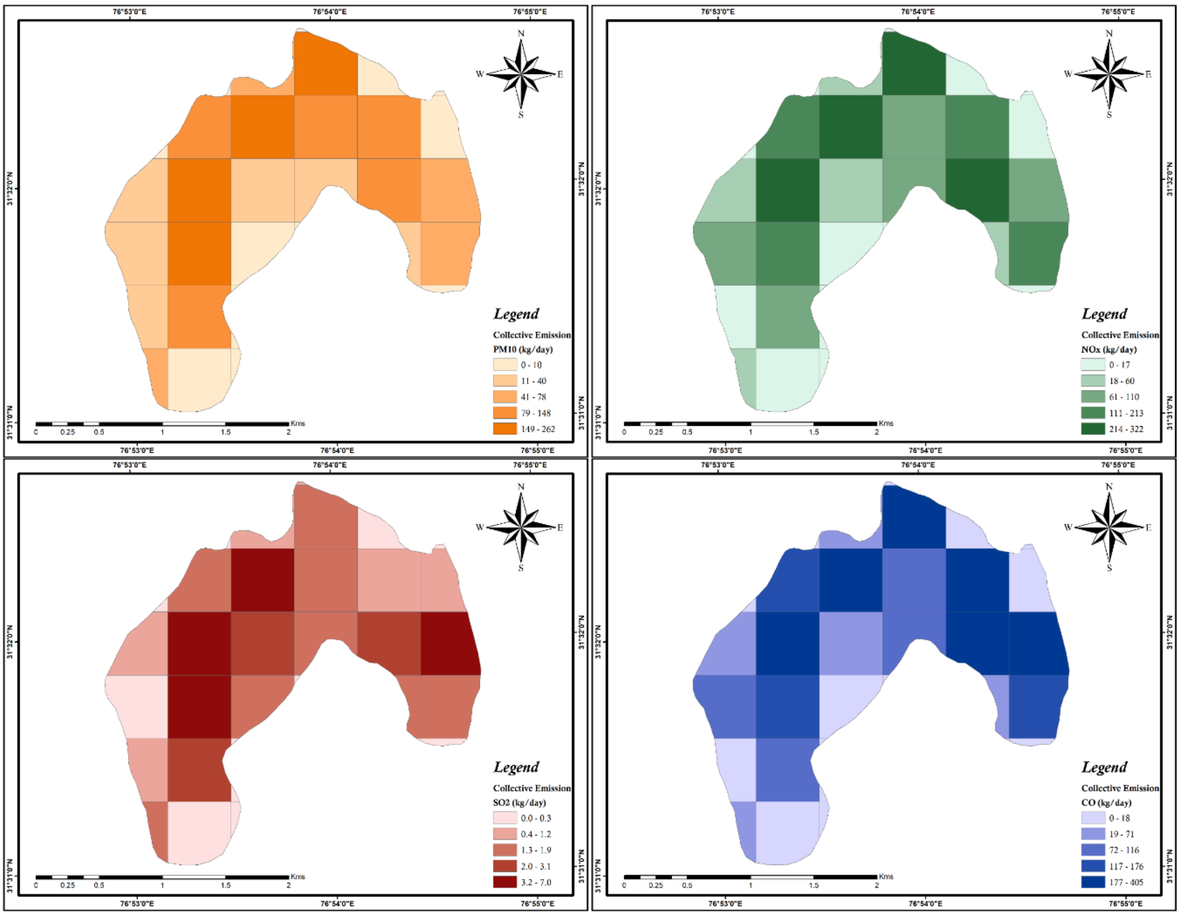

Figure 6: Spatial distribution of PM_{10}, NOx, SO_2 and CO emissions in the city

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 soil and road dust (26 – 19%), MSW burning (20 – 24%), SIA (15 – 16%), vehicles (13 – 13%), biomass burning (12 – 14%), coal combustion and flyash (9 – 9%) and construction activities (5 – 4%).
- The consistent sources for PM_{10} and $PM_{2.5}$ are soil and road dust and MSW burning. 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 coal combustion and fly ash.
- Soil and road dust is the most significant contributor in PM_{10} (26%) and reduced significantly in $PM_{2.5}$ (19%), showing high variability, which infers that the road condition in the town is not up to the mark. It indicates that most parts of roads and kerb-sides were poorly maintained.
- From the uncollected solid waste (plastic waste, packaging material, etc.) the major part is burned. It is seen that MSW burning is a major source that contributes to both PM_{10} (20%) and $PM_{2.5}$ (24%). 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. The dumping and burning of MSW and plastic waste along the roadsides may be a routine practice.
- Vehicles' contribution is significant and consistent at 13% in PM_{10} and $PM_{2.5}$ in the town.
- BRH site was in the commercial area and near the industrial area having major commercial activities and polluting industries in nearby region. Therefore, it has the movement of large trucks ferrying raw material and finished products. Vehicular contribution and soil and road dust is highest at BRH.

- Coal and flyash contribute 15% in PM_{10} and 11% 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.
- The contribution of biomass burning is also significant among all sources at 12% (for PM_{10}) and 14% (for $PM_{2.5}$). Sizeable biomass is consistent in PM, indicating local sources present in Sunder Nagar and nearby areas. Biomass burning is because of arboriculture activities, agricultural residue burning, high energy crop burning for fuel, etc.
- Industrial contribution in the town is negligible in PM_{10} and $PM_{2.5}$. This contribution may be partially merged in coal combustion, biomass and MSW burning. Most of the industrial emissions are from combustion and process emissions.

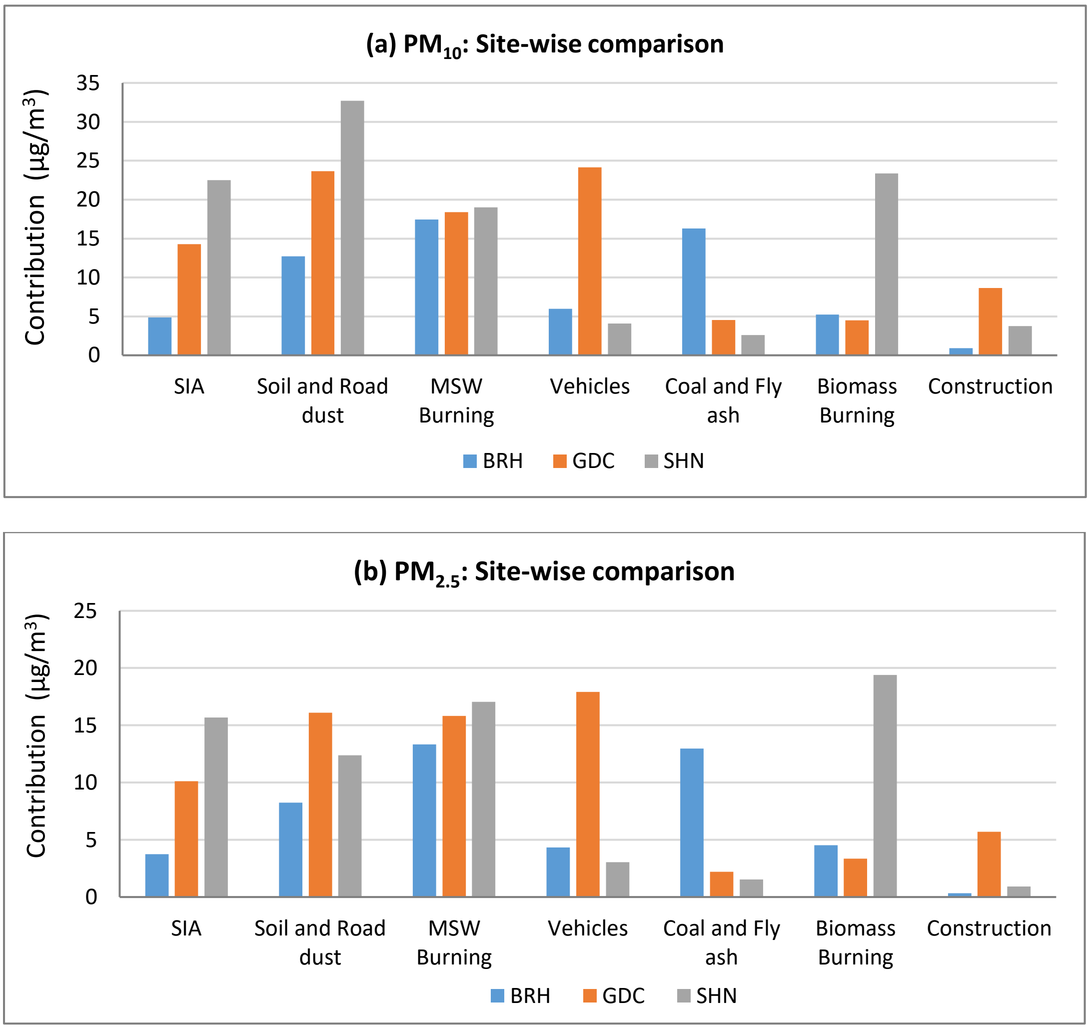

Figure 7: Site-specific source-wise contribution to PM_{10} and $PM_{2.5}$

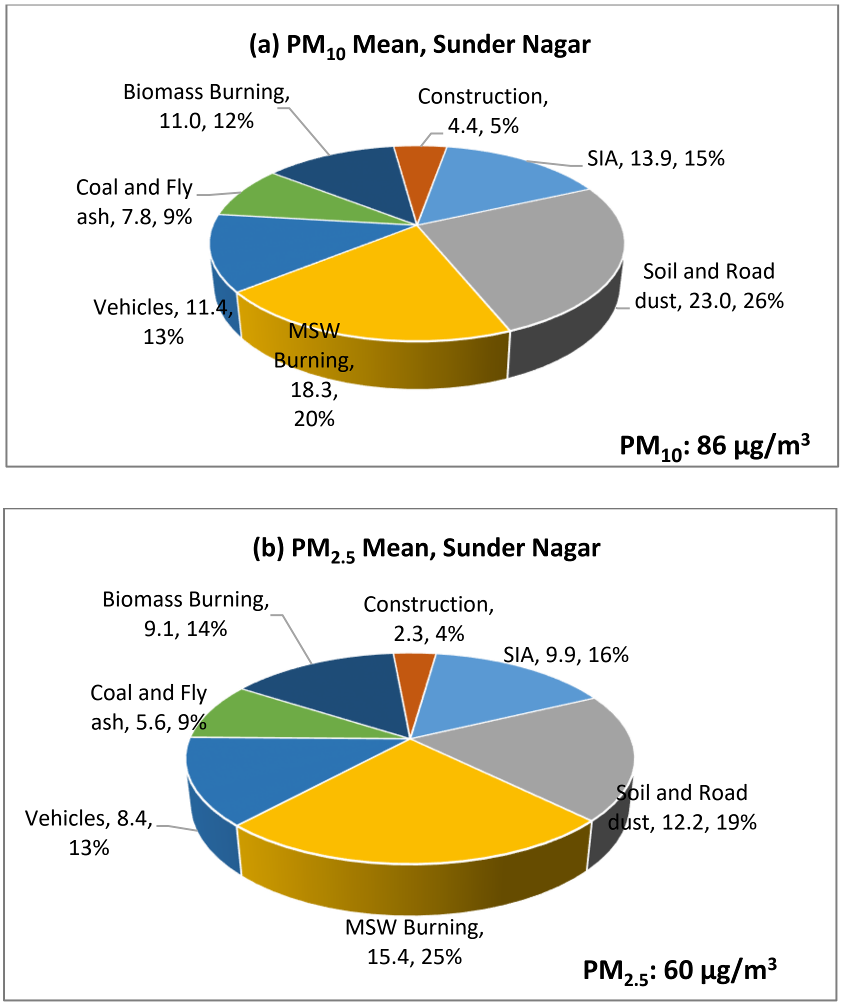

Figure 8: City level source contributions to PM_{10} and $PM_{2.5}$ levels

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 41, mainly situated in the central part of the town and along with the National Highway-154. 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 Sunder Nagar should enforce coal-free cooking in the hotels and restaurants, BHs and marriage places. The ash must be stored in leak-free bags and properly disposed of. One may consider linking the commercial license to clean fuel, which may be enforced by Municipal Council Sunder Nagar, 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 Sunder Nagar. In winter, the overall source contribution from MSW burning is 20% in PM_{10} and 24% 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 Sunder Nagar with help of sub-district administration 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 Naresh chowk, Old Market and Bhojpur Bazar.

  Desilting and cleaning of municipal drains by Municipal Council Sunder Nagar 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 Sunder Nagar, '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 Sunder Nagar should prioritize the MSW collection mechanism starting systematically in each ward/section 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 by District Administration for Sunder Nagar and nearby region. 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 Sunder Nagar, 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 Sunder Nagar authorities, a common practice in large cities/towns. 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 Development Authority, Himachal Pradesh Housing Board, Municipal Council Sunder Nagar, 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 can be seen from Chapters 4 and 5, that the soil and road dust emissions and their contributions to ambient air concentration are consistent and it is one of the largest sources of PM_{10} and $PM_{2.5}$ emissions. The silt load, an important factor in PM emissions from the road varied from 4 to 5 g/m^2, which is high (typical in developed countries less than 1 g/m^2). The contruction of NH-154 was ongoing that results high silt load on the city. The industrial area, where heavy vehicle movement is seen, also shows the high road dust emission. It is suggested that high traffic density roads should be properly maintained, paved from one end to another, have sidewalks through interlocking blocks for the pedestrians, proper drainage from the road, and shrubs should be planted on on-road dividers. Out of the total road network, about 40% of surface quality is poor. The following control measures are suggested to reduce the dust emissions from the major roads:

  - Convert all unpaved, partially paved roads to fully paved roads.
  - Municipal Council should carry out vacuum-assisted sweeping.
  - If the silt road is greater than 3 gm/m^2, the vacuum-assisted sweeping should be carried out along with washing and there should be regular surveillance for maintaining low silt content on road.
  - NHAI should ensure that the silt load on highways maintained by them should have a silt load of less than 3 gm/m^2 across the road in the entire stretch in the city.
  - The condition of the roads must be maintained properly with no potholes and shoulders paved by interlocking concrete to have a proper sidewalk.

- The truck carrying construction material or any airborne material should be covered.
- Vacuum sweeping of roads with high silt load locations (NH-154, Zero Chowk, Bhojpur road, Naresh Chowk and Old Market Road) 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 Development Authority, Himachal Pradesh Housing Board, Municipal Council Sunder Nagar, 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 320 kg/day emissions of $PM_{2.5}$ from vehicles, about 70% is from diesel vehicles, especially trucks and buses. Therefore, control measures must focus on advanced technological intervention for diesel vehicles like Diesel Particulate Filter (DPF). The general recommendations for vehicular emission control are enumerated below (specific recommendations are discussed later).

- Retro-fitment of DPF: This option must be explored as Bharat stage VI fuel is available and this technology can be adopted.
- Industries should encourage employing trucks and heavy-duty vehicles of Bharat stage-VI or IV with DPF for transportation of the raw and finished products at and from the industry.
- By the end of 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, MoP), including public buildings and

parking lots and battery swapping facilities should be planned to avoid long charging periods, especially for two-wheelers.

- Emissions from in-use vehicles also depend on the maintenance and upkeep of vehicles. In this regard, it is suggested that each vehicle manufacturing company should have its authorized service centres in sufficient numbers to cater to the need of their vehicles in the city. Every vehicle at least once a year should undergo a thorough check-up and compliance with pollution control devices and their proper functioning from an authorized centre.
  - 4 - 8 PUC Centres are required per 1,00,000 vehicles (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.
- Check the overload vehicles: Expedite installation of weigh-in-motion bridges and machines at all entry points of Sunder Nagar to ensure that vehicles are not overloaded.
- Himachal Road Transport Corporation (HRTC) should plan and install multiple electric charging facilities in its depots (Sunder Nagar 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: Improvement of availability by rationalizing routes and fleet enhancement with requisite modifications. Ensure integration of the existing metro system with bus service.
- Information Technology (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 some places in Sunder Nagar city. Steps shall be taken to install traffic signals on all the major intersections and traffic police shall enforce smooth traffic.

- Other than a few roads, there is a lack of footpath availability and marking of zebra crossing for the pedestrian movements and people are forced to walk on the road. Proper footpaths and ease of crossing should be available for the pedestrians.

- **Decongestion of Roads**

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

  - Strict action on roadside encroachment.
  - The operation of unauthorized vehicle service centres should be stopped
  - The points of congestion are Sunder Nagar bus station, Naresh Chowk and Old market road which meet to NH-154 and service road; As a result, the Highway within the city will also be congested at some time.
  - Areas that are adjacent to the market centers like Naresh chowk, Old Market, Zero Chowk and Bhojpur Bazar experience traffic congestion due to the unregulated parking and encroachment by local shop owners. The on-street parking has to be removed and if required multistorey parking is developed.
  - Parking spaces: Off-street parking is inadequate in the city. There must be no parking zone (up to 50 m including auto, electric and hand-pulled rickshaw) near the intersections. It will help the smooth traffic flow.
  - Certain parking policies in congestion areas (high parking costs, at city centers, only parking should be limited for physically challenged people.
  - The city should strictly follow recommendations from IRC 12-2015 of prohibiting on-street parking as detailed below:
  - Near Intersections: the capacity of an intersection is greatly reduced if vehicles are allowed to park on the approaches.
  - Narrow Streets: Narrow streets with heavy traffic require that all possible measures should be taken to remove obstacles to traffic flow. Prohibition of parking can have a salutary effect on traffic flow & congestion.
  - Pedestrian Crossings: Desirable to prohibit parking within about 8.0 m from the pedestrian crossings.

- Parking prices: Since on-street parking has been a major concern within the city, strict guidelines need to be adopted to discourage private vehicles in the settlements.
- Promoting public transport travel: Increasing the efficiency of public transport can deliver benefits of enhanced road capacities, accessibility and safety, and security.

- **Industries and Diesel Generator Sets**

There are approximately 3 industrial units in Sunder Nagar City having boilers and furnaces (electric and melting furnace) and other air-polluting units (as per consent data), that contribute to particulate as well as gaseous emissions. The installed devices are inadequate or poorly operated with very low collection efficiency. It is suggested that these industries must control PM with highly efficient capture devices and suitable disposal of collected particles.

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

A coordinated effort under the supervision of HPSPCB and Industries Departments (i.e., Development Authority) 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).
- 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 Sunder Nagar. It is recommended that no industrial waste should be mixed with MSW but rather disposed of at TSDF for hazardous waste disposal.
- 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 Sunder Nagar and HPSPCB.

Strengthening of HPSPCB Sunder Nagar, 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 Sunder Nagar

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 Sunder Nagar	1 year
	Link Commercial license to clean fuel	Municipal Council Sunder Nagar, 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 Sunder Nagar	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	Any type of garbage burning should be strictly stopped. Current waste collection and surveillance are poor.	Municipal Council Sunder Nagar	Immediate
	Surveillance is required that hazardous waste goes to TSDF.	Municipal Council Sunder Nagar, HPSPCB, Development Authority	
	Desilting and cleaning of municipal drains	Municipal Council Sunder Nagar	
	Waste burning in Industrial areas should be stopped.	HPSIDC, HPSPCB	
	Daily, Monthly mass balance of MSW generation and disposal	Municipal Council Sunder Nagar	
	Sensitize people and media through workshops and literature distribution so as not to burn the waste.	Municipal Council Sunder Nagar, HPSPCB, and NGO	
Construction and Demolition	Wet suppression	Development Authority, Municipal Council Sunder Nagar, Urban Development Department, PWD	Immediate
	Wind speed reduction (for large construction sites)	Development Authority, Municipal Council Sunder Nagar, Urban Development Department, PWD	
	Enforcement of C&D Waste Management Rules. The	Development Authority, Municipal Council	Immediate

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
	waste should be sent to a construction and demolition processing facility	Sunder Nagar, Urban Development Department, PWD	
	Proper handling and storage of raw material: covered the storage and provide the windbreakers.	Development Authority, Municipal Council Sunder Nagar, Urban Development Department, PWD	
	Vehicle cleaning and specific fixed wheel washing on leaving the site and damping down of haul routes.	Development Authority, Municipal Council Sunder Nagar, Urban Development Department, PWD	
	The actual construction area should be covered by a fine screen.	Development Authority, Municipal Council Sunder Nagar, 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)	Development Authority, Municipal Council Sunder Nagar, Urban Development Department, PWD	
	Builders should leave 25% area for green belt in residential colonies to be made mandatory.	Development Authority, Municipal Council Sunder Nagar, Urban Development Department, PWD	
	Sensitize construction workers and contract agencies through workshops.	Development Authority, Municipal Council Sunder Nagar, Urban Development	

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
		Department, PWD, HPSPCB, and NGO	
Road Dust	The silt load in Sunder Nagar varies from 4 to 5 g/m^2. The silt load on each road should be reduced to under 3 gm/m^2. Regular vacuum sweeping should be done on the road having a silt load above 3 $gm/m^{2.}$	Development Authority, Municipal Council Sunder Nagar, National Highway Authority, PWD, HPSPCB (for silt load compliance)	Immediate
	Convert unpaved roads to paved roads. Maintain pothole-free roads.	Development Authority, Municipal Council Sunder Nagar, 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.	Development Authority, Municipal Council Sunder Nagar, National Highway Authority, PWD	
	Increase green cover and plantation. Undertake the green of open areas, community places, schools, and housing societies.	Development Authority, Municipal Council Sunder Nagar, National Highway Authority, State Forest Department, PWD	
	vacuum-assisted sweeping is carried out four times a month on major roads with road washing.	Development Authority, Municipal Council Sunder Nagar, National Highway Authority, PWD	
Vehicles	Diesel vehicles entering the city should be equipped with DPF which will bring a reduction of 40% in	State Transportation Department	3 years

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
	emissions (This option can be implemented with vehicles of the BS-IV category as well)		
	Industries must be encouraged to use BS-VI or BS-IV (with DPF) vehicles for the transportation of raw and finished products	Industrial Associations and State transport Department	Immediate
	Restriction on plying and phasing out of 10 years old commercial diesel-driven vehicles.	Transport Department	2 years
	Introduction of cleaner fuels (CNG/ LPG) for all vehicles (other than 2-W).	Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian Oil/HP, etc.)	2 years
	Check to overload: Expedited installation of weigh-in-motion bridges and machines at all entry points to Sunder Nagar.	Transport Department, Traffic Police, Sunder Nagar, 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, RTO Sunder Nagar	1 year
	Bus stop and their parking should be rationalized to ensure more efficient utilization. The depots should	Transport Department, RTO Sunder Nagar	1year

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
	include well-equipped maintenance workshops. Adequate charging stations.		
	Enforcement of bus lanes and keeping them free from obstruction and encroachment.	Municipal Council Sunder Nagar, RTO Sunder Nagar	1 year
	Route rationalization: Improvement of availability by rationalizing routes and fleet enhancement with requisite modification.	Development Authority, RTO Sunder Nagar, Traffic Police, Sunder Nagar	1 year
	IT systems in buses, bus stops, control centers, and passenger information systems for the reliability of bus services and monitoring.	Development Authority, RTO Sunder Nagar, Traffic Police, Sunder Nagar	1 year
	Movement of materials (raw and product) within the city should be allowed between 10 PM to 5 AM.	Transport Department, Sunder Nagar, Development Authority, RTO Sunder Nagar, Traffic Police, Sunder Nagar	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, Development Authority, HPSIDC, Industries Department,	2 years

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
		HPSPCB	
	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		Immediate
	Area and road in front of the industry should be the responsibility of the industry		
	Category A Industries (using coal and other dirty fuels)		
	About 3 boilers and hot mix plant in Sunder Nagar are running over wood and LDO 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

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
	Diesel Generator Sets		
	Strengthening of grid power supply, uninterrupted power supply to the industries.	State Energy Department, HPSEBL	2 years
	Renewable energy should be used to cater to the need of office requirements in the absence of power failure to stop the use of DG Set.	Industrial Associations	2 years
Decongestion of Roads in high traffic areas	Strict action on roadside encroachment. Disciplined movement of tempos to stop only at designated spots. Action on driving in the wrong lane.	Development Authority, Municipal Council Sunder Nagar, RTO Sunder Nagar, Traffic Police, Sunder Nagar	6 months
	Disciplined Public transport (designate one lane stop).	RTO Sunder Nagar., Traffic Police, Sunder Nagar	
	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.	Development Authority, Municipal Council Sunder Nagar, RTO Sunder Nagar, Traffic Police, Sunder Nagar	
	Examine the existing framework for removing broken vehicles from roads and create a system for speedy removal and ensure minimal disruption to traffic.	Development Authority, RTO Sunder Nagar, NHAI, Traffic Police, Sunder Nagar	
	Synchronize traffic movements or introduce intelligent traffic systems for lane-driving.	Development Authority, RTO Sunder Nagar, NHAI, Traffic Police, Sunder Nagar	

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
	Mechanized multi-story parking at bus stands, and big commercial areas. Remove at least 50 percent of on-street parking in the city.	Development Authority, RTO Sunder Nagar, Municipal Council Sunder Nagar, NHAI, Traffic Police, Sunder Nagar	
	Identify traffic bottleneck intersections and develop a smooth traffic plan. For example, NH-154, Bhojpur Road, Naresh Chowk, Zero Chowk and Old Market Road. Naresh Chowk are the main bottlenecks for traffic.	Development Authority, RTO Sunder Nagar, Municipal Council Sunder Nagar, Traffic Police, Sunder Nagar	
	Parking policy in congestion areas (high parking cost, at city centers, only parking is limited for physically challenged people, etc).	Development Authority, RTO Sunder Nagar, Municipal Council Sunder Nagar, NHAI, Traffic Police, Sunder Nagar	
	The important point of congestion is Naresh Chowk and Bhojpur road; Parking on Main market should be strictly prohibited.	RTO Sunder Nagar, Traffic Police	2 years
*The above steps should not only be implemented in Sunder Nagar boundary limits rather these should be extended up to at least 10 km beyond the boundary. This will need support from the state government and adjacent city administration.			

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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 Sunder Nagar, a small city and Tehsil in Mandi District in Himachal Pradesh having a large number of industries in different sectors, i.e., food processing units, brick kilns, batching plants, agriculture, stone crushers, and engineering industries in and around nearby areas within 5 km.

1.2 General Description of Sunder Nagar

1.2.1 Geography and Demography

Sunder Nagar is a small city and Tehsil in Mandi district of Himachal Pradesh situated at 31.5299° N, 76.8889° E with the elevation of 900 m. The city lies in the lap of Shiwalik foothills and near the border of Himachal Pradesh and Panjab states. It is situated on National Highway 154 that is about 22 kms away from Mandi, district headquarter. It has immense potential for future growth for establishing an export market for fruits, vegetables, timbers, and other forest produces.

In Sunder Nagar, the key business activities are trade, commerce, industries and agriculture. The major industry sectors in and around Sunder Nagar are categorized as food processing units, brick kilns, batching plants, agriculture, stone crushers, and engineering industries. Sunder Nagar and its nearby region houses about 13 industries in different sectors (red and orange category). The air polluting (red category) industries are comprising batching plants, metal finishing, food processing and stone crushing.

As per the 2011 census, the population of Sunder Nagar is 24,344; of which males and females are 12,461 and 11,883 respectively (Census-India, 2012) with the population density of 240 persons per km^2. The city is governed by Municipal Council Sunder Nagar having 13 wards.

1.2.2 Climate

The climate of Sunder Nagar features humid sub-tropical (warm and temperate) nature and the temperature varies from 7°C to 37°C with an annual average of 17.4°C. The city features the sweltering and wet summers, the cool and dry winters and a monsoon season. The total average rainfall in Sunder Nagar area is about 1,407 mm with occasionally foggy weather. The relative humidity in the city varies between 21% to 85%.

1.2.3 Emission Source Activities

The source activities for air pollution in the town 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 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 1.1 to 1.8 for the period of 2010 to 2018 shown in Figure 1.1 (CPCB, 2019).

A report (CPCB, 2020) on air quality status and trend showed the annual average levels of PM_{10} (72 µg/m^3), $PM_{2.5}$ (38 µg/m^3), NO_2 (9 µg/m^3) and SO_2 (2 µg/m^3) for the year 2019. The CPCB (CBCB, 2020) has reported the levels of in the range 5 - 193 µg/m^3 for PM_{10}, 6 - 86 µg/m^3 for $PM_{2.5}$, 5 - 26 µg/m^3 for NO_2 and 2 µg/m^3 for SO_2 in Sunder Nagar.

Although Sunder Nagar 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.

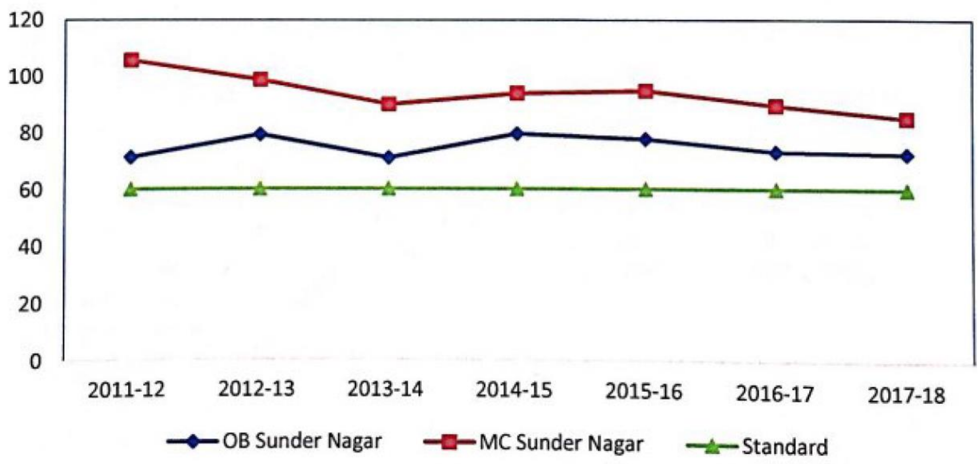


Figure 1.1: Annual average levels of PM_{10} from 2010 to 2018 (CPCB, 2019)

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.

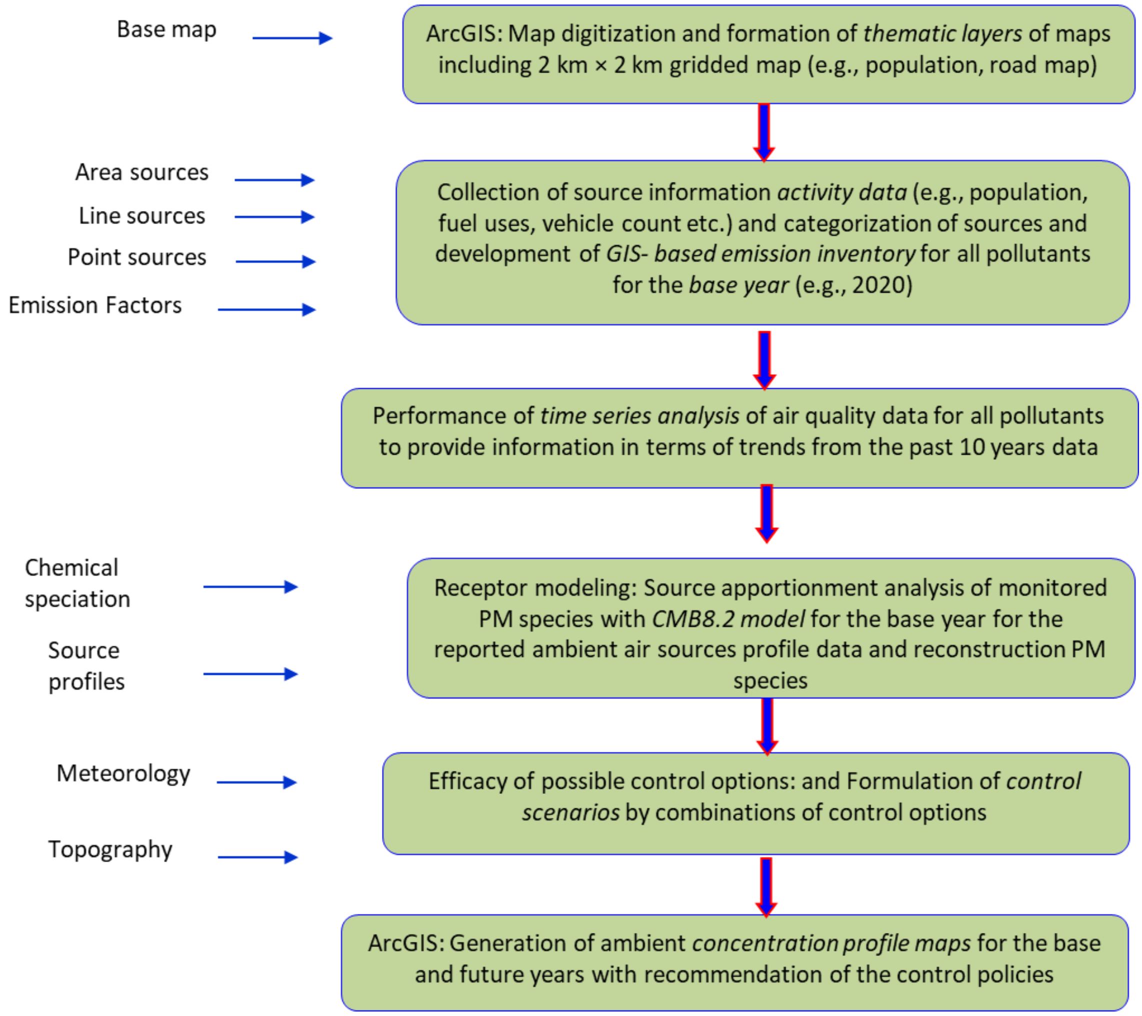


Figure 1.2: Approach to the Study and Major Tasks

1.5.1 Selection of sampling sites

It was considered appropriate that three sites in a city like Sunder Nagar 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, Sunder Nagar.

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 Sunder Nagar 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 Sunder Nagar in Himachal Pradesh for the winter season from the sampling and chemical analysis results carried out in the present study.

2.1 Methodology

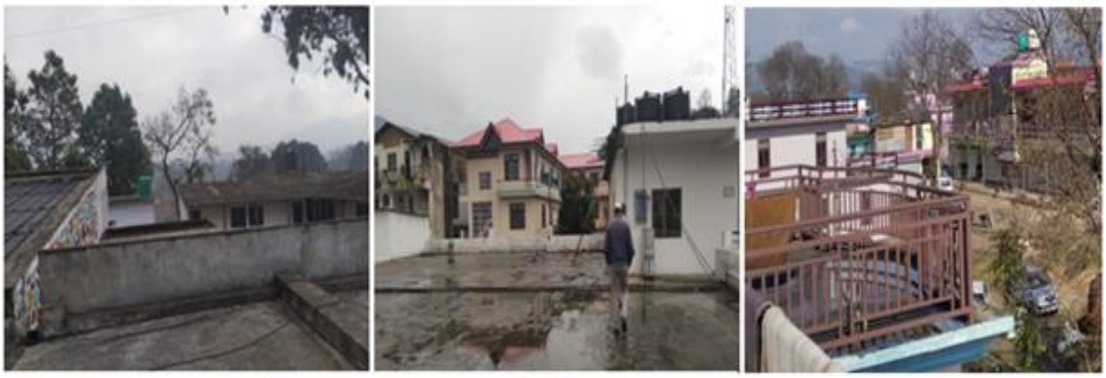
2.1.1 Site Selection and details

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 Sunder Nagar

S. No.	Sampling Site	Site Code	Description of the site	Type of sources
1.	BBMB Rest House	**BRH**	Residential	Domestic cooking, vehicles, road dust, garbage/MSW burning, biomass
2.	Govt. Dental College	**GDC**	Commercial and institutional	DG sets, vehicles, road dust, garbage/waste burning, hotels, restaurants, coal uses
3.	Surya Hotel Naulakha	**SHN**	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/town.



Sunder Nagar: 1. BRH **2. GDC** **3. SHN**

Figure 2.1: Photographs of Sampling Sites

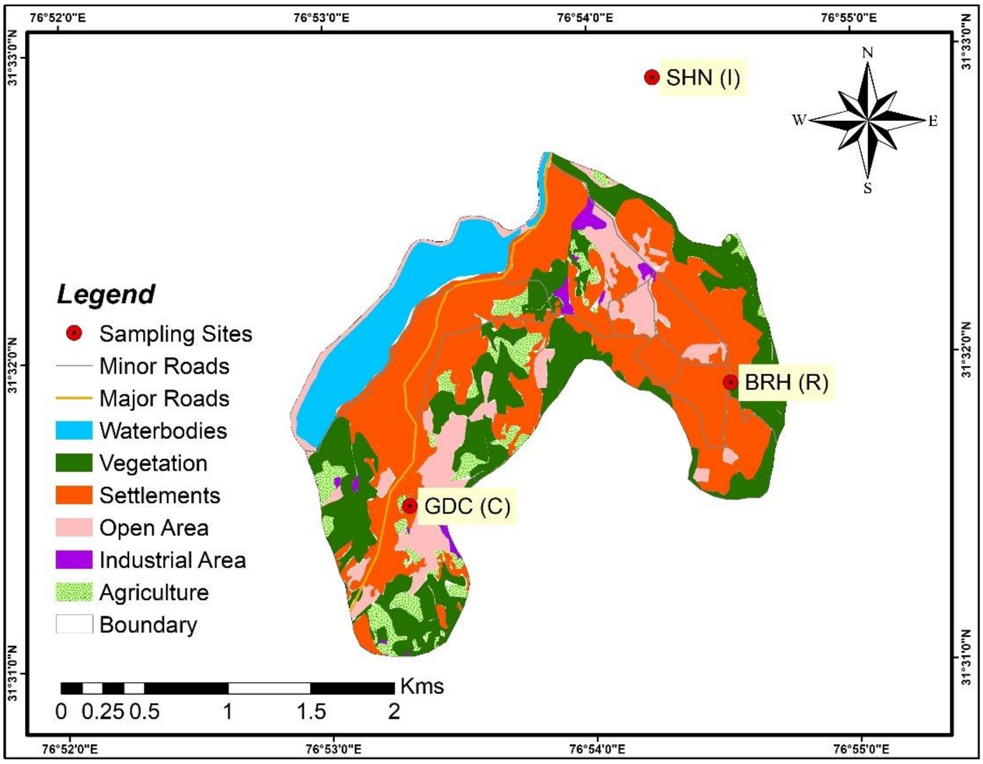


Figure 2.2: Land-use Pattern and Locations of Sampling Sites

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 (January 31 - February 06, 2020). The analysis of SO_2, NO_2 and NH_3 was carried out daily at the laboratory in Sunder Nagar 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 BRH

BRH - Sunder Nagar, Winter							
	31-Jan-20	1-Feb-20	2-Feb-20	3-Feb-20	4-Feb-20	5-Feb-20	6-Feb-20
PM10							
PM2.5							
OC							
EC							
VOC							
NO2							
NH3							
SO2							

Table 2.5: Sampling Days of Various Pollutants at GDC

GDC - Sunder Nagar, Winter							
	31-Jan-20	1-Feb-20	2-Feb-20	3-Feb-20	4-Feb-20	5-Feb-20	6-Feb-20
PM10							
PM2.5							
OC							
EC							
VOC							
NO2							
NH3							
SO2							
CO							
O3							

Table 2.6: Sampling Days of Various Pollutants at SHN

SHN - Sunder Nagar, Winter							
	31-Jan-20	1-Feb-20	2-Feb-20	3-Feb-20	4-Feb-20	5-Feb-20	6-Feb-20
PM10							
PM2.5							
OC							
EC							
VOC							
NO2							
NH3							
SO2							
CO							
O3							

2.3 Ambient Air Quality – Results

The air quality standards are legally binding numbers that must be attained in ambient air. Attainment of air quality standards should ensure safety (or acceptable risk) for human beings and other receptors. The Indian National Ambient Air Quality Standards (NAAQS) standards for 12 parameters as notified by Central Pollution Control Board (CPCB), Delhi are presented in Table 2.7. 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.

BBMB Rest House (BRH)

The time-series of 24-hr average concentrations of PM_{10} and $PM_{2.5}$ are shown in Figure 2.4. Average levels were 44±10 μg/m^3 (for $PM_{2.5}$) and 59±12 μg/m^3 (for PM_{10}). The levels of PM_{10} and $PM_{2.5}$ are complying with the NAAQS. The corresponding CPCB air quality Index (AQI) was less than 98 and 77 in the category *satisfactory*. The ratio of $PM_{2.5}$ to PM_{10} was 0.75 at BRH.

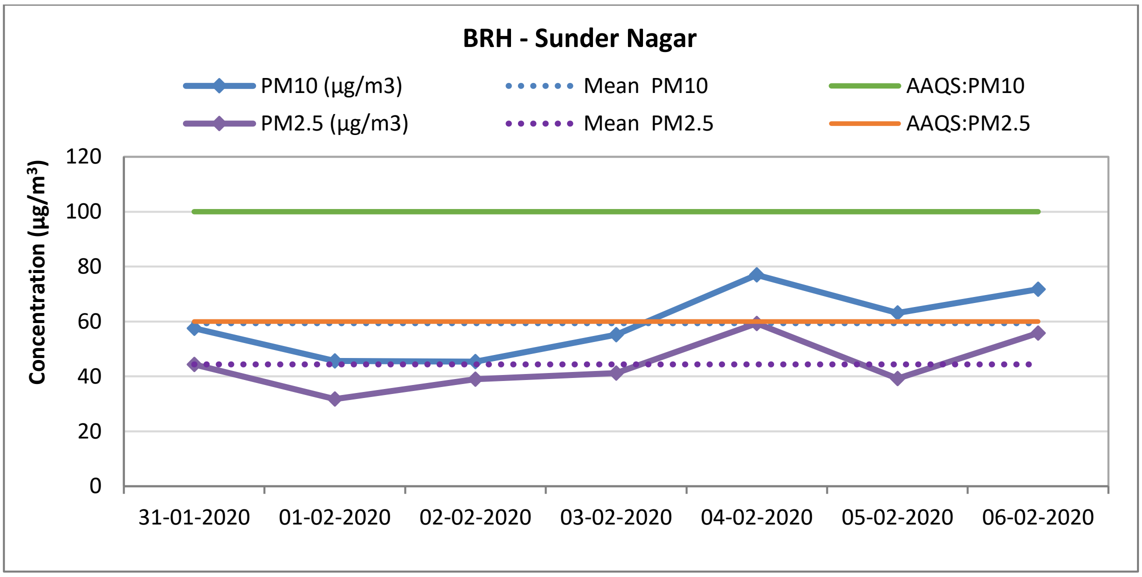


Figure 2.4: PM Concentrations at BRH

Govt. Dental College (GDC)

Time-series of 24-hr average concentrations of PM_{10} and $PM_{2.5}$ is shown in Figure 2.5. Average levels were 69±15 μg/m^3 (for $PM_{2.5}$) and 92±25 μg/m^3 (for PM_{10}). The levels of PM_{10} are complying the NAQS and $PM_{2.5}$ are non-complying with the NAQS. The corresponding CPCB air quality Index (AQI) was less than 183 and 119 in the category *moderate*. The ratio of $PM_{2.5}$ to PM_{10} was 0.76 at GDC.

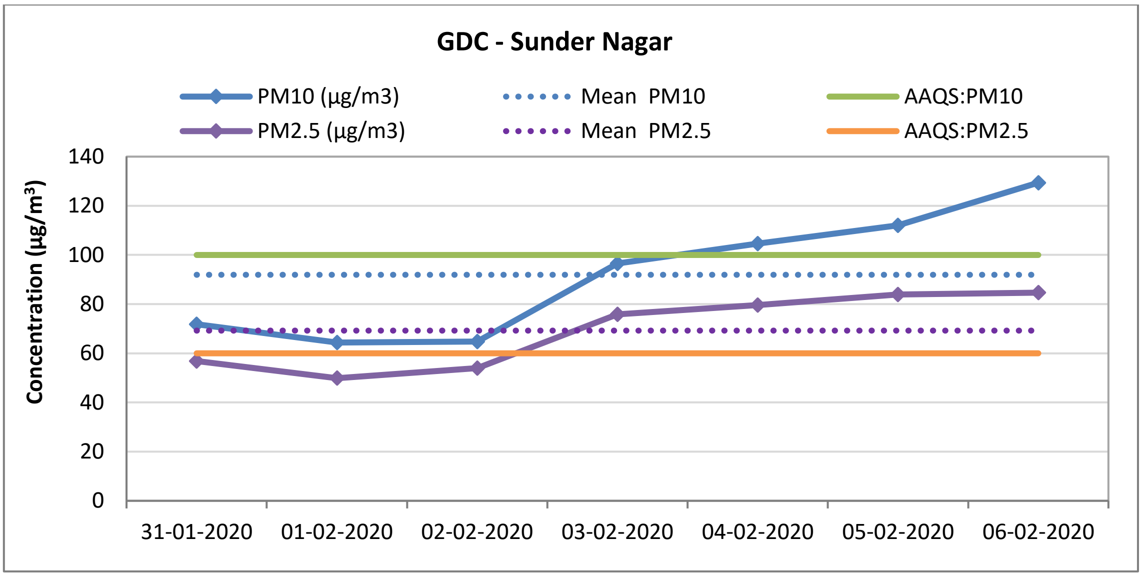


Figure 2.5: PM Concentrations at GDC

Surya Hotel Naulakha (SHN)

The time-series of 24-hr average concentrations of PM_{10} and $PM_{2.5}$ is shown in Figure 2.6. Average levels were 66±18 µg/m^3 (for $PM_{2.5}$) and 108±29 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 177 and 119 in the category *moderate*. The ratio of $PM_{2.5}$ to PM_{10} was 0.62 at SHN.

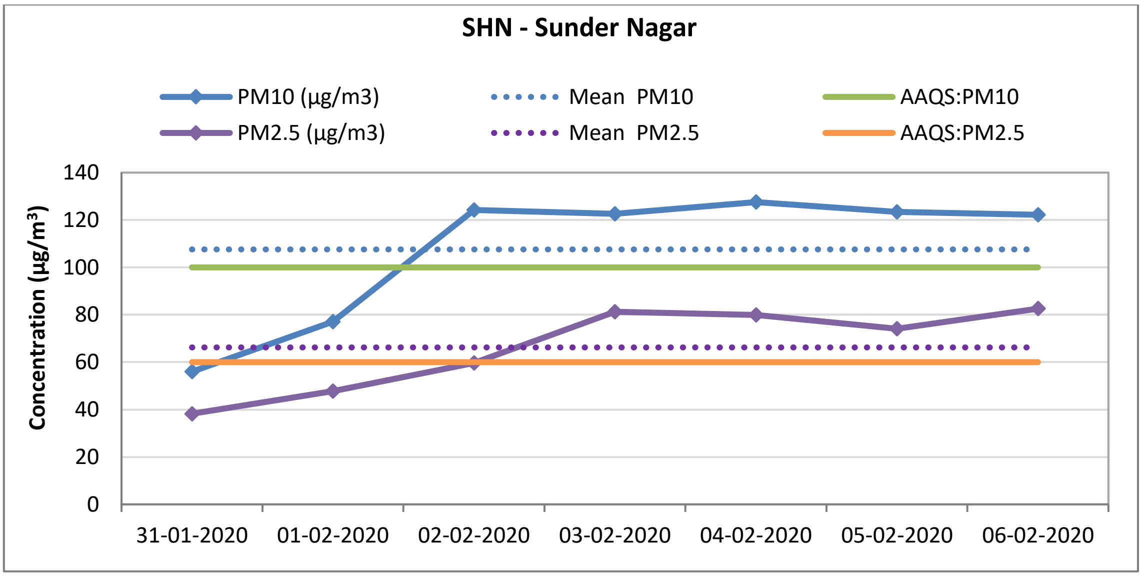


Figure 2.6: PM Concentrations at SHN

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 Sunder Nagar (Table 2.8).

The overall city mean levels in winter were 60±11 µg/m^3 (for $PM_{2.5}$) and 86±20 µg/m^3 (for PM_{10}) and the ratio ($PM_{2.5}/PM_{10}$) was 0.71±0.06. The $PM_{2.5}$ levels are about to comply the NAAQS (60 µg/m^3) and PM_{10} levels are satisfactorily complying the standard (100 µg/m^3). The PM_{10} levels were highest at SHN (108 µg/m^3) and $PM_{2.5}$ levels were highest at GDC (69 µg/m^3). The PM_{10} and $PM_{2.5}$ levels were lowest at BRH (59 and 44 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 0.71 and it was highest at GDC (0.76) followed by BRH (0.75). The relatively high $PM_{2.5}$ at these sites could be attributed to high traffic and emissions from industrial units.

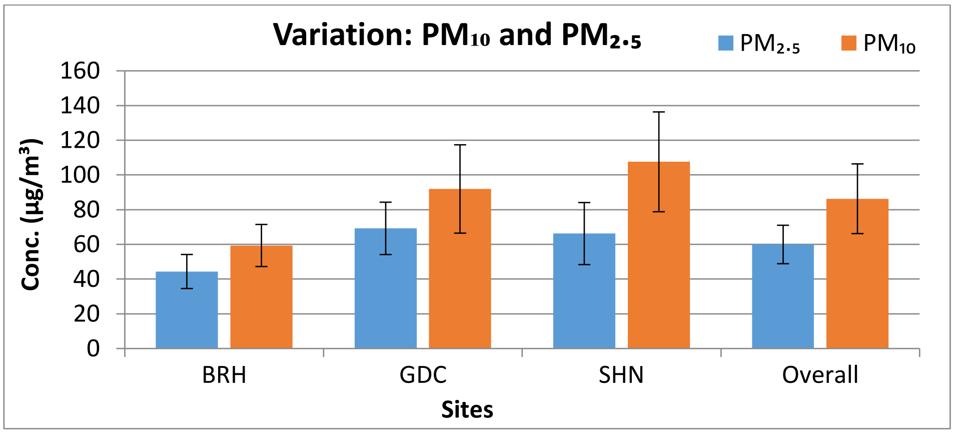


Figure 2.7: Comparison of PM levels at all sites

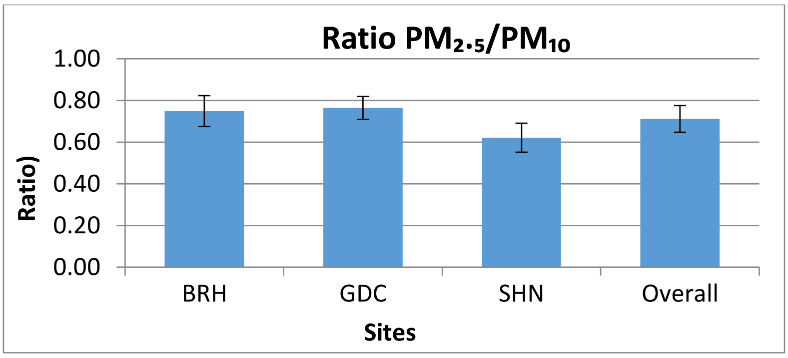


Figure 2.8: Comparison of $PM_{2.5}/PM_{10}$ ratio for all sites

Table 2.8: Statistical Results of $PM_{2.5}$ and PM_{10} in (µg/m^3) at Sunder Nagar

Site		$PM_{2.5}$	PM_{10}	$PM_{2.5}/PM_{10}$
BRH	Mean±SD	44±10	59±12	0.75±0.07
	Range	32-59	45-77	0.62-0.86
GDC	Mean±SD	69±15	92±25	0.76±0.06
	Range	50-85	64-129	0.65-0.83
SHN	Mean±SD	66±18	108±29	0.62±0.07
	Range	38-83	56-128	0.48-0.68
Overall	Mean±SD	60±11	86±20	0.71±0.06

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.

BRH

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.

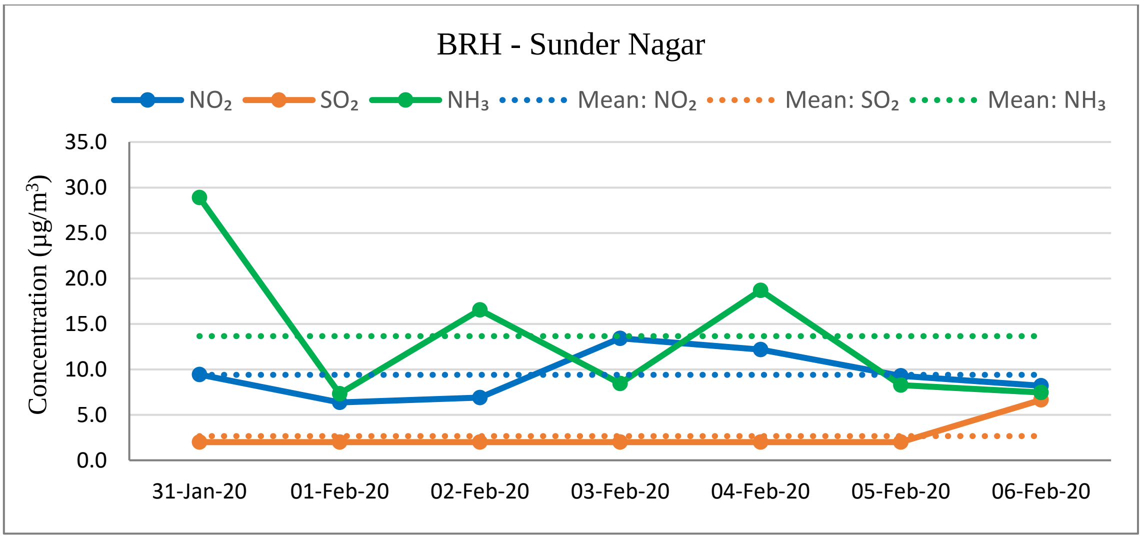


Figure 2.9: SO_2, NO_2 and NH_3 concentrations at BRH

GDC

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.

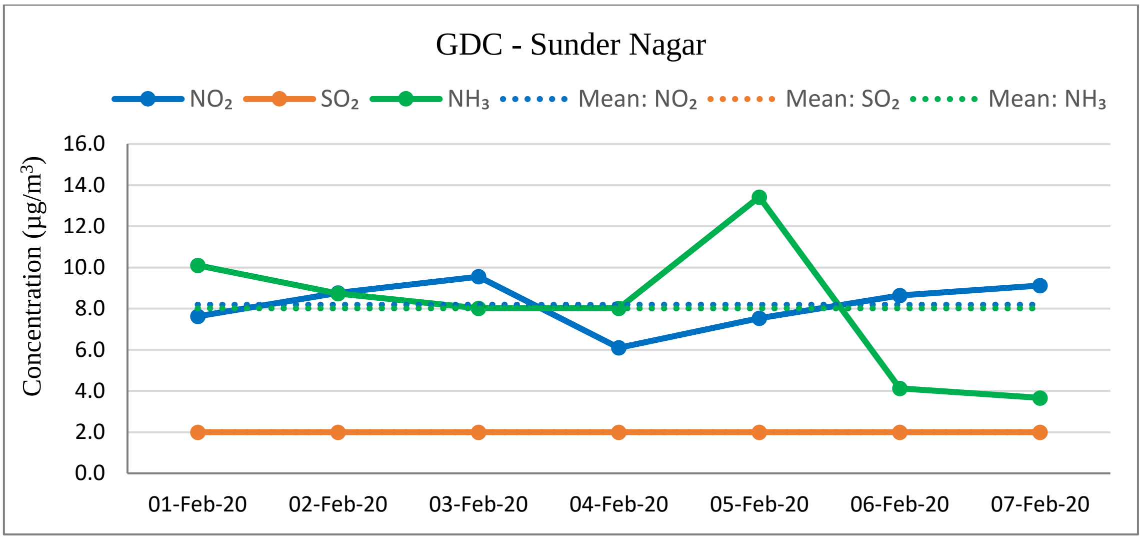


Figure 2.10: SO_2, NO_2 and NH_3 concentrations at GDC

SHN

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.

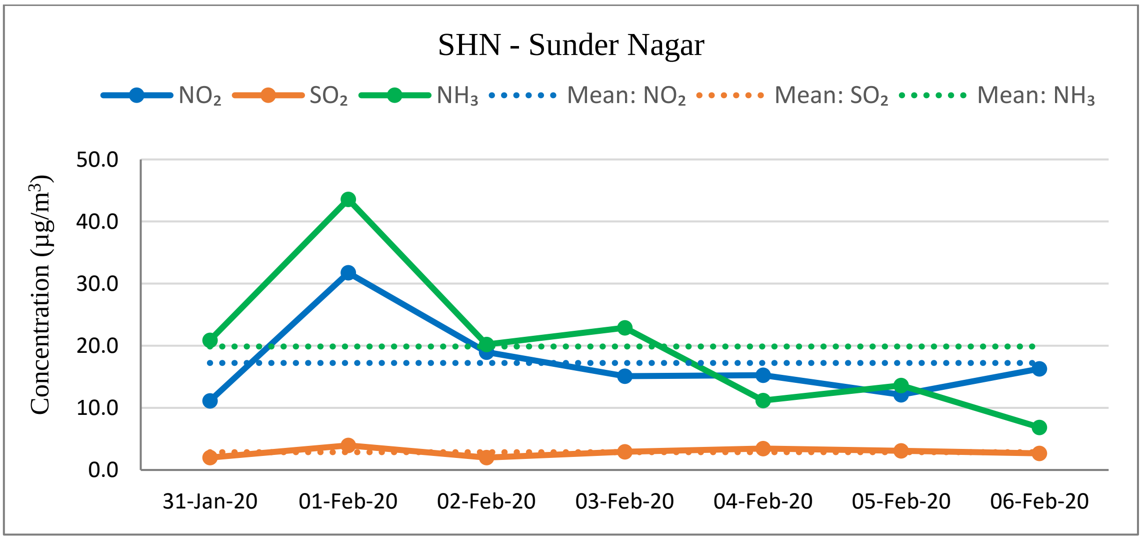


Figure 2.11: SO_2, NO_2 and NH_3 concentrations at SHN

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 Sunder Nagar

(Table 2.9). It was observed that SO_2, NO_2 and NH_3 concentrations were met the air quality standard at all sites.

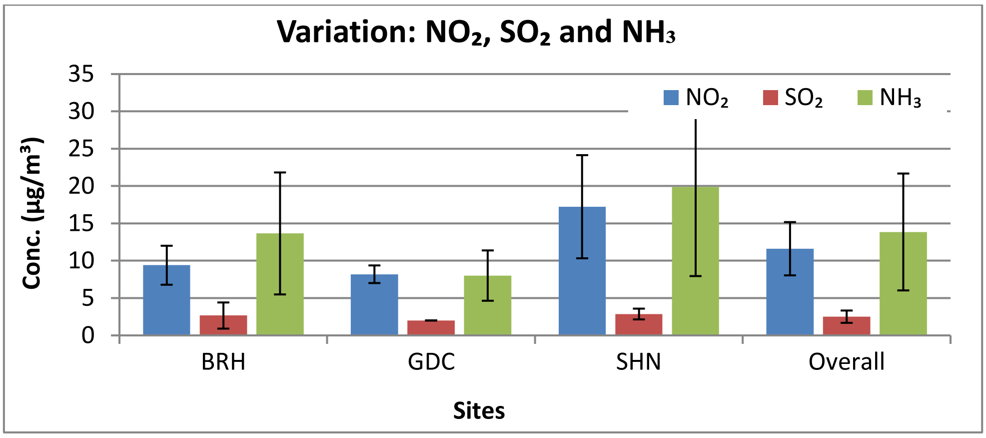


Figure 2.12: Comparison of gaseous pollutants levels at all sites

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

Site		NO_2	SO_2	NH_3
BRH	Mean±SD	9.4±2.6	2.7±1.8	13.7±8.2
	Range	6.4-13.4	2.0-6.6	7.3-28.9
GDC	Mean±SD	8.2±1.2	2.0±0.0	8.0±3.4
	Range	6.1-9.6	2.0-2.0	3.7-13.4
SHN	Mean±SD	17.2±6.9	2.9±0.7	19.9±11.9
	Range	11.1-31.7	2.0-4.0	6.9-43.6
Overall	Mean±SD	11.6±3.6	2.5±0.8	13.9±7.8

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 Sunder Nagar are presented in Table 2.10.

The overall city-level average of BTX levels is 15.3±3.0 µg/m^3 in winter. It is observed that the BTX concentrations are highest at GDC (17 µg/m^3) could be due to the more commercial and traffic activities and the lowest at the BRH (12 µg/m^3) could be due to the less organic solvent uses. The possible reason for higher concentrations in GDC could be more vehicle movement in this area alongside the main road and which may cause large evaporative losses from fuel tanks of vehicles and petrol pump.

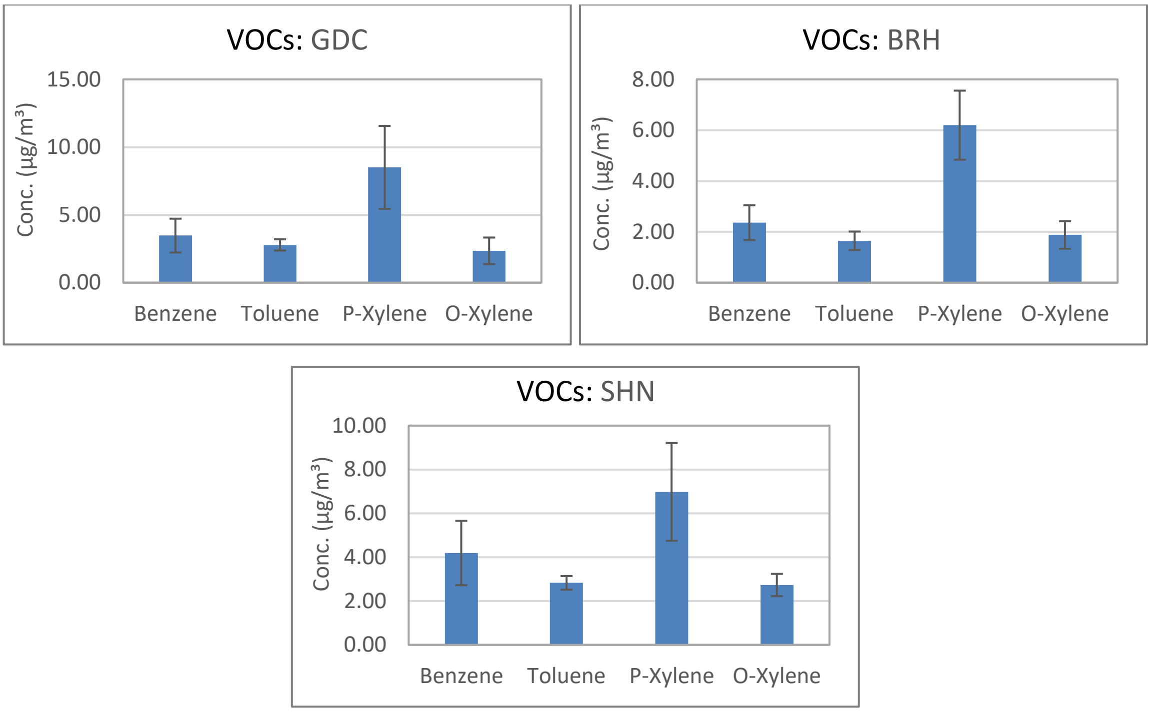


Figure 2.13: VOCs Concentrations at different sites in Sunder Nagar

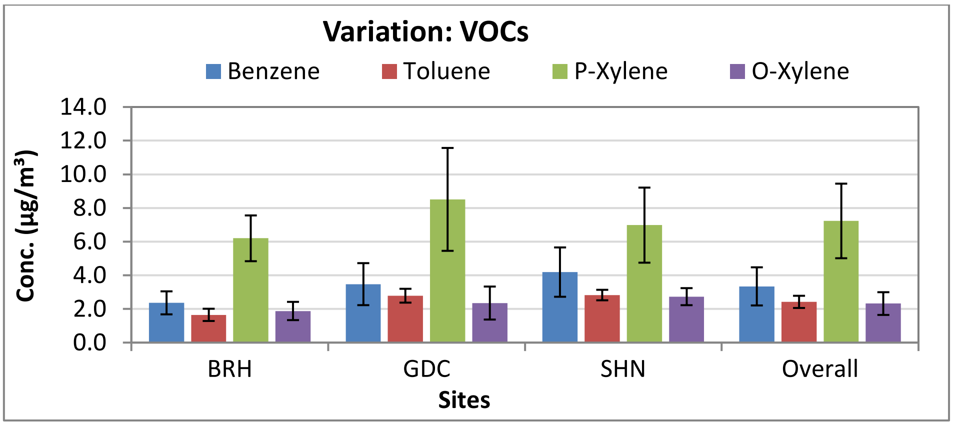


Figure 2.14: Comparison of gaseous pollutants levels at all sites

Table 2.10: Statistical Results of VOCs Contents (µg/m³) at Sunder Nagar

Site		Benzene	Toluene	P-Xylene	O-Xylene	Total (BTX)
BRH	Mean±SD	2.4±0.7	1.6±0.4	6.2±1.4	1.9±0.5	12.1±1.8
	Range	1.5-3.2	1.3-2.1	5.0-8.4	1.1-2.4	9.3-14.3
GDC	Mean±SD	3.5±1.2	2.8±0.4	8.5±3.1	2.3±1.0	17.1±4.7
	Range	1.5-4.7	2.2-3.2	5.5-12.4	0.6-2.9	9.9-22.6
SHN	Mean±SD	4.2±1.5	2.8±0.3	7.0±2.2	2.7±0.5	16.7±2.5
	Range	2.2-5.9	2.3-3.1	4.7-10.7	2.1-3.4	13.2-19.4
Overall	Mean±SD	3.3±1.1	2.4±0.4	7.2±2.2	2.3±0.7	15.3±3.0

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

BRH

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 BRH. Statistical results of carbon contents (µg/m^3) in $PM_{2.5}$ at BRH are presented in Table 2.11.

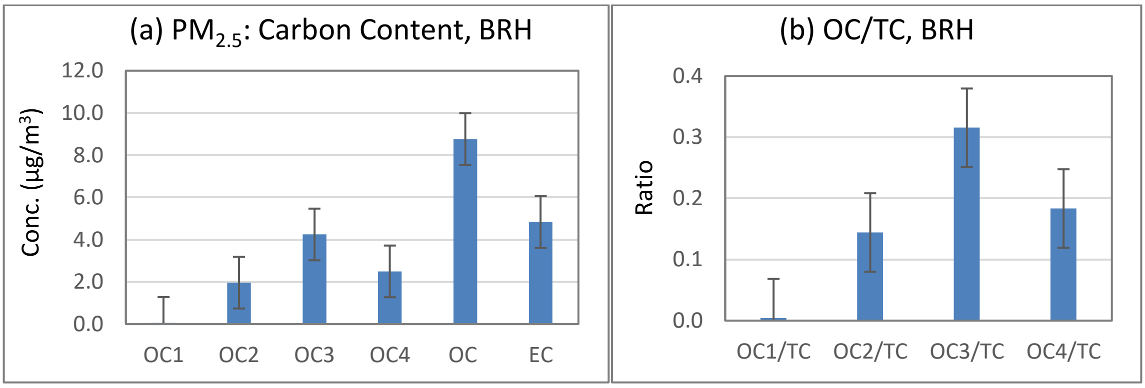


Figure 2.15: EC and OC Content in $PM_{2.5}$ at BRH

Table 2.11: Statistical Results of Carbon Contents (µg/m^3) in $PM_{2.5}$ at BRH

	OC1	OC2	OC3	OC4	OC	EC	TC	OC1/TC	OC2/TC	OC3/TC	OC4/TC
Mean	0.06	1.96	4.25	2.50	8.76	4.84	13.60	0.00	0.14	0.32	0.18
SD	0.03	0.32	0.35	0.38	0.51	0.90	1.35	0.00	0.02	0.05	0.02
CV	0.51	0.16	0.08	0.15	0.06	0.19	0.10	0.46	0.12	0.15	0.11
Max	0.11	2.41	4.88	3.04	9.47	5.95	15.40	0.01	0.18	0.42	0.22
Min	0.02	1.50	3.83	1.79	8.24	3.46	11.70	0.00	0.13	0.28	0.15

GDC

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 GDC. Statistical results of carbon contents (µg/m^3) in $PM_{2.5}$ at GDC are presented in Table 2.12.

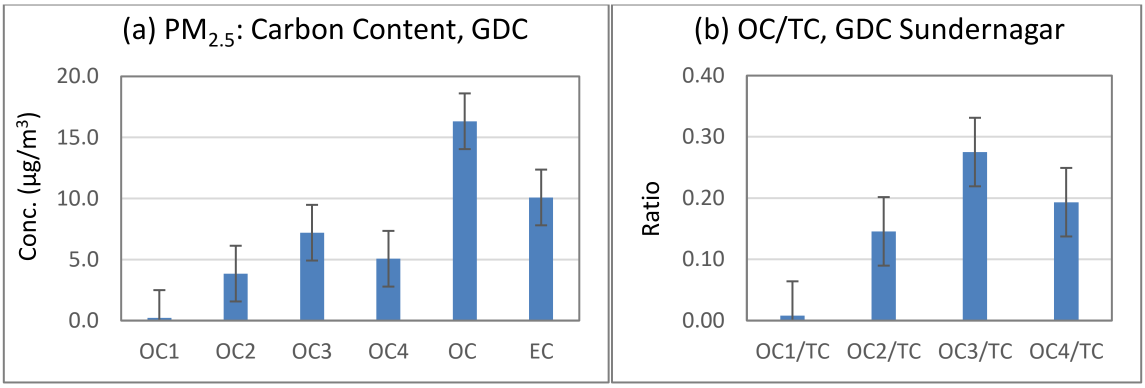


Figure 2.16: EC and OC Content in $PM_{2.5}$ at GDC

Table 2.12: Statistical Results of Carbon Contents (µg/m^3) in $PM_{2.5}$ at GDC

	OC1	OC2	OC3	OC4	OC	EC	TC	OC1/TC	OC2/TC	OC3/TC	OC4/TC
Mean	0.21	3.85	7.20	5.07	16.33	10.09	26.41	0.01	0.15	0.28	0.19
SD	0.07	1.43	2.47	1.99	5.89	4.11	9.98	0.00	0.01	0.01	0.02
CV	0.33	0.37	0.34	0.39	0.36	0.41	0.38	0.15	0.04	0.04	0.09
Max	0.33	6.79	12.31	9.64	29.07	18.45	47.52	0.01	0.15	0.29	0.22
Min	0.10	1.84	3.83	2.91	8.68	4.74	13.42	0.01	0.14	0.26	0.16

SHN

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 SHN. Statistical results of carbon contents (µg/m^3) in $PM_{2.5}$ at SHN are presented in Table 2.13.

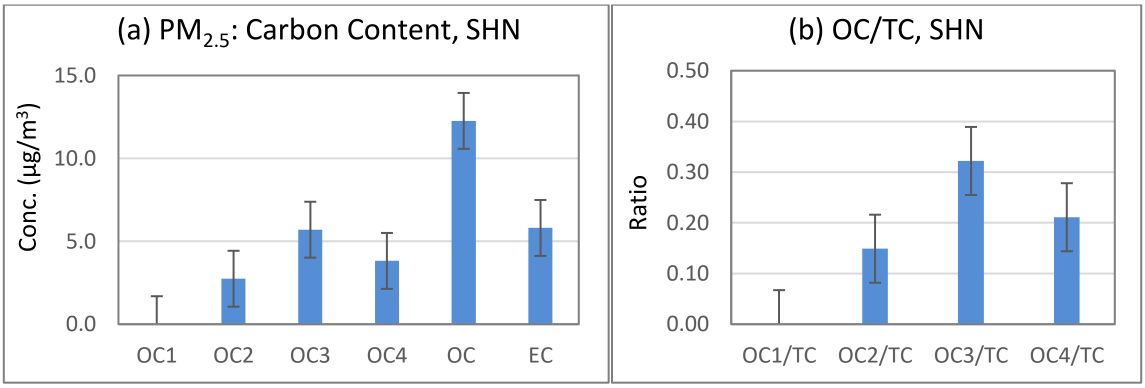


Figure 2.17: EC and OC Content in $PM_{2.5}$ at SHN

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

	OC1	OC2	OC3	OC4	OC	EC	TC	OC1/TC	OC2/TC	OC3/TC	OC4/TC
Mean	0.001	2.74	5.70	3.82	12.26	5.81	18.07	0.00	0.15	0.32	0.21
SD	0.004	0.92	1.38	1.18	3.28	1.95	5.14	0.00	0.02	0.05	0.02
CV	2.65	0.34	0.24	0.31	0.27	0.34	0.28	2.65	0.10	0.14	0.11
Max	0.01	3.49	6.78	4.85	14.94	7.91	22.40	0.00	0.17	0.41	0.24
Min	0.00	1.00	2.76	1.71	5.48	2.57	8.04	0.00	0.12	0.28	0.19

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 32% in winter. The OC is observed higher than the EC at all sites; 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 GDC (38%) and minimum at SHN (27%) in winter (Table 2.14). It may be noted that TC to $PM_{2.5}$ is consistent at all sites.

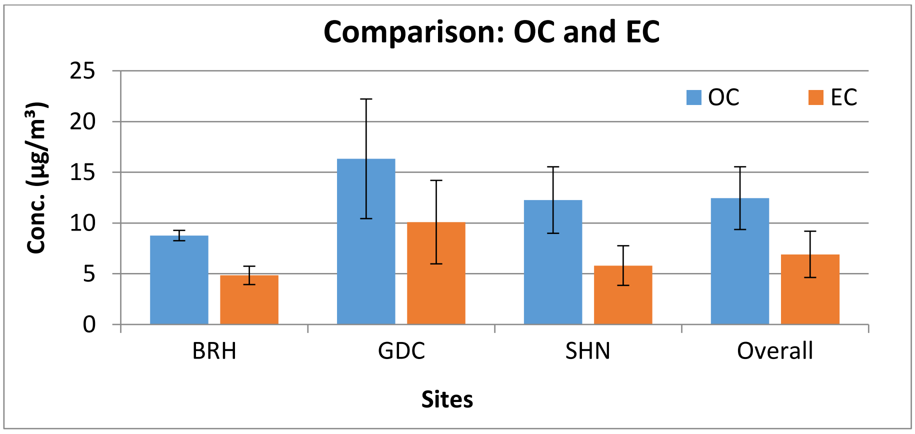


Figure 2.18: Comparison of EC and OC in $PM_{2.5}$ for all Sites

Table 2.14: Overall summary of Carbon Contents (µg/m³) in PM2.5

Sites	**PM2.5**	**OC1**	**OC2**	**OC3**	**OC4**	**OC**	**EC**	**TC**	**OC1/TC**	**OC2/TC**	**OC3/TC**	**OC4/TC**
BRH	44	0.06	1.96	4.25	2.50	8.76	4.84	13.60	0.00	0.14	0.32	0.18
GDC	69	0.21	3.85	7.20	5.07	16.33	10.09	26.41	0.01	0.15	0.28	0.19
SHN	66	0.00	2.74	5.70	3.82	12.26	5.81	18.07	0.00	0.15	0.32	0.21
Overall	**60**	**0.09**	**2.85**	**5.71**	**3.79**	**12.45**	**6.91**	**19.36**	**0.00**	**0.15**	**0.30**	**0.20**
SD	**11**	**0.09**	**0.77**	**1.21**	**1.05**	**3.09**	**2.28**	**5.31**	**0.00**	**0.00**	**0.02**	**0.01**

2.3.5 PAHs in PM2.5

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 Sunder Nagar 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 B(b)F (2.46 ng/m³), DmP (1.43 ng/m³), DEP (1.29 ng/m³), B(ghi)P (1.18 ng/m³), Phe (1.09 ng/m³), B(a)P (1.02 ng/m³) and InP (0.80 ng/m³) in winter.

The overall average total PAHs were 12.4±6.6 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: 1.02 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 (0.40) 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.

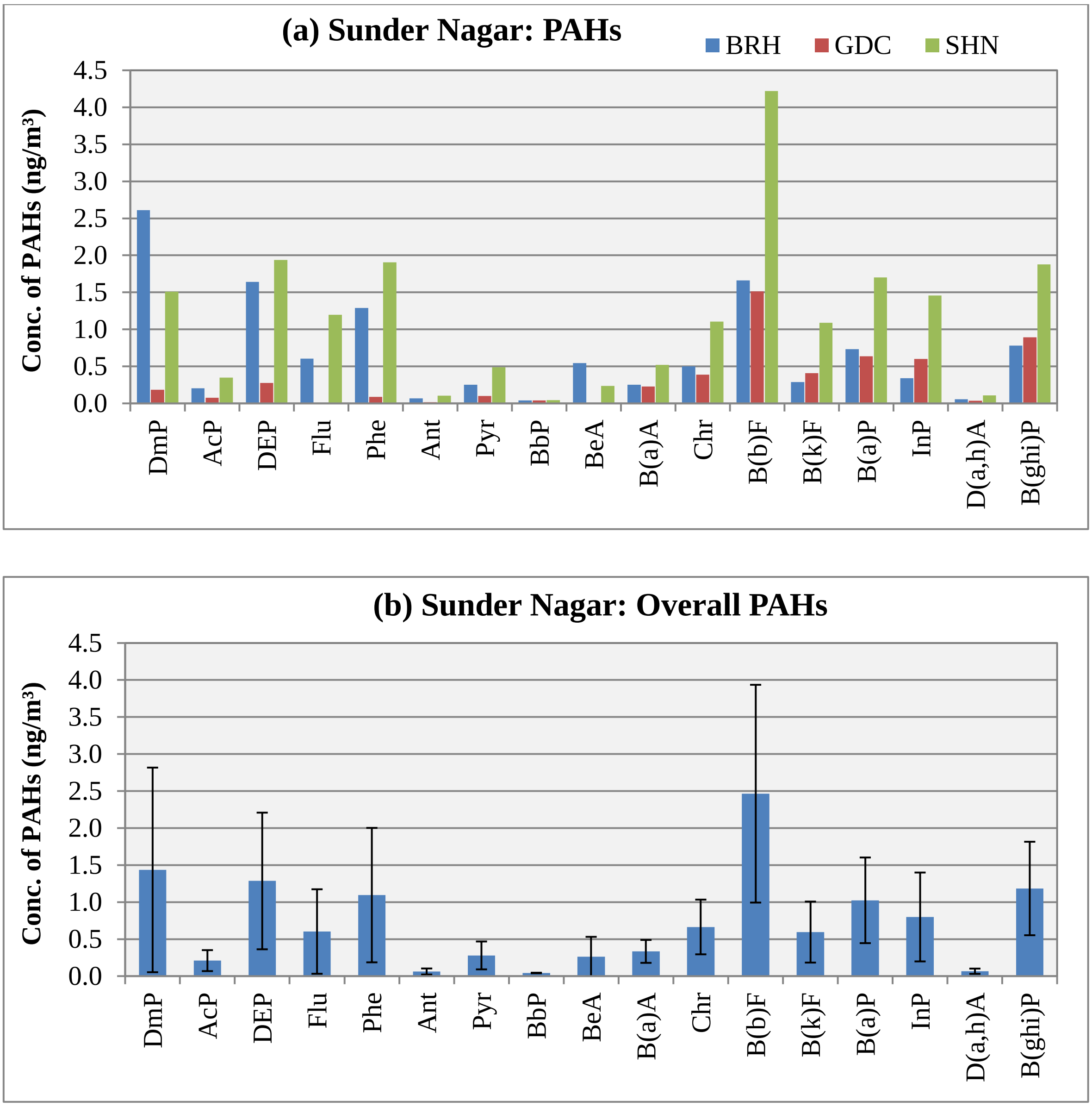
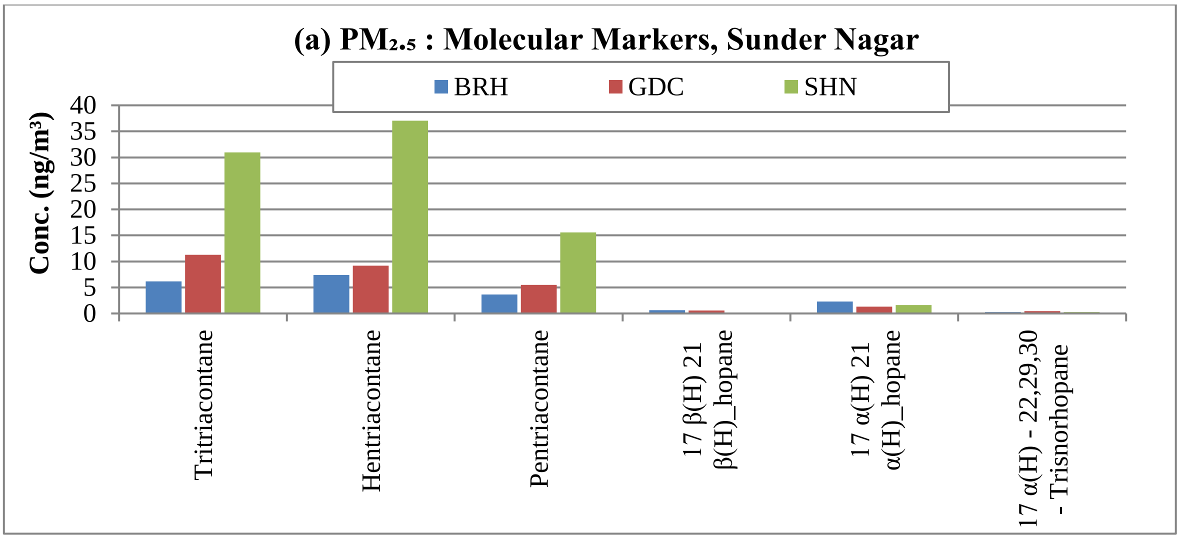


Figure 2.19: PAHs Concentrations in $PM_{2.5}$

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 44.7±35.4 ng/m^3 in winter. The presence of significant quantities of molecular markers, especially hopanes conclusively establishes contribution of CGD.



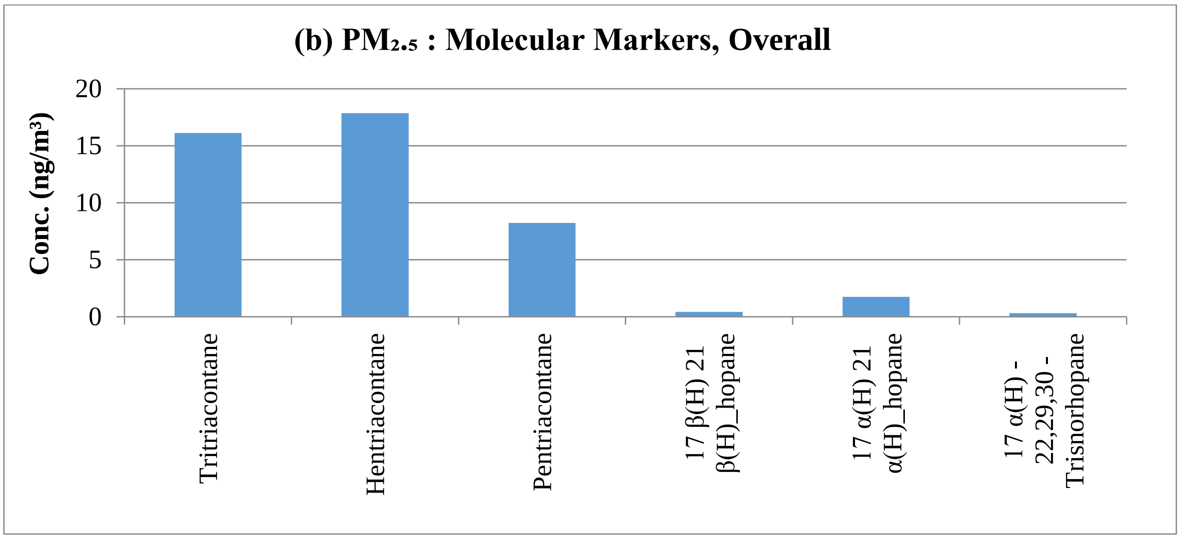


Figure 2.20: Molecular Markers in $PM_{2.5}$

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 Sunder Nagar 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.

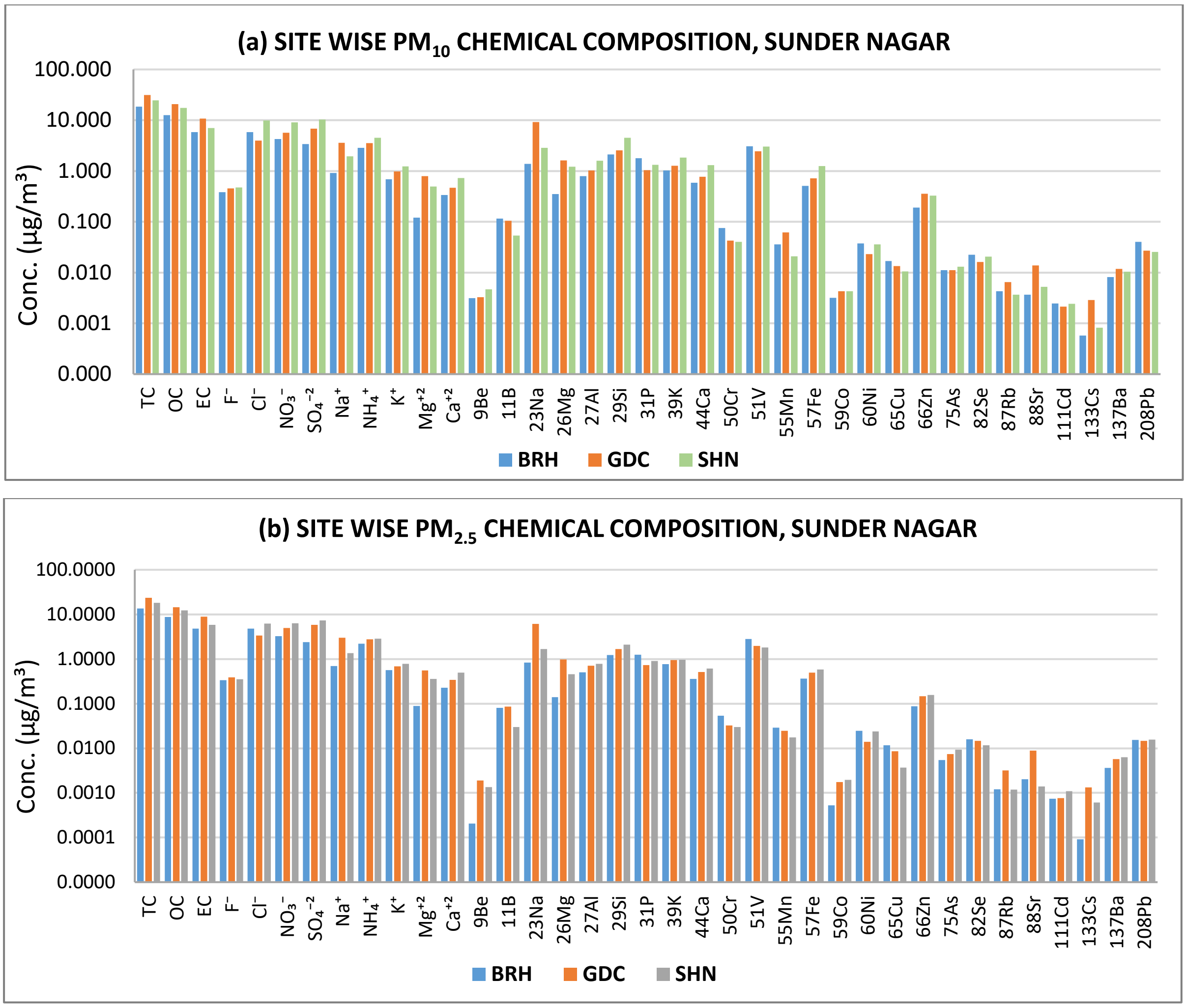
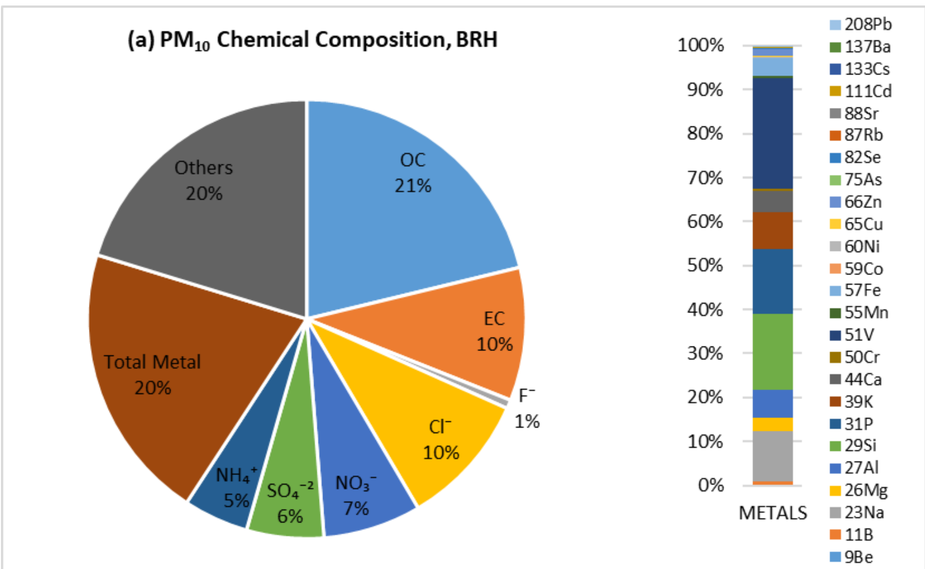


Figure 2.21: Concentrations of species in (a) PM_{10} and (b) $PM_{2.5}$



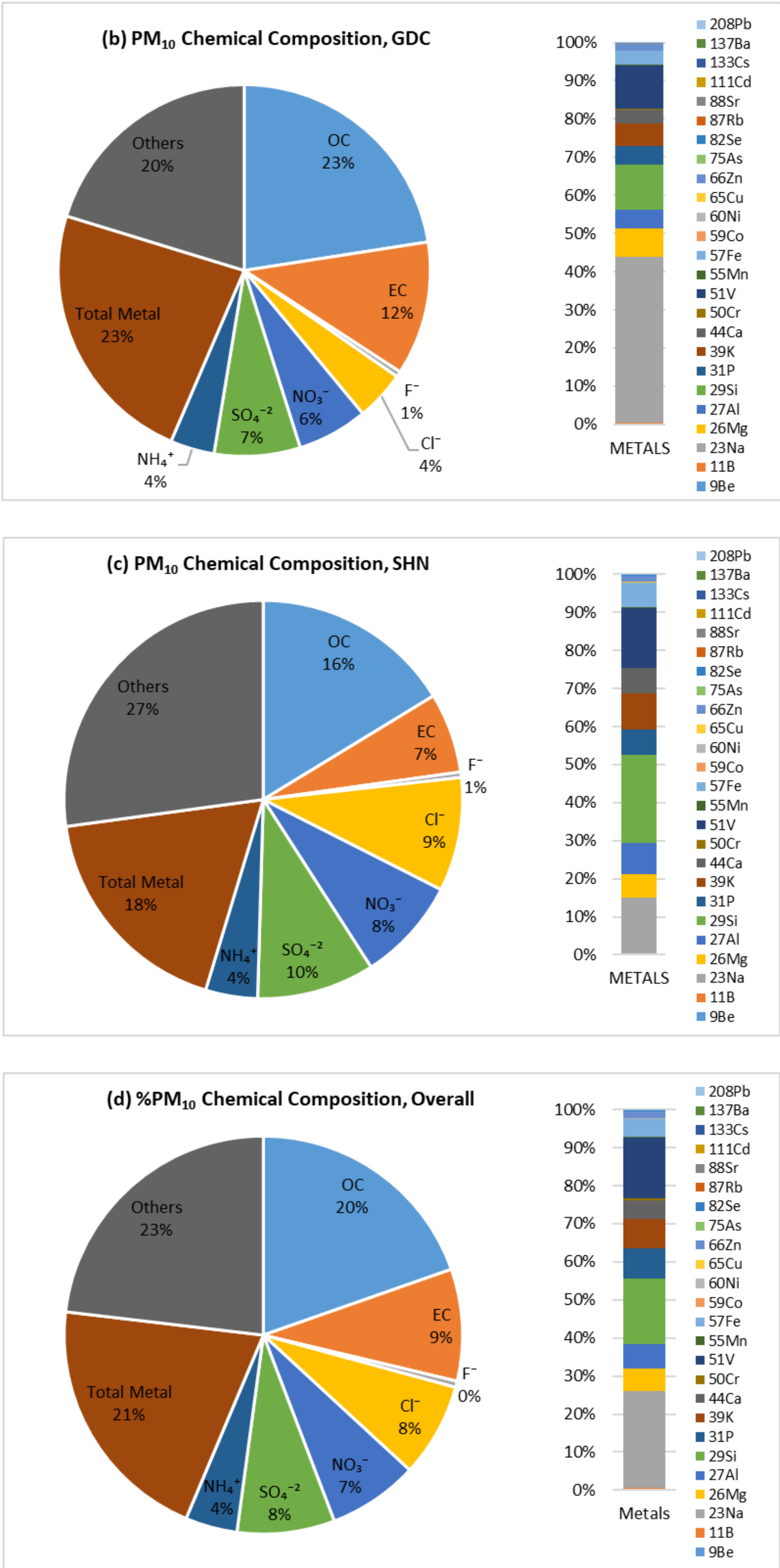
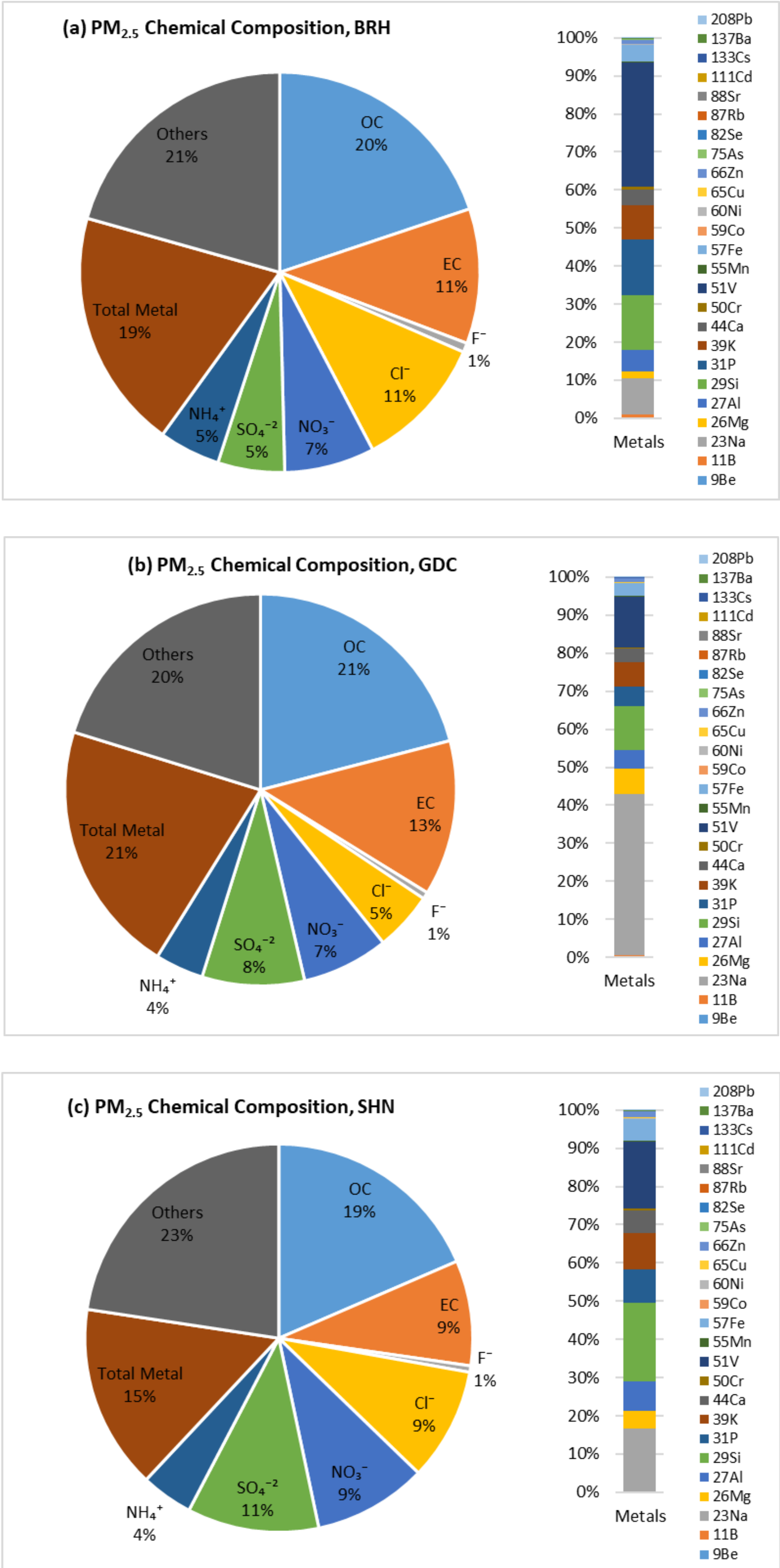


Figure 2.22: Percentage distribution of species in PM_{10}



(a) PM2.5 Chemical Composition, BRH
OC 20%
EC 11%
F⁻ 1%
Cl⁻ 11%
NO3⁻ 7%
SO4⁻² 5%
NH4⁺ 5%
Total Metal 19%
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
(b) PM2.5 Chemical Composition, GDC
OC 21%
EC 13%
F⁻ 1%
Cl⁻ 5%
NO3⁻ 7%
SO4⁻² 8%
NH4⁺ 4%
Total Metal 21%
Others 20%
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) PM2.5 Chemical Composition, SHN
OC 19%
EC 9%
F⁻ 1%
Cl⁻ 9%
NO3⁻ 9%
SO4⁻² 11%
NH4⁺ 4%
Total Metal 15%
Others 23%
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

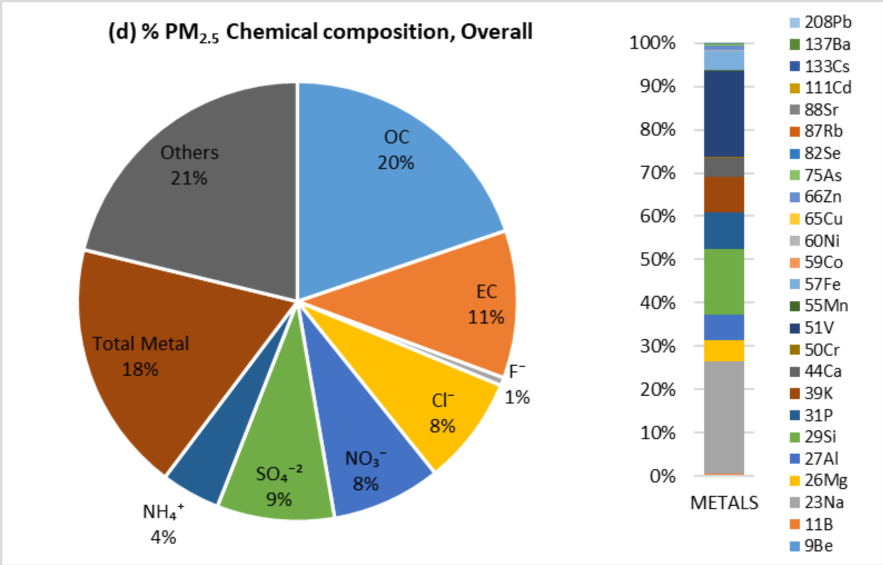


Figure 2.23: Percentage distribution of species in $PM_{2.5}$

Table 2.15: Overall summary of average concentration (ng/m³) of PAHs in $PM_{2.5}$ all sites

	DmP	AcP	DEP	Flu	Phe	Ant	Pyr	BbP	BeA	B(a)A	Chr	B(b)F	B(k)F	B(a)P	InP	D(a,h)A	B(ghi)P	Total PAHs
BRH	2.61	0.20	1.64	0.60	1.29	0.07	0.25	0.04	0.55	0.25	0.50	1.66	0.29	0.73	0.34	0.06	0.78	11.86
GDC	0.18	0.08	0.28	0.01	0.09	0.02	0.10	0.04	0.01	0.23	0.39	1.51	0.41	0.63	0.60	0.03	0.89	5.50
SHN	1.51	0.35	1.94	1.20	1.91	0.10	0.49	0.04	0.24	0.52	1.10	4.22	1.09	1.70	1.46	0.11	1.88	19.85
Mean	1.43	0.21	1.29	0.60	1.09	0.06	0.28	0.04	0.26	0.33	0.66	2.46	0.60	1.02	0.80	0.07	1.18	12.41
SD	1.38	0.14	0.92	0.57	0.91	0.04	0.19	0.00	0.27	0.15	0.37	1.47	0.41	0.58	0.60	0.04	0.63	6.64
Max	3.94	0.44	2.35	1.52	2.49	0.11	0.58	0.05	0.72	0.58	1.25	4.82	1.24	2.01	1.61	0.12	1.91	20.17
Min	0.02	0.06	0.09	0.00	0.00	0.02	0.04	0.04	0.00	0.17	0.24	0.87	0.24	0.42	0.00	0.02	0.39	2.92
CV	0.96	0.68	0.72	0.95	0.83	0.65	0.67	0.09	1.01	0.46	0.56	0.60	0.69	0.57	0.75	0.54	0.53	0.54

Table 2.16: Overall summary of average concentration (ng/m³) of molecular markers in $PM_{2.5}$ all sites

	Tritriacontane	Hentriacontane	Pentriacontane	17 β(H) 21 β(H)_hopane	17 α(H) 21 α(H)_hopane	17 α(H) - 22,29,30 - Trisnorhopane	Total
MHR	6.15	7.37	3.66	0.66	2.31	0.24	20.39
GDC	11.26	9.16	5.49	0.56	1.29	0.44	28.21
SHN	30.95	37.02	15.55	0.08	1.62	0.26	85.48
Mean	16.12	17.85	8.23	0.43	1.74	0.31	44.69
SD	13.10	16.62	6.40	0.31	0.52	0.11	35.54
CV	0.81	0.93	0.78	0.72	0.30	0.35	0.80

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
BRH	MEAN	59.38	12.52	5.83	0.39	5.84	4.29	3.37	0.91	2.85	0.69	0.12	0.34	0.00	0.11	1.39	0.35	0.79	2.11	1.78
	SD	12.13	0.73	1.09	0.04	3.57	1.26	0.87	0.52	1.17	0.18	0.07	0.10	0.00	0.03	0.67	0.28	0.26	0.77	0.71
GDC	MEAN	91.94	20.72	10.71	0.45	3.97	5.64	6.87	3.62	3.52	0.99	0.79	0.46	0.00	0.10	9.27	1.62	1.02	2.54	1.04
	SD	25.45	4.42	3.05	0.18	2.00	3.17	2.44	2.58	1.74	0.63	0.59	0.17	0.00	0.02	4.68	0.92	0.53	1.32	0.54
SHN	MEAN	107.58	17.52	7.00	0.48	9.95	9.07	10.27	1.94	4.54	1.23	0.50	0.73	0.00	0.05	2.86	1.22	1.60	4.52	1.32
	SD	28.76	4.68	2.35	0.16	3.88	3.91	3.28	0.72	2.32	0.58	0.41	0.27	0.00	0.02	0.76	0.39	0.54	1.47	0.28
		K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	%R
BRH	MEAN	1.02	0.59	0.08	3.07	0.04	0.51	0.00	0.04	0.02	0.19	0.01	0.02	0.00	0.00	0.00	0.00	0.01	0.04	80.44
	SD	0.27	0.21	0.07	0.79	0.03	0.12	0.00	0.01	0.01	0.17	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.02	2.14
GDC	MEAN	1.27	0.77	0.04	2.46	0.06	0.72	0.00	0.02	0.01	0.36	0.01	0.02	0.01	0.01	0.00	0.00	0.01	0.03	81.18
	SD	0.39	0.36	0.02	0.84	0.06	0.33	0.00	0.02	0.01	0.16	0.01	0.01	0.00	0.01	0.00	0.00	0.01	0.02	4.81
SHN	MEAN	1.83	1.31	0.04	3.05	0.02	1.25	0.00	0.04	0.01	0.33	0.01	0.02	0.00	0.01	0.00	0.00	0.01	0.03	73.99
	SD	0.61	0.41	0.01	0.98	0.01	0.41	0.00	0.01	0.01	0.12	0.01	0.01	0.00	0.00	0.00	0.00	0.01	0.01	4.21

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	86.30	16.92	7.85	0.44	6.59	6.33	6.84	2.16	3.64	0.97	0.47	0.51	0.00	0.09	4.51	1.07	1.14	3.06	1.38
SD	30.16	4.95	3.06	0.14	4.01	3.51	3.68	1.88	1.85	0.53	0.49	0.25	0.00	0.04	4.38	0.79	0.56	1.58	0.60
MAX	129.40	25.82	14.74	0.82	16.98	13.63	14.24	9.28	8.35	2.43	1.97	1.14	0.01	0.16	17.84	3.03	2.49	6.52	2.60
MIN	45.37	7.82	3.09	0.26	1.94	2.85	1.70	0.24	0.72	0.14	0.04	0.22	0.00	0.03	0.56	0.19	0.42	1.05	0.49
CV	0.35	0.29	0.39	0.32	0.61	0.55	0.54	0.87	0.51	0.55	1.04	0.48	0.38	0.41	0.97	0.74	0.49	0.52	0.43
	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	%R
MEAN	1.37	0.89	0.05	2.86	0.04	0.83	0.00	0.03	0.01	0.29	0.012	0.020	0.005	0.008	0.002	0.001	0.010	0.031	78.534
SD	0.55	0.45	0.04	0.88	0.04	0.44	0.00	0.01	0.01	0.16	0.006	0.009	0.002	0.006	0.001	0.002	0.006	0.016	4.960
MAX	3.03	1.95	0.23	5.11	0.13	1.77	0.01	0.07	0.05	0.56	0.032	0.047	0.011	0.023	0.005	0.004	0.025	0.072	85.601
MIN	0.54	0.33	0.02	0.65	0.01	0.33	0.00	0.01	0.01	0.06	0.005	0.003	0.002	0.001	0.001	0.000	0.001	0.007	69.929
CV	0.40	0.50	0.84	0.31	1.01	0.53	0.46	0.46	0.75	0.55	0.54	0.44	0.50	0.79	0.54	1.09	0.55	0.51	0.06

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
BRH	MEAN	44.38	8.76	4.84	0.34	4.79	3.23	2.40	0.69	2.20	0.56	0.09	0.23	0.00	0.08	0.83	0.14	0.50	1.24	1.26
	SD	9.81	0.51	0.90	0.05	3.21	0.74	0.56	0.37	0.93	0.19	0.06	0.07	0.00	0.03	0.40	0.06	0.16	0.44	0.56
GDC	MEAN	69.23	14.51	8.89	0.39	3.37	4.95	5.86	2.98	2.77	0.68	0.56	0.34	0.00	0.09	6.13	0.99	0.70	1.68	0.73
	SD	15.09	3.09	2.53	0.16	1.90	2.63	1.96	2.78	1.33	0.39	0.43	0.12	0.00	0.03	2.46	0.75	0.20	0.57	0.50
SHN	MEAN	66.23	12.26	5.81	0.35	6.23	6.27	7.28	1.36	2.86	0.79	0.36	0.50	0.00	0.03	1.68	0.46	0.78	2.10	0.90
	SD	17.87	3.28	1.95	0.12	1.98	3.17	3.24	0.45	1.57	0.35	0.33	0.16	0.00	0.01	0.55	0.33	0.20	0.55	0.19
		K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	%R
BRH	MEAN	0.77	0.36	0.05	2.81	0.03	0.36	0.00	0.02	0.01	0.09	0.01	0.02	0.00	0.00	0.00	0.00	0.00	0.02	80.36
	SD	0.21	0.12	0.05	0.61	0.03	0.11	0.00	0.01	0.01	0.13	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01	5.79
GDC	MEAN	0.94	0.51	0.03	1.95	0.02	0.49	0.00	0.01	0.01	0.15	0.01	0.01	0.00	0.01	0.00	0.00	0.01	0.01	80.80
	SD	0.36	0.20	0.02	0.89	0.04	0.18	0.00	0.01	0.01	0.04	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01	4.63
SHN	MEAN	0.96	0.61	0.03	1.80	0.02	0.59	0.00	0.02	0.00	0.16	0.01	0.01	0.00	0.00	0.00	0.00	0.01	0.02	78.52
	SD	0.28	0.15	0.01	0.65	0.02	0.19	0.00	0.01	0.00	0.08	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.01	3.80

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	59.95	11.84	6.51	0.36	4.80	4.82	5.18	1.68	2.61	0.68	0.34	0.36	0.00	0.07	2.88	0.53	0.66	1.67	0.96
SD	17.94	3.47	2.54	0.11	2.60	2.62	2.97	1.84	1.27	0.32	0.36	0.16	0.00	0.04	2.76	0.58	0.21	0.62	0.48
MAX	84.67	18.08	12.23	0.70	9.37	11.73	13.69	9.08	5.40	1.48	1.44	0.77	0.01	0.14	10.56	2.51	1.03	2.85	1.79
MIN	31.74	5.48	2.57	0.24	1.20	2.23	1.27	0.18	0.67	0.12	0.02	0.13	0.00	0.02	0.43	0.10	0.29	0.76	0.25
CV	0.30	0.29	0.39	0.32	0.54	0.54	0.57	1.10	0.49	0.47	1.07	0.45	1.00	0.54	0.96	1.09	0.32	0.37	0.50
	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	%R
MEAN	0.89	0.49	0.04	2.19	0.02	0.48	0.00	0.02	0.01	0.13	0.01	0.01	0.002	0.004	0.001	0.001	0.005	0.015	79.890
SD	0.29	0.19	0.03	0.83	0.03	0.18	0.00	0.01	0.01	0.09	0.01	0.01	0.002	0.004	0.001	0.001	0.003	0.007	4.671
MAX	1.51	0.90	0.16	3.62	0.11	0.87	0.01	0.05	0.03	0.36	0.03	0.02	0.009	0.016	0.003	0.003	0.014	0.028	91.710
MIN	0.40	0.22	0.00	0.33	0.00	0.23	0.00	0.01	0.00	0.01	0.00	0.00	0.000	0.000	0.000	0.000	0.000	0.005	73.283
CV	0.33	0.38	0.83	0.38	1.14	0.38	0.95	0.51	0.83	0.70	0.68	0.48	1.01	1.01	0.66	1.23	0.62	0.48	0.06

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	0.91	0.84	0.74	-0.11	0.27	0.80	0.79	0.45	0.69	0.33	0.51	0.52	0.63	0.76
PM_{10}	0.91	1.00	0.75	0.57	-0.21	0.33	0.80	0.80	0.31	0.65	0.52	0.38	0.63	0.47	0.79
OC	0.80	0.75	1.00	0.92	-0.35	0.01	0.49	0.55	0.52	0.33	0.29	0.29	0.33	0.50	0.58
EC	0.74	0.57	0.92	1.00	-0.24	0.00	0.31	0.34	0.59	0.24	0.20	0.26	0.10	0.55	0.50
NO_3^-	0.80	0.80	0.49	0.31	-0.20	0.34	1.00	0.90	0.11	0.78	0.18	0.40	0.48	0.29	0.58
SO_4^{-2}	0.79	0.80	0.55	0.34	-0.05	0.25	0.90	1.00	0.26	0.69	0.21	0.58	0.59	0.35	0.61
NH_4^+	0.69	0.65	0.33	0.24	0.07	0.16	0.78	0.69	0.03	1.00	0.25	0.51	0.52	0.43	0.60
Metals_$PM_{2.5}$	0.63	0.47	0.50	0.55	0.42	-0.18	0.29	0.35	0.56	0.43	0.27	0.66	0.39	1.00	0.83
Metals_PM_{10}	0.76	0.79	0.58	0.50	0.13	-0.04	0.58	0.61	0.42	0.60	0.52	0.53	0.58	0.83	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 (66%). The major species contributing to fine mode are TC, OC, EC, Cl^-, NO_3^-, SO_4^{-2}, Na^+, K^+, Mg^{2+}, Ca^{2+}, B, Na, P, K, Cr, V, Mn, Ni and Se; whereas major species contributing to coarse mode are Be, Mg, Al, Si, Co, Zn, Rb, Cd, 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.

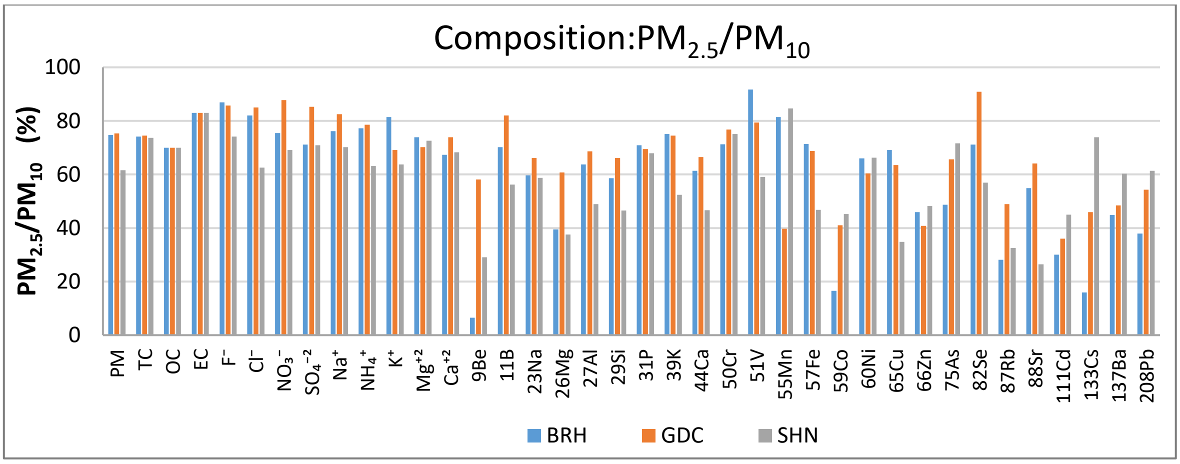


Figure 2.24: Compositional comparison of species in $PM_{2.5}$ vs PM_{10}

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}
BRH	59	4.0	0.067	10.5	0.177	18.4	0.310
GDC	92	5.1	0.055	16.0	0.174	31.4	0.342
SHN	108	8.7	0.081	23.9	0.222	24.5	0.228
Overall	86	5.9	0.068	16.8	0.191	24.8	0.293
SD	20.1	2.5	0.013	6.7	0.027	6.5	0.059
CV	0.233	0.415	0.190	0.400	0.140	0.263	0.201

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/$PM_{2.5}$
BRH	44	2.5	0.056	7.8	0.176	13.7	0.308
GDC	69	3.4	0.049	13.6	0.196	23.4	0.338
SHN	66	4.1	0.062	16.4	0.248	18.1	0.273
Overall	60	3.3	0.055	12.6	0.207	18.4	0.306
SD	11.1	0.8	0.006	4.4	0.037	4.9	0.033
CV	0.185	0.244	0.114	0.347	0.178	0.266	0.106

2.3.9 Carbon monoxide (CO)

CO levels were measured at two sites. 8 Hourly Statistical Results of CO ($\mu g/m^3$) at all two sites are presented in Table 2.24.

GDC

The hourly average concentration of CO was observed at GDC. From Figure 2.25, it can be seen that the maximum concentration is observed during the peak hours of traffic during the day (both in the morning as well as evening). It was observed that maximum concentration occurs at the time peak traffic in morning and evening hours.

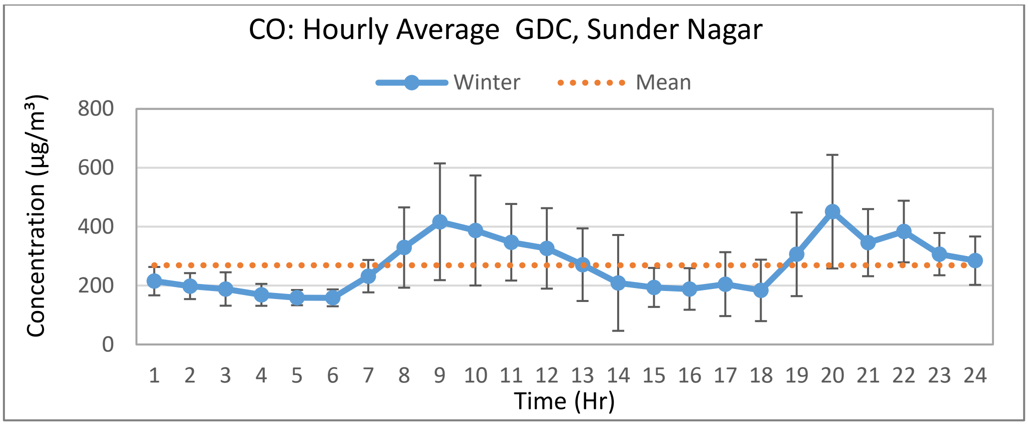


Figure 2.25: Hourly average concentration (µg/m^3) of CO at GDC

SHN

The hourly average concentration of CO was observed at SHN. From Figure 2.26, it can be seen that the maximum concentration is observed during the peak hours of traffic during the day (both in the morning as well as evening). It was observed that maximum concentration occurs at the time peak traffic and higher in morning hours than in evening hours.

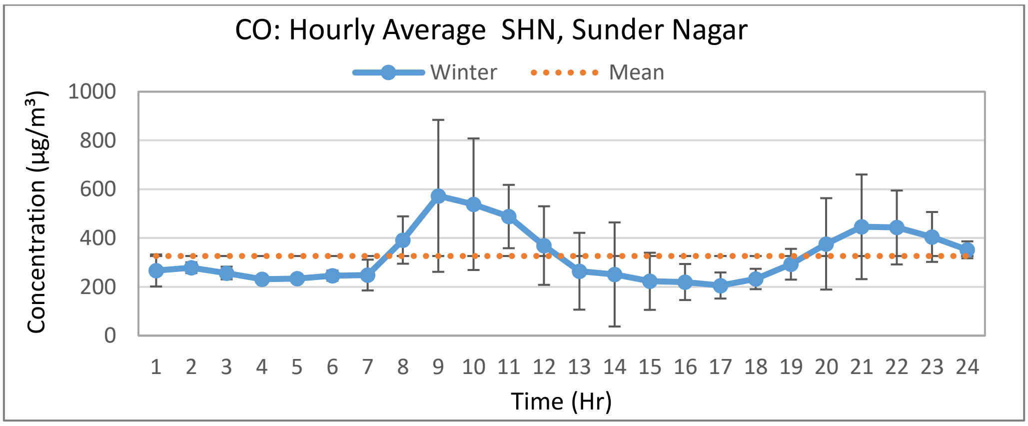


Figure 2.26: Hourly average concentration (µg/m^3) of CO at SHN

Table 2.24: 8 Hourly Statistical Results of CO (µg/m^3) at Sunder Nagar

SITE	CO at GDC			CO at SHN		
Time	**0-8 Hr**	**8-16 Hr**	**16-24 Hr**	**0-8 Hr**	**8-16 Hr**	**16-24 Hr**
Mean	206	292	308	269	366	344
SD	56.3	89.8	88	52	148	92.1
CV	0.27	0.31	0.29	0.19	0.4	0.27
Max	329	417	451	392	573	446
Min	158	189	184	232	220	206

2.3.10 Ozone (O_3)

O_3 levels were measured at two sites. 8 Hourly Statistical Results of O_3 levels (µg/m^3) at two sites are presented in Table 2.25.

GDC

The hourly average concentration of O_3 was observed at GDC. From Figure 2.27, it can be seen that the maximum concentration is observed during the peak hours of traffic during the day (both in the morning as well as evening). It was observed that maximum concentration occurs at the time peak traffic hours and higher in evening hours than in morning hours. The lower levels of ozone in noon period appears due to rapid increase in convective mixing height and concurrent increase in wind speed in day time. The increase in ozone levels during evening hours could be due to decrease in mixing height and lowered wind speed (Varshney and Aggarwal, 1992).

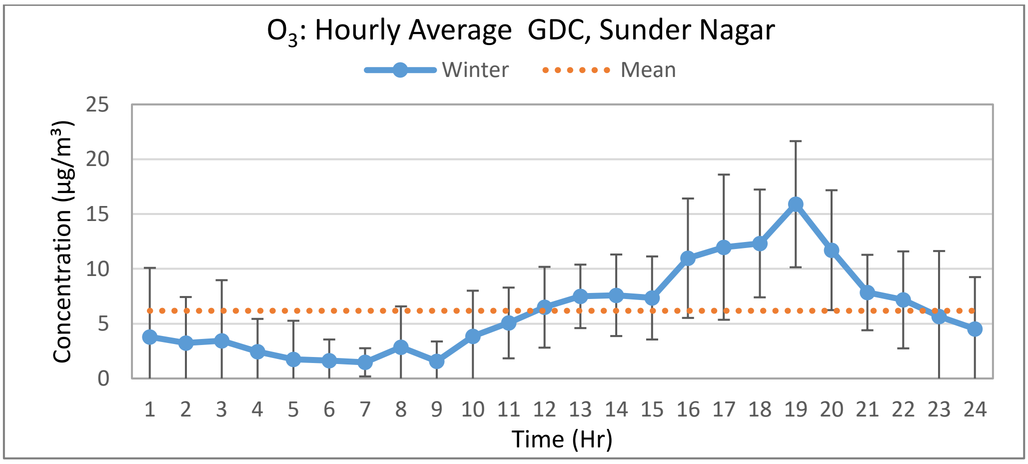


Figure 2.27: Hourly average concentration (µg/m^3) of O_3 at GDC

SHN

Hourly average concentration of O_3 was observed at SHN. From Figure 2.28, it can be seen that the maximum concentration is observed during the peak hours of traffic during the day (both in morning as well as evening). It was observed that maximum concentration occurs at the time peak traffic hours and higher in evening hours than in morning hours.

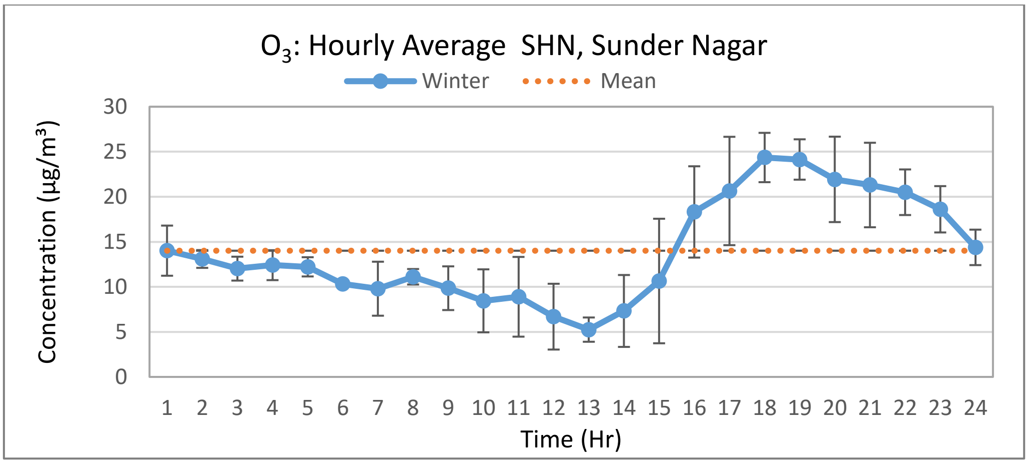


Figure 2.28: Hourly average concentration (µg/m^3) of O_3 at SHN

Table 2.25: 8 Hourly Statistical Results of O_3 (µg/m^3) at Sunder Nagar

SITE	O_3 at GDC			O_3 at SHN		
Time	**0-8 Hr**	**8-16 Hr**	**16-24 Hr**	**0-8 Hr**	**8-16 Hr**	**16-24 Hr**
Mean	2.58	6.3	9.64	11.9	9.43	20.74
SD	0.89	2.82	3.91	1.41	3.99	3.19
CV	0.34	0.45	0.41	0.12	0.42	0.15
Max	3.78	11	15.9	14	18.32	24.36
Min	1.47	1.59	4.54	9.8	5.25	14.38

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 59 – 108 µg/m^3 and the mean $PM_{2.5}$ levels were 44 – 69 µg/m^3.
- PM_{10} and $PM_{2.5}$ levels are about to meet the national air quality standards except at SHN, an industrial area in Naulakha. However, particulate pollution is the main concern in the city. It is observed that the air quality in terms of PM_{10} and $PM_{2.5}$ falls in the satisfactory to moderate 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 86±20 µg/m^3 against the acceptable level of 100 µg/m^3. The highest levels were observed at SHN and the lowest at BRH.

The important components are the secondary particles (NO_3^- + SO_4^{2-} + NH_4^+), which account for about 19% of total PM_{10}, and combustion-related total carbon (TC = EC + OC) accounts for about 29%; both fractions of secondary particles and combustion-related carbons account for 48% of PM_{10} in winter months.

The crustal component (Si + Al + Fe + Ca) accounts for about seven percent in PM_{10}. This suggests soil and road dust have less significant contributions. The coefficient of variation (CV) is about 0.41 (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 4 – 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 SHN at 10 µg/m^3 compared to the overall city level of 6.7 µg/m^3. The high level at SHN signifies some local burning of waste in as a means of disposal of solid waste.

$PM_{2.5}$

The overall average concentration of $PM_{2.5}$ in winter is 60±11 µg/m^3 against the acceptable level of 60 µg/m^3. The highest levels are observed at GDC and the lowest at BRH.

The important components are the secondary particles (NO_3^- + SO_4^{2-} + NH_4^+), which account for about 21% of total $PM_{2.5}$ and combustion-related total carbon (TC = EC + OC) accounts for about 31%; 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 SHN (25%) and TC at GDC (34%).

The Cl^- content in $PM_{2.5}$ is consistent and varies between 5 – 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 SHN with some high peaks. SHN was a industrial site having uses of coal in industries 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 GDC. 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.

The mean 8-hourly ozone and CO levels are within the acceptable limits of NAQS (8-hourly O_3: 100 µg/m^3; CO: 2 mg/m^3). The diurnal pattern of CO and ozone are consistent as expected.

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 Sunder Nagar.

Total PAH levels (17 compounds; particulate phase) had high variability in the range of 2.9 to 20.2 and B(a)P at 1.02 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 BRH.

The concentrations of molecular markers in $PM_{2.5}$ (a total of 6 compounds) vary in the range of 20 to 85 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 (2012 – 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 (2012 – 2019) air quality data for two sites were considered for Sunder Nagar. The sites were Station-I Office Building and Station-II MC Office. 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.

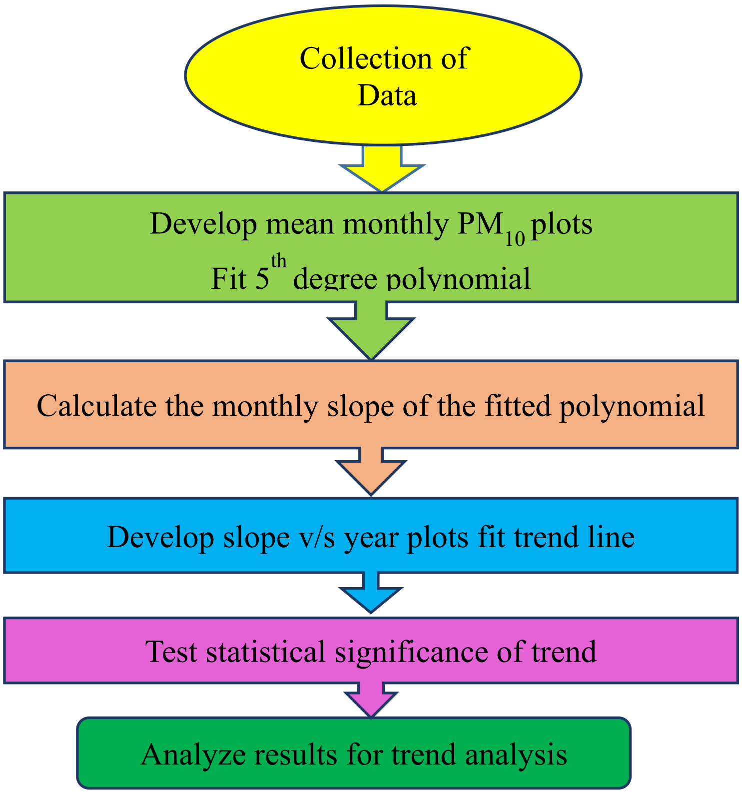


Figure 3.1: Stepwise methodology and major tasks (Nagar et al., 2019)

3.3 Results and Interpretations

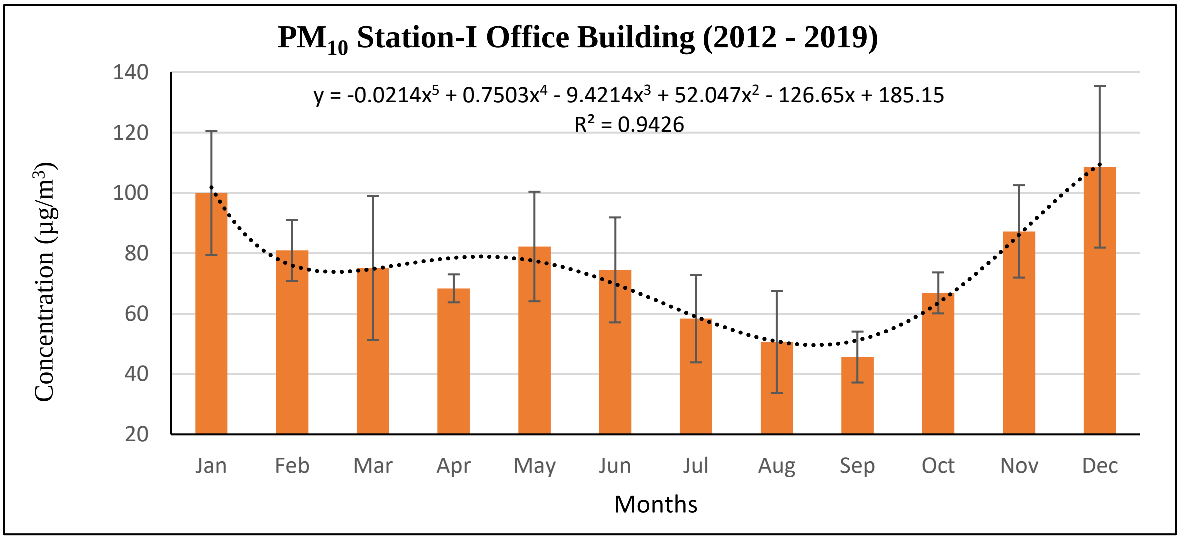
3.3.1 Annual pattern in PM_{10} and NO_2

The total number of monthly means of 24-hr PM_{10} and NO_x measurements in Sunder Nagar was about 130 (at each site). The monthly mean levels of PM_{10} and NO_x averaged over 2012 – 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. It is interesting to note that in the month of May, levels increase and show significant variability. Sunder Nagar may have been dust storms in the months of May and June. However, PM_{10} levels in the most of months (except April, July September and October) exceed the 24-hr national air quality standard at station-I and station-II, however, monthly means meet the 24-hr NAAQ standards at both stations except January, November and December.

The NO_x levels are highest in April, May, June and December months at station-I and station-II while lowest concentration observed in August and September (month of monsoon) (Figure 3.3). There is a sharp increase seen in NO_x in winter months. The NO_x levels meet the 24-hr national standard and well below the acceptable limit.

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.



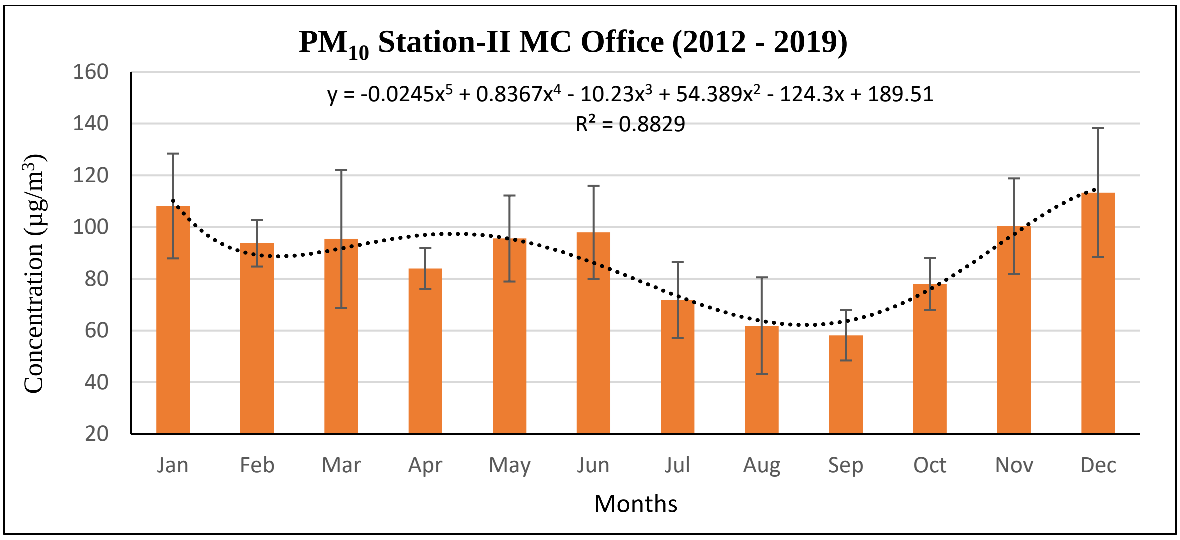
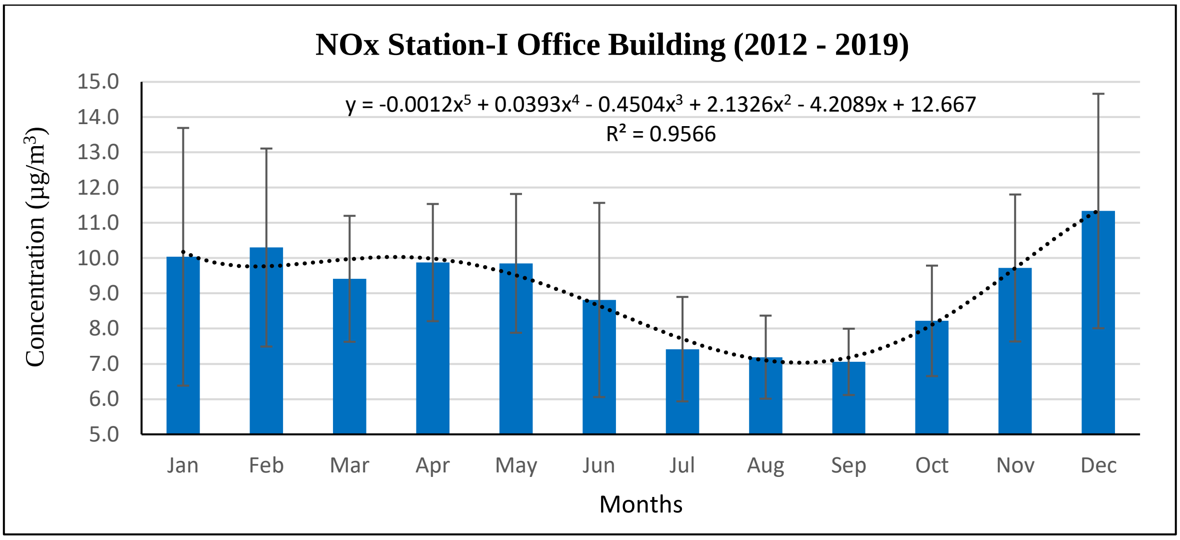


Figure 3.2: Variation in PM_{10} at (a) Station-I and (b) Station-II



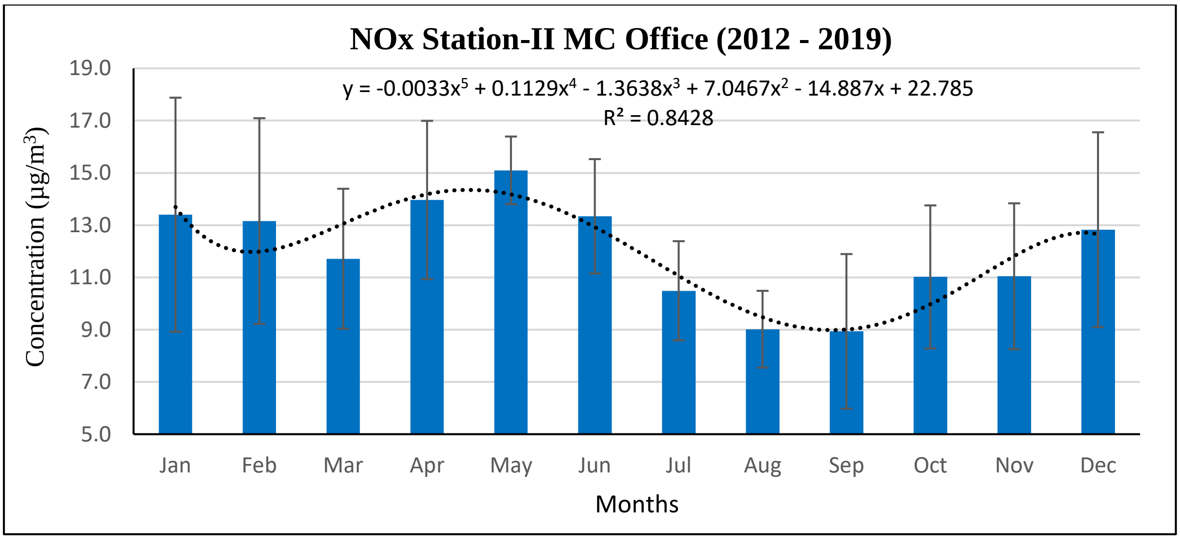
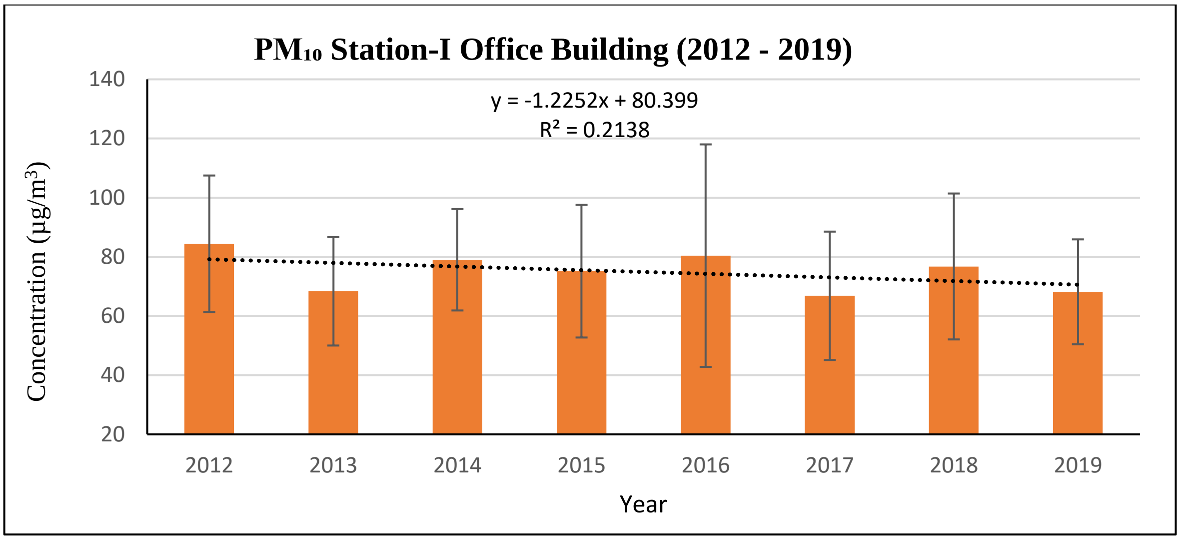


Figure 3.3: Variation in NO_x at (a) Station-I and (b) Station-II



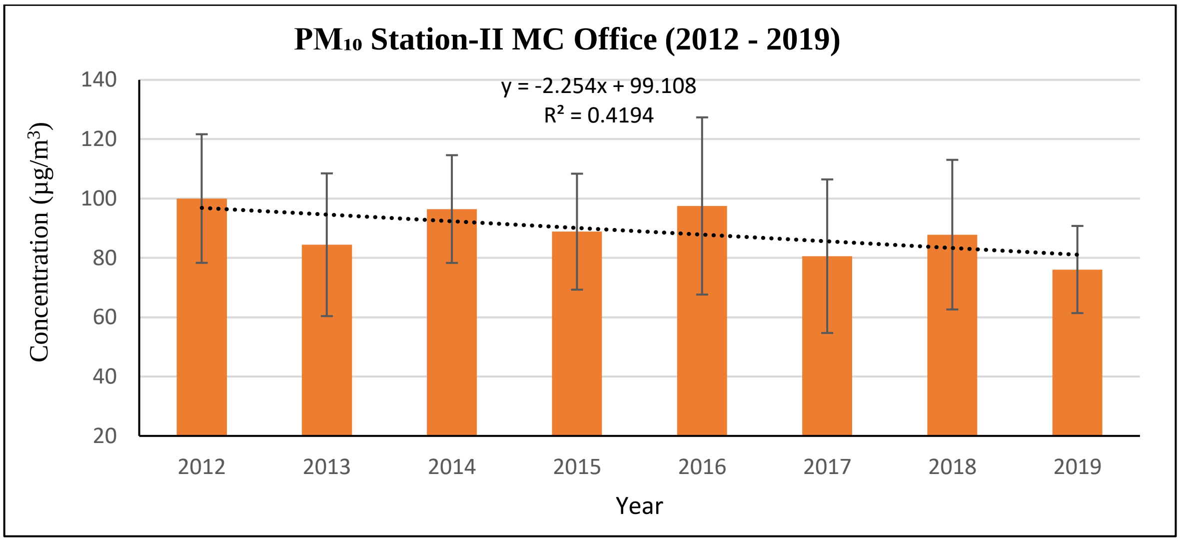
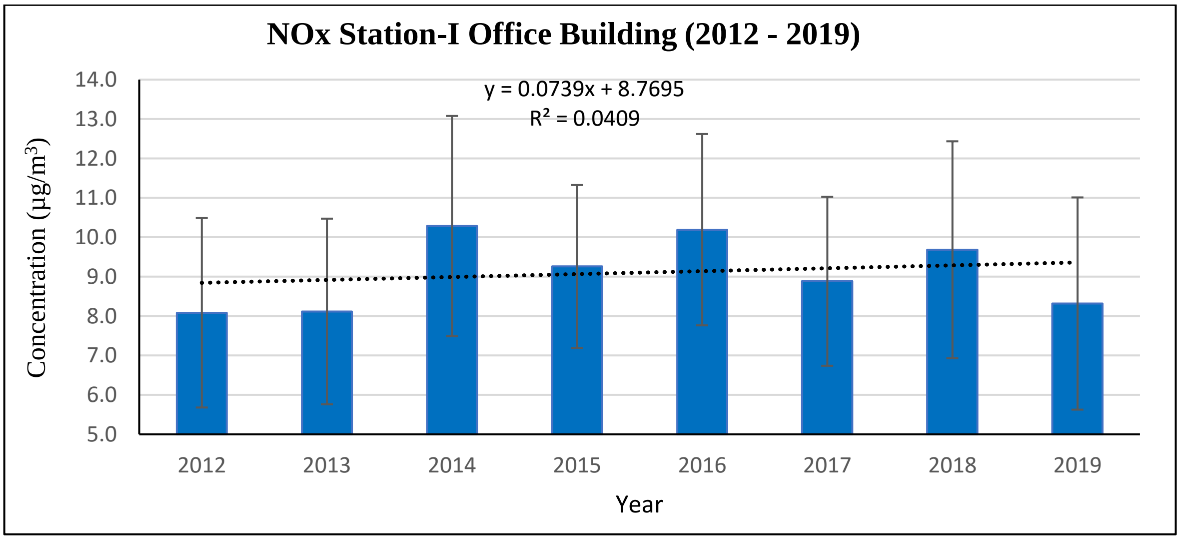


Figure 3.4: Timeseries of annual mean levels of PM_{10}



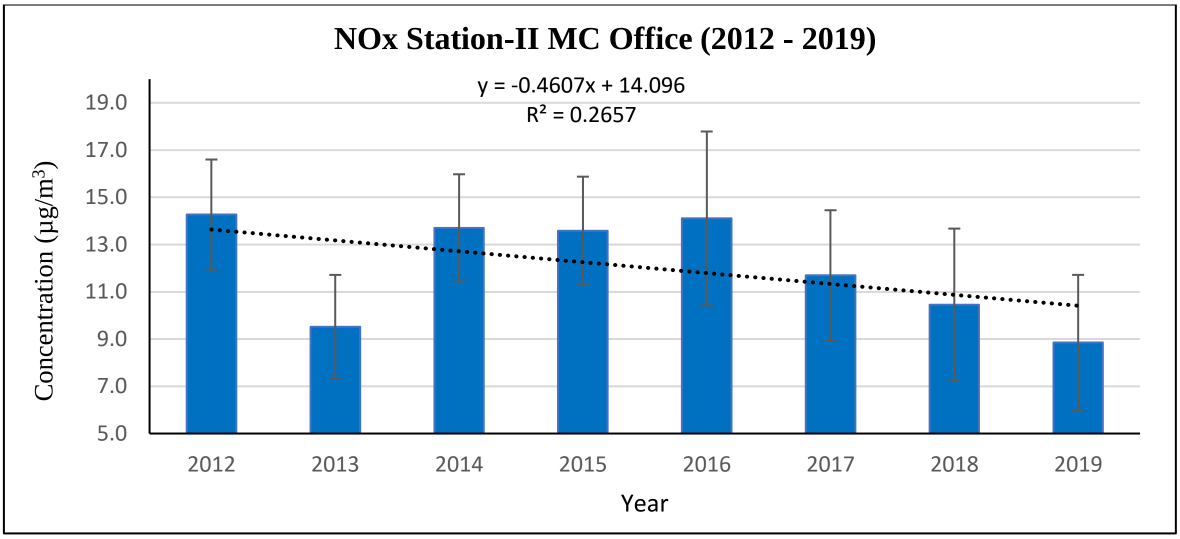


Figure 3.5: Timeseries of annual mean levels of NO_x

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 Sunder Nagar. 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} and NO_x in Sunder Nagar as most of months show no trend and few months indicate decreasing or decreasing trend. The annual levels of PM_{10} and NO_x also show no trend at Station I and Station II.

Table 3.1: Comparison of mean PM_{10} slopes (in µg/m³/year) and trends in monthly slots during 2012-2019

Sites	PM_{10}	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Station I	Slope	3.67	-0.50	2.00	0.25	-2.83	0.33	-0.25	-3.75	0.60	0.67	1.20	-5.67	-0.38
	Trend (MK)	No (↔)	No (↔)	No (↔)	No (↔)	No (↔)	No (↔)	No (↔)	No (↔)	No (↔)	No (↔)	No (↔)	No (↔)	No (↔)
Station II	Slope	2.50	-0.33	-9.50	-0.13	1.00	-5.00	-2.50	-5.80	-5.00	-0.40	-2.00	-8.50	-2.16
	Trend (MK)	No (↔)	No (↔)	No (↔)	No (↔)	No (↔)	No (↔)	Yes (↓)	No (↔)	No (↔)	No (↔)	No (↔)	No (↔)	No (↔)
MK: Mann Kendall Test		**↑ Increasing Trend**				**↓ Decreasing Trend**				**↔ Statistically Insignificant Trend**				

Table 3.2: Comparison of mean NO_x slopes (in µg/m³/year) and trends in monthly slots during 2012-2019

Sites	NOx	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Station I	Slope	0.25	-0.77	0.15	-0.20	0.98	1.27	0.23	0.10	-0.07	-0.02	-0.80	-1.00	-0.15
	Trend (MK)	No (↔)	No (↔)	No (↔)	No (↔)	Yes (↑)	Yes (↑)	No (↔)	No (↔)	No (↔)	No (↔)	No (↔)	No (↔)	No (↔)
Station II	Slope	0.80	-1.50	-0.50	-1.57	-0.30	0.64	-0.43	-0.85	-1.80	-1.50	-1.67	-1.54	-0.81
	Trend (MK)	No (↔)	No (↔)	No (↔)	No (↔)	No (↔)	No (↔)	No (↔)	No (↔)	No (↔)	No (↔)	No (↔)	No (↔)	No (↔)
MK: Mann Kendall Test		**↑ Increasing Trend**					**↓ Decreasing Trend**				**↔ Statistically Insignificant Trend**			

4 Emission Inventory

4.1 Introduction

Emission inventory (EI) is a basic necessity for planning air pollution control activities. EI provides a reliable estimate of total emissions of different pollutants, their spatial and temporal distribution, and identification and characterization of main sources. This information on EI is an essential input to air quality models for developing strategies and policies. In this chapter, the emission inventory of Sunder Nagar for the year 2020 is presented.

4.2 Methodology

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

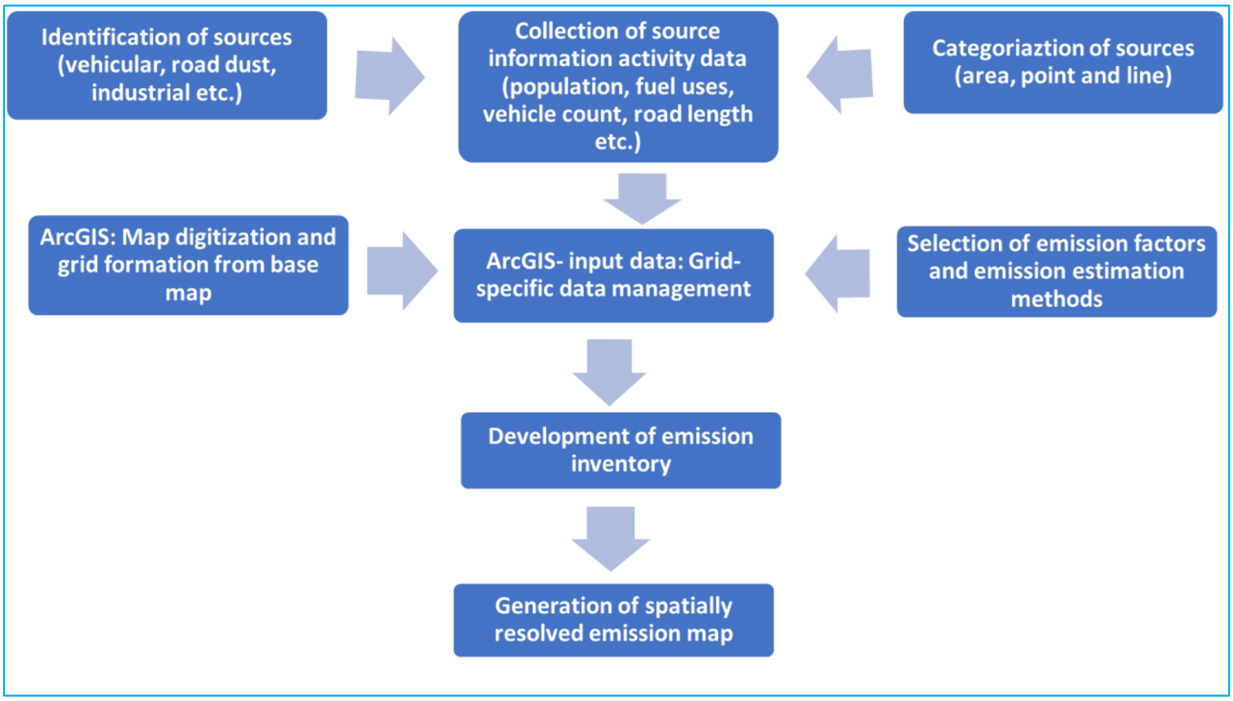


Figure 4.1: Stepwise Methodology adopted for the Study

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.

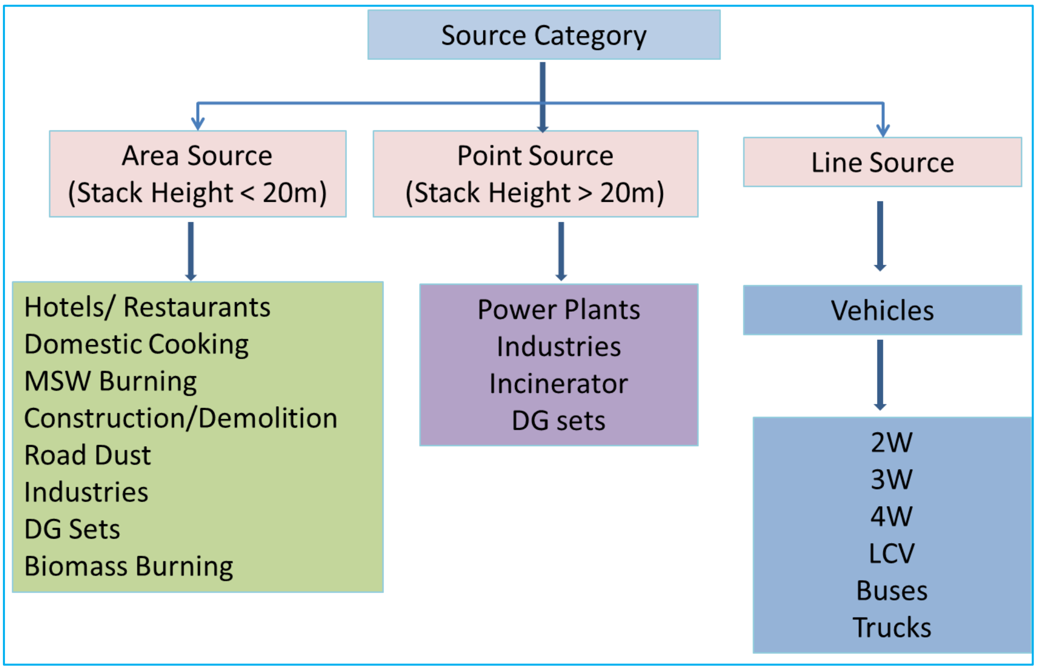


Figure 4.2: Source Category and type of sources

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 3 locations was conducted. A physical survey of industrial areas was also done. The main sources of secondary data collection are from HPPCB, Census of India, CPCB website, 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. Details on Field survey for data collection information, frequency of data collection in various sectors, time period during physical verification is given in the Annexure-I.

4.2.3 Digital Data Generation

The land-use map of the study area is prepared in terms of settlements, agriculture, road network, water bodies, etc. (Figure 4.3 to Figure 4.11).

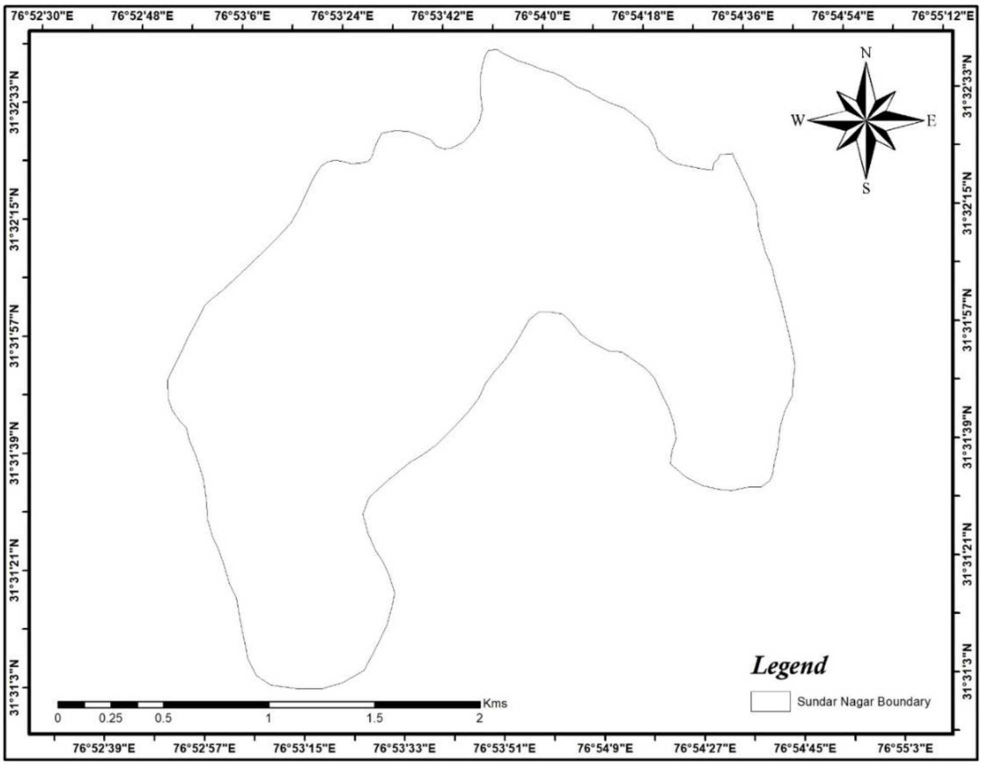


Figure 4.3: Sunder Nagar Boundary

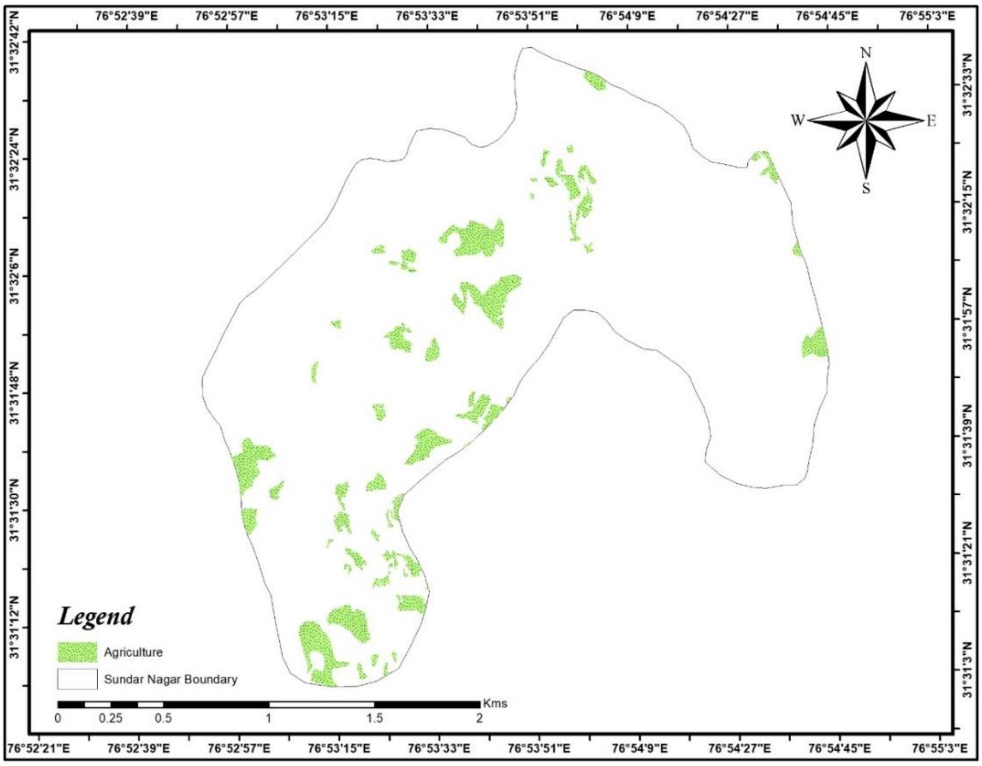


Figure 4.4: Agricultural Area Map

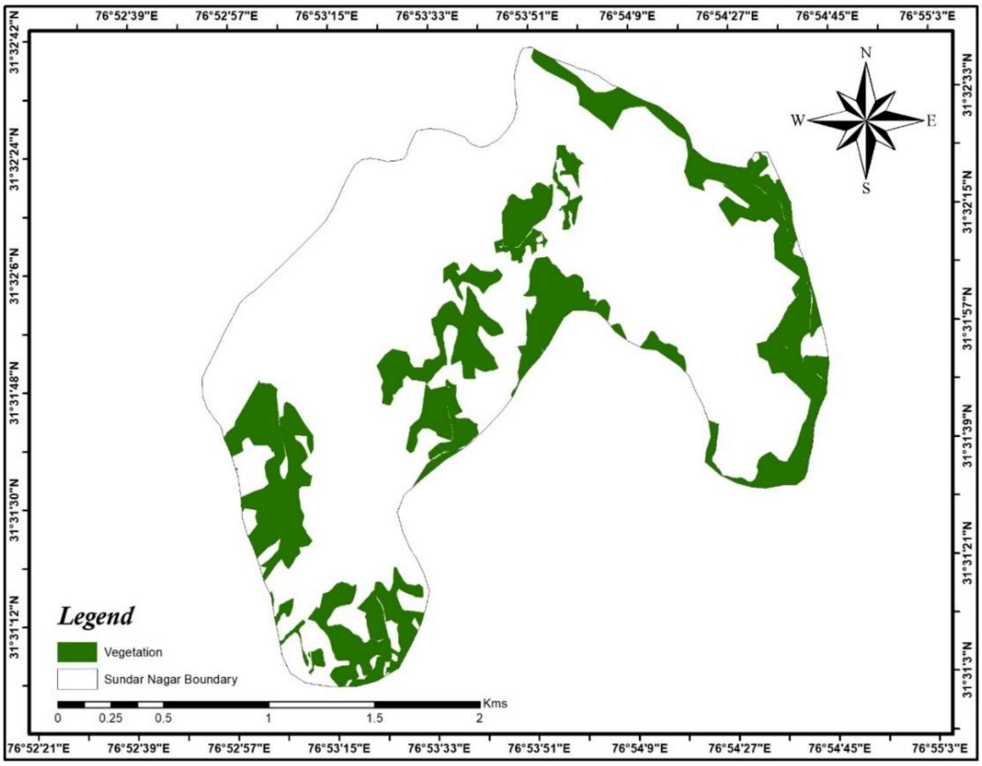


Figure 4.5: Green Area Map

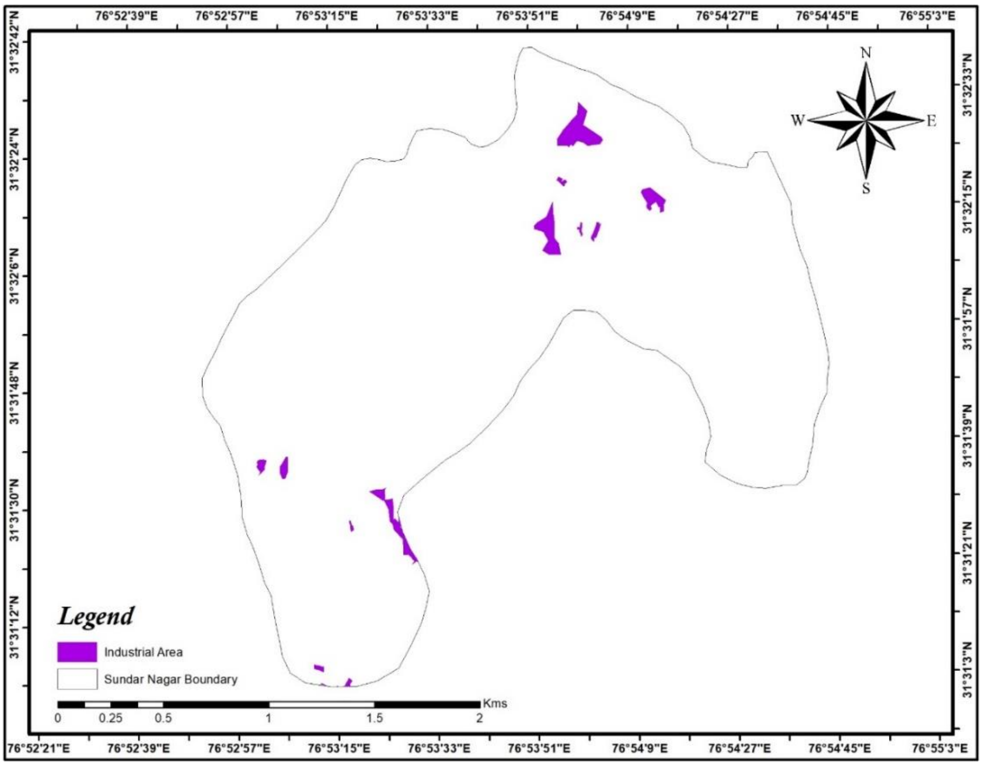


Figure 4.6: Industrial Area Map

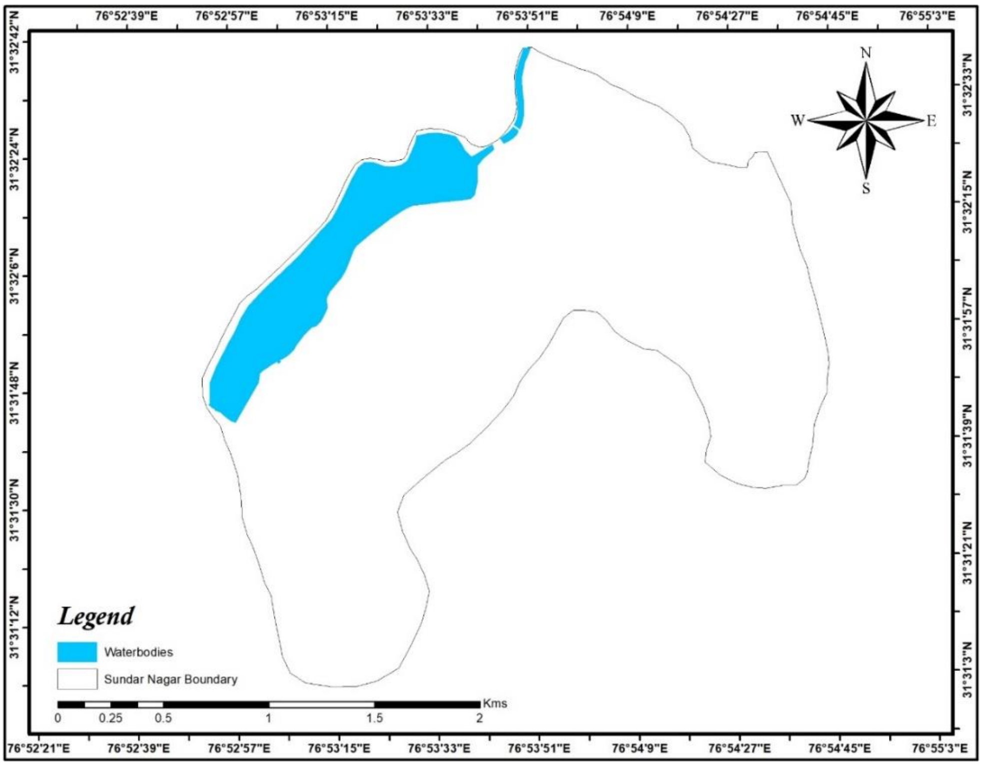


Figure 4.7: Waterbodies Area Map

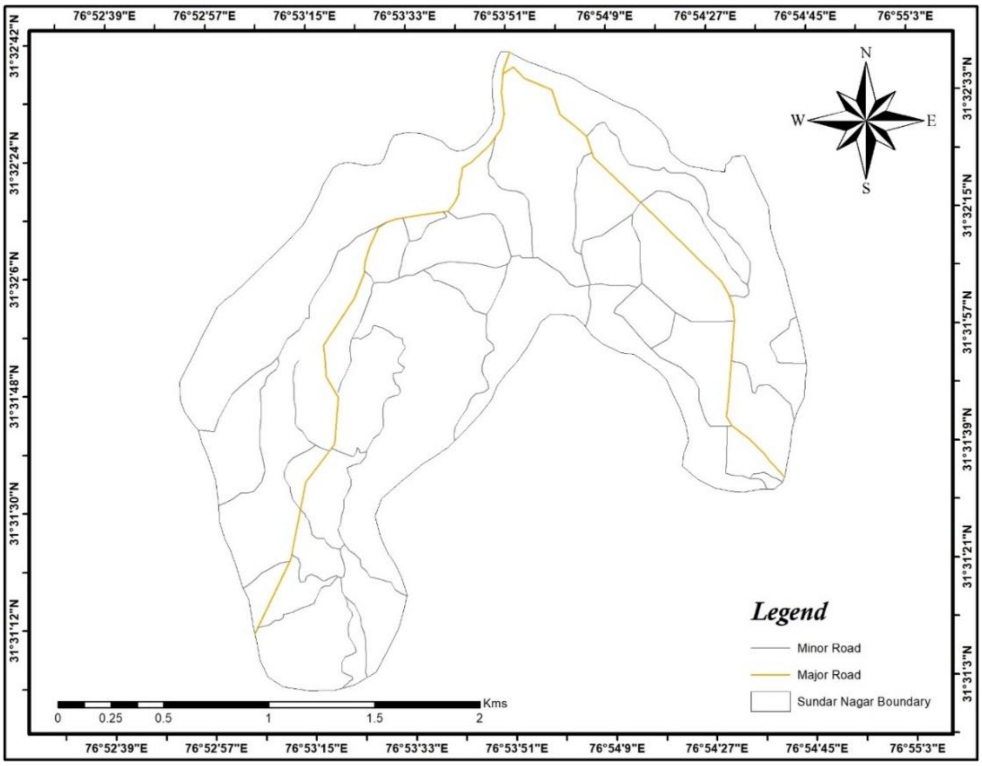


Figure 4.8: Major & Minor Road Network Map

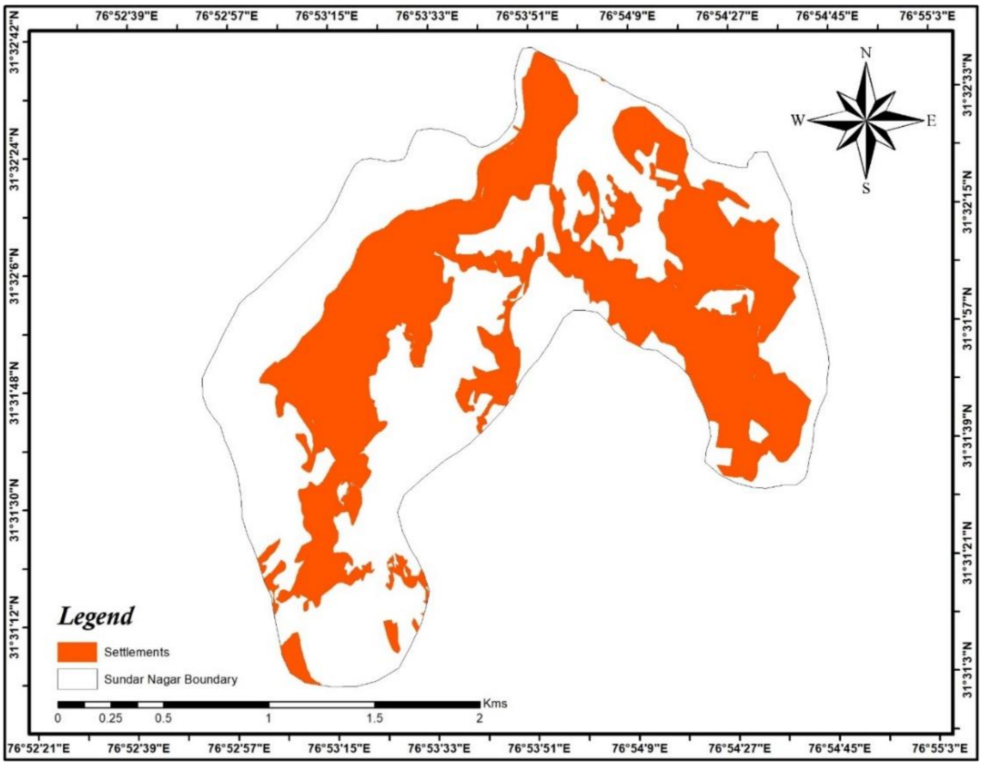


Figure 4.9: Settlement Area Map

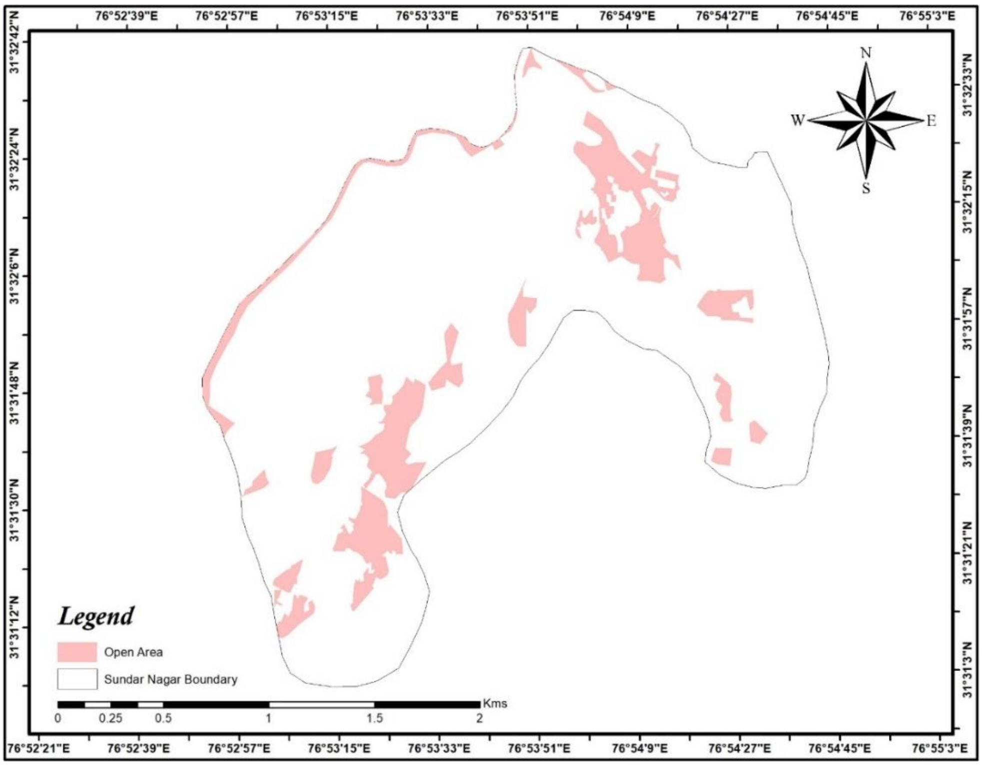


Figure 4.10: Open Area Map

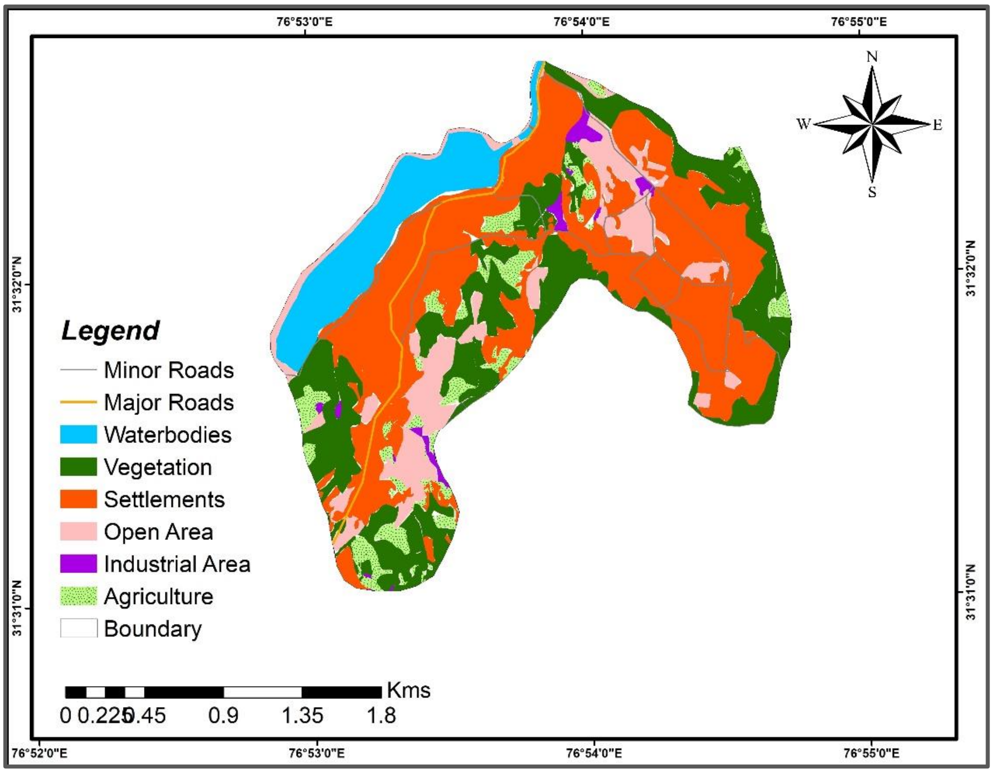


Figure 4.11: Land use and Land cover Map of Sunder Nagar

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 Sunder Nagar. The Grid map of Sunder Nagar with grid identity numbers is shown in Figure 4.12. The entire study area was divided into grid cells of 0.2 km × 0.2 km.

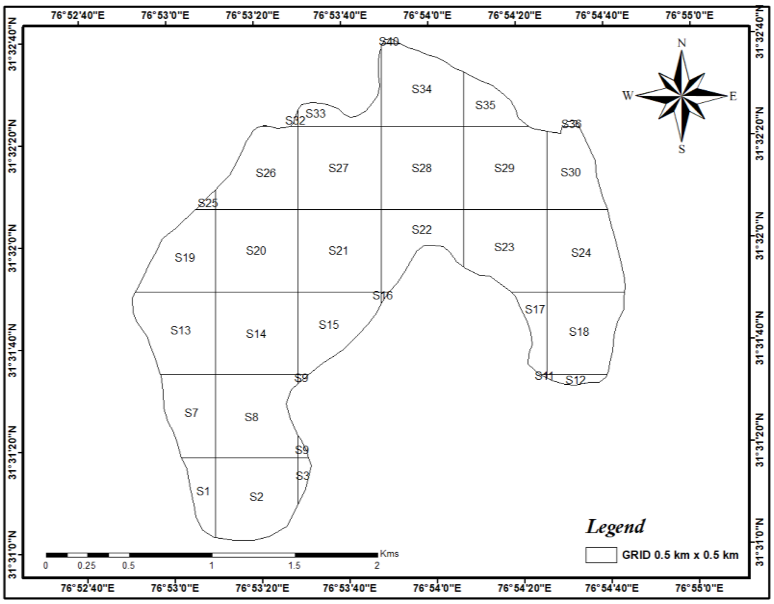


Figure 4.12: Grid Map of Sunder Nagar City showing Grid Identity Numbers

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:

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

Where:

E = Emissions;

A = Activity rate;

EF = Emission factor, and

ER = Overall emission reduction efficiency, %

4.2.5 Domestic Sector

Sunder Nagar is a municipal Council city in the district of Mandi, Himachal Pradesh. The Sunder Nagar city is divided into 13 wards. The projected population of Sunder Nagar city for the year 2020 is approximately 33000 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%).

The area of wards was calculated using GIS, after obtaining the area of wards, the emission density (for e.g., PM_{10} per sq. km) for each ward is calculated for different pollutants (PM_{10}, $PM_{2.5}$, SO_2, NOx, and CO). The emission factors are given by CPCB (2011) was used for each fuel type.

The overall emission from domestic sources is presented in Figure 4.13 (a) & (b). The emission contribution from different fuel types to different pollutants is shown in Figure 4.14 to Figure 4.18. For spatial distribution of different pollutants (Figure 4.19 to Figure 4.23), emission per capita, in each ward and village was calculated, as activity data was available based on per capita.

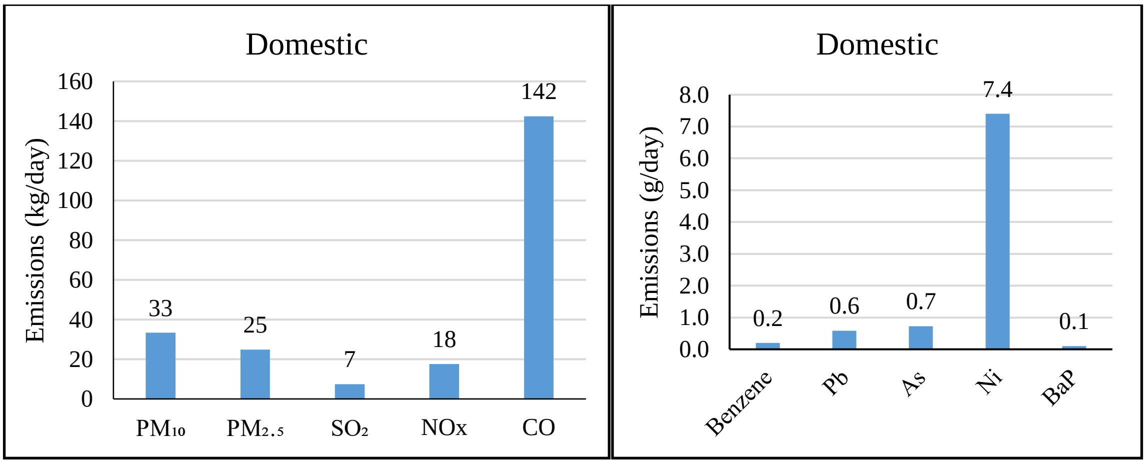
The emission density in terms of kg/day/m^2 in each ward was calculated based on population and area of the ward for different pollutants (PM_{10}, $PM_{2.5}$, SO_2, NOx, and CO); see below.

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

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

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 4.13: Emission Load from Domestic Sector

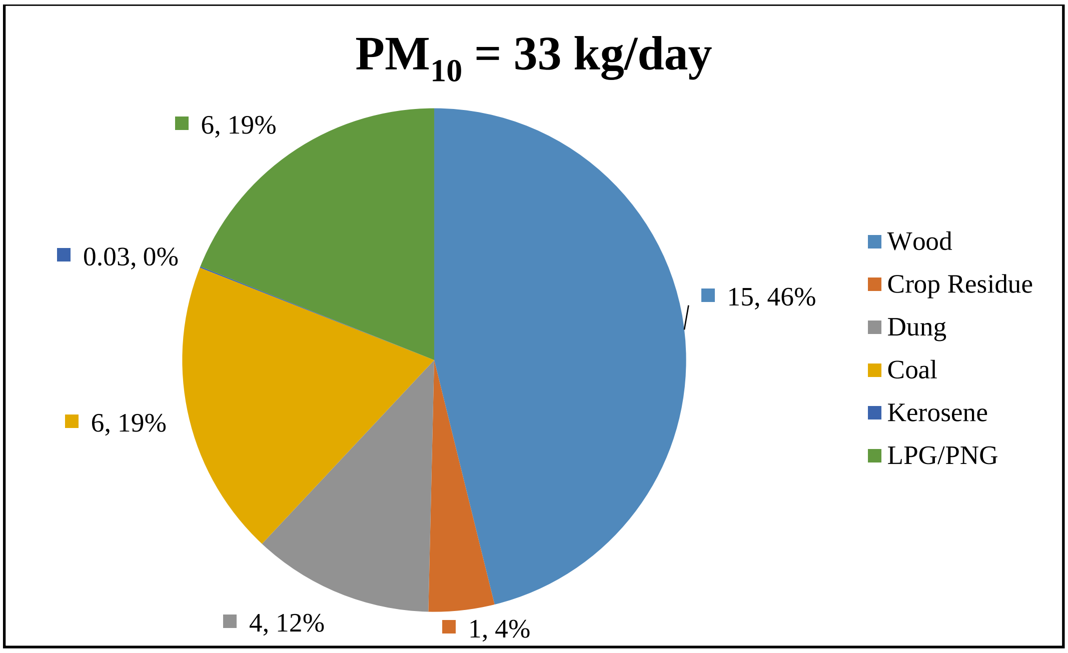


Figure 4.14: PM_{10} Emission load from Domestic Sector (Kg/day, %)

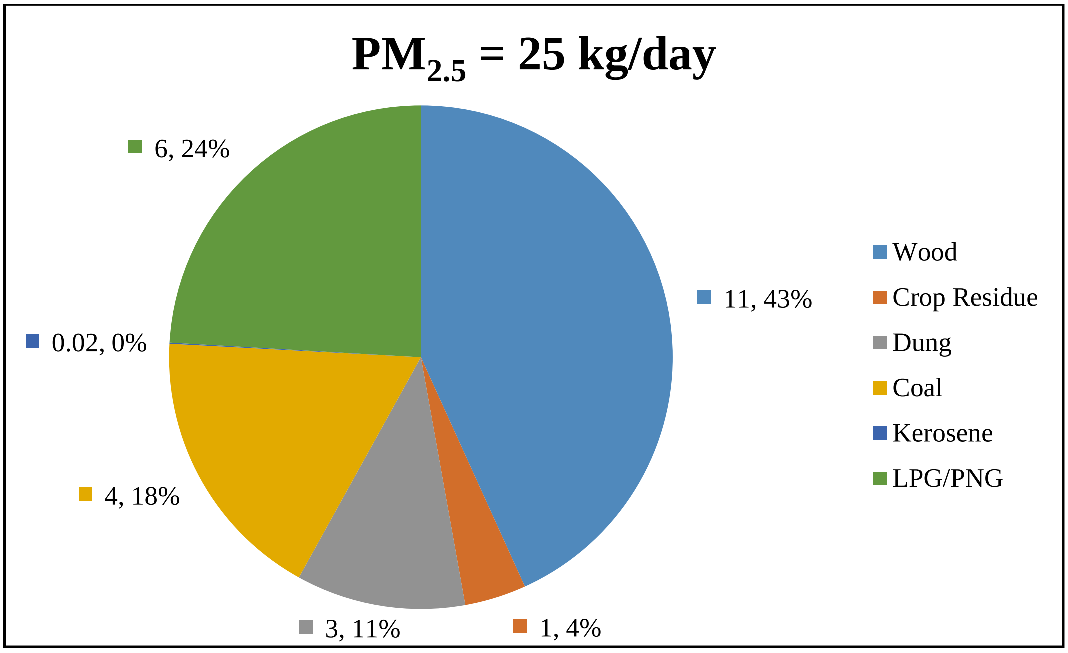


Figure 4.15: $PM_{2.5}$ Emission load from Domestic Sector (Kg/day, %)

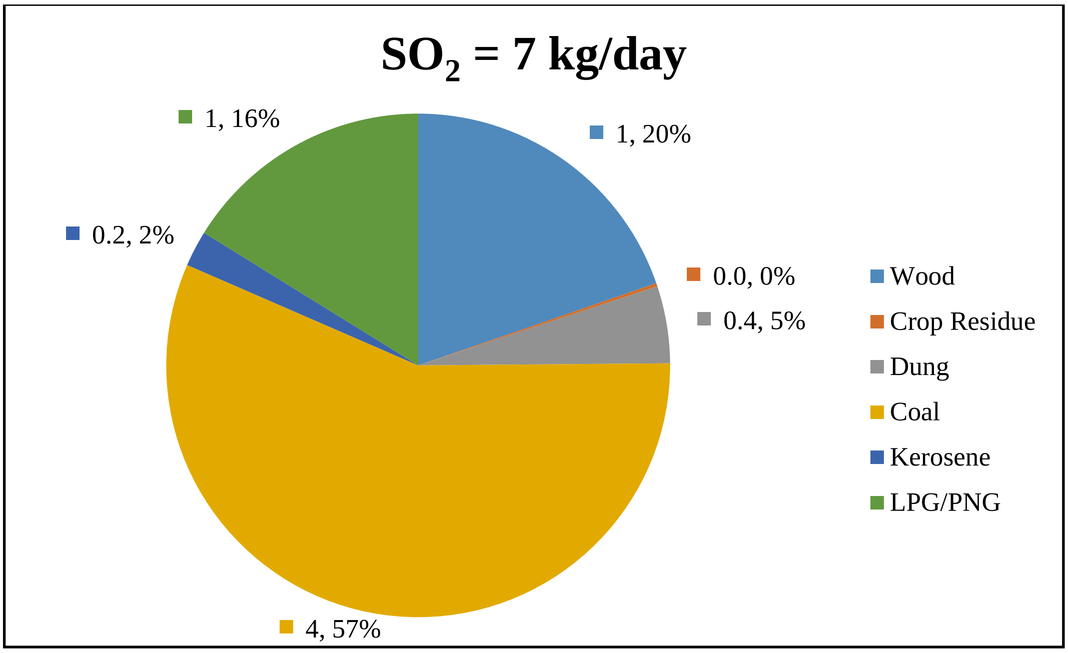


Figure 4.16: SO_2 Emission load from Domestic Sector (Kg/day, %)

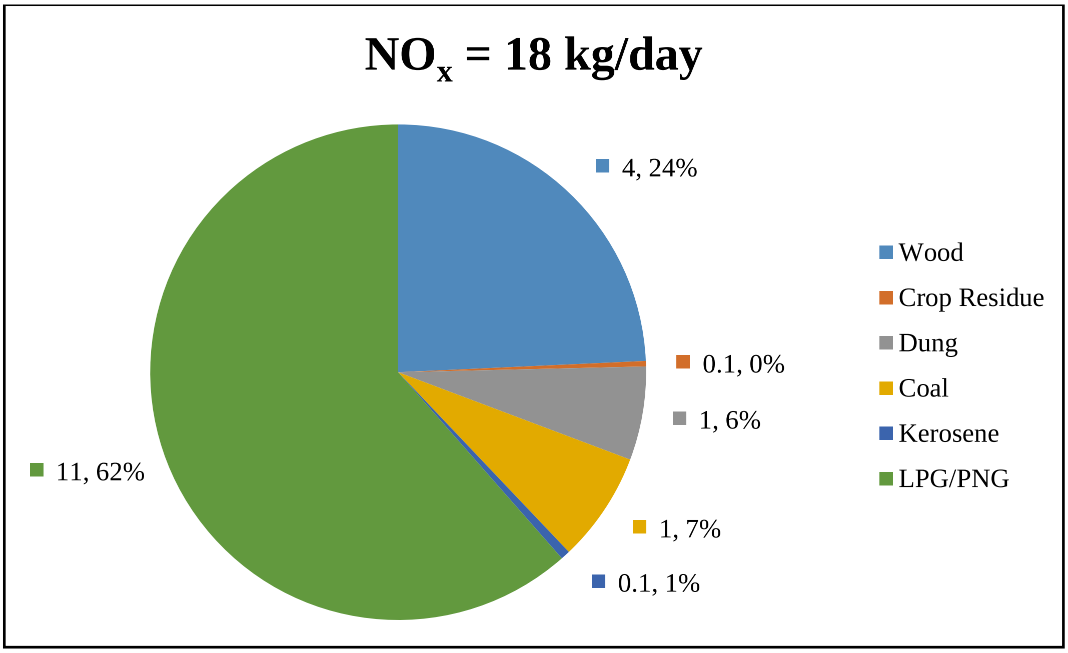


Figure 4.17: NOx Emission load from Domestic Sector (Kg/day, %)

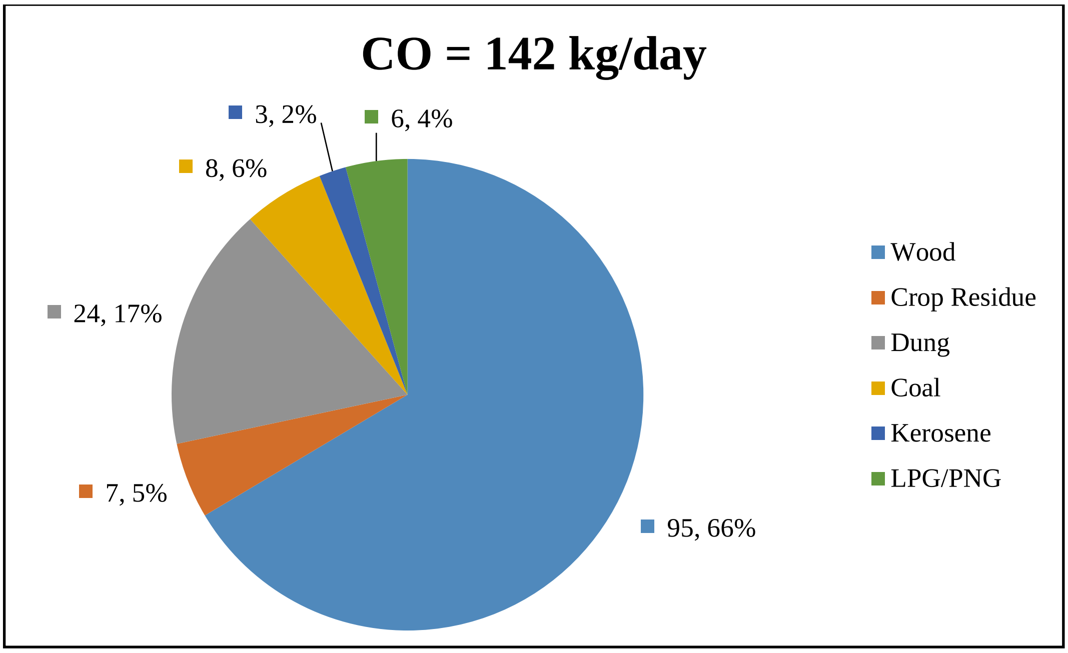


Figure 4.18: CO Emission load from Domestic Sector (Kg/day, %)

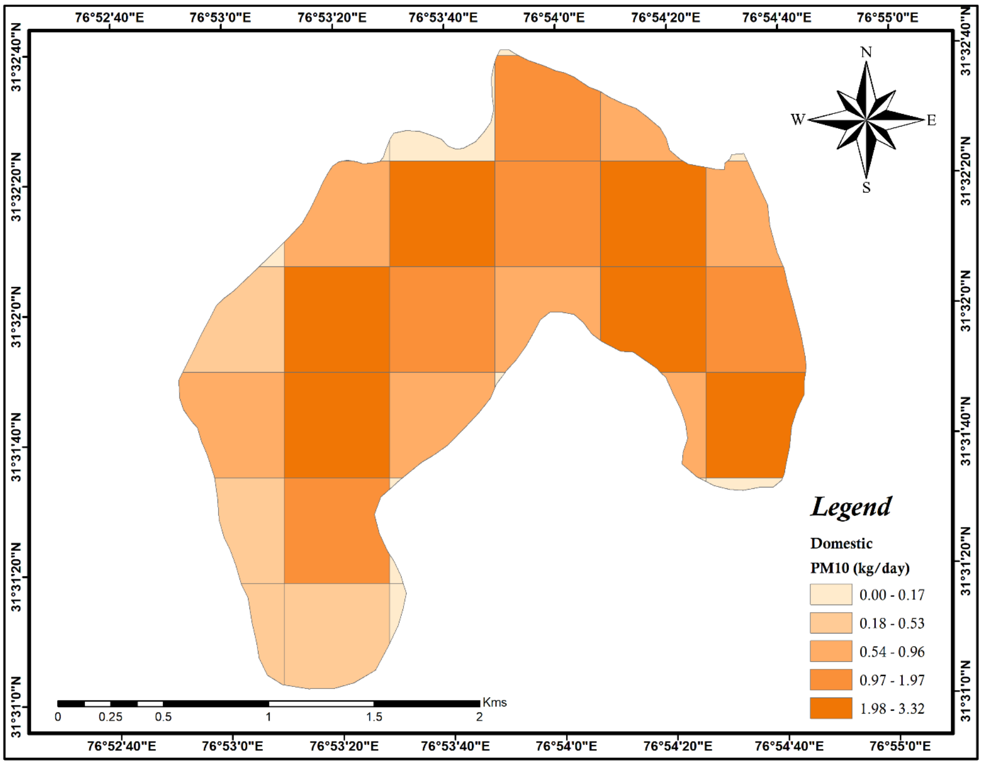


Figure 4.19: **Spatial Distribution of PM_{10} Emissions from Domestic Sector**

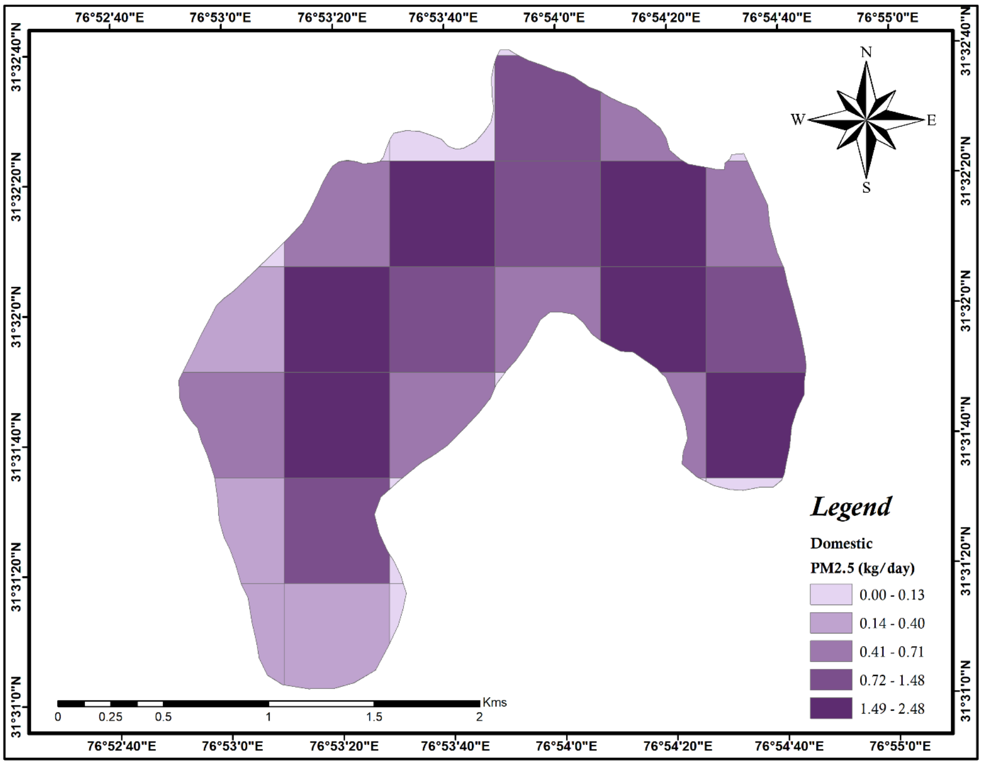


Figure 4.20: **Spatial Distribution of $PM_{2.5}$ Emissions from Domestic Sector**

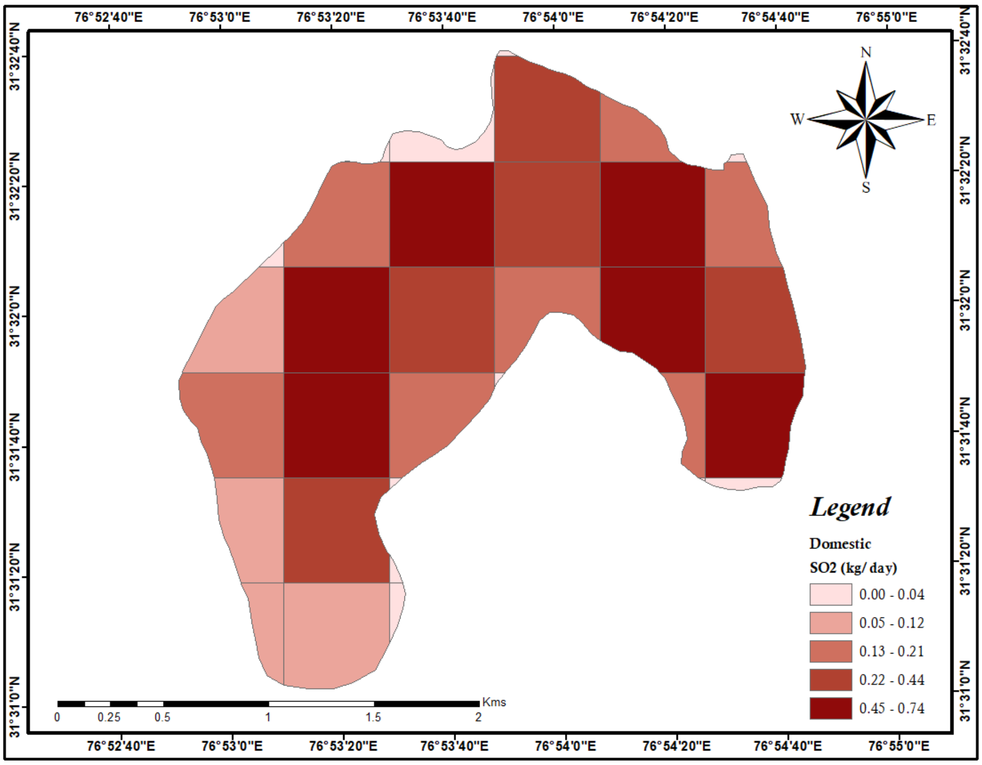


Figure 4.21: **Spatial Distribution of SO_2 Emissions from Domestic Sector**

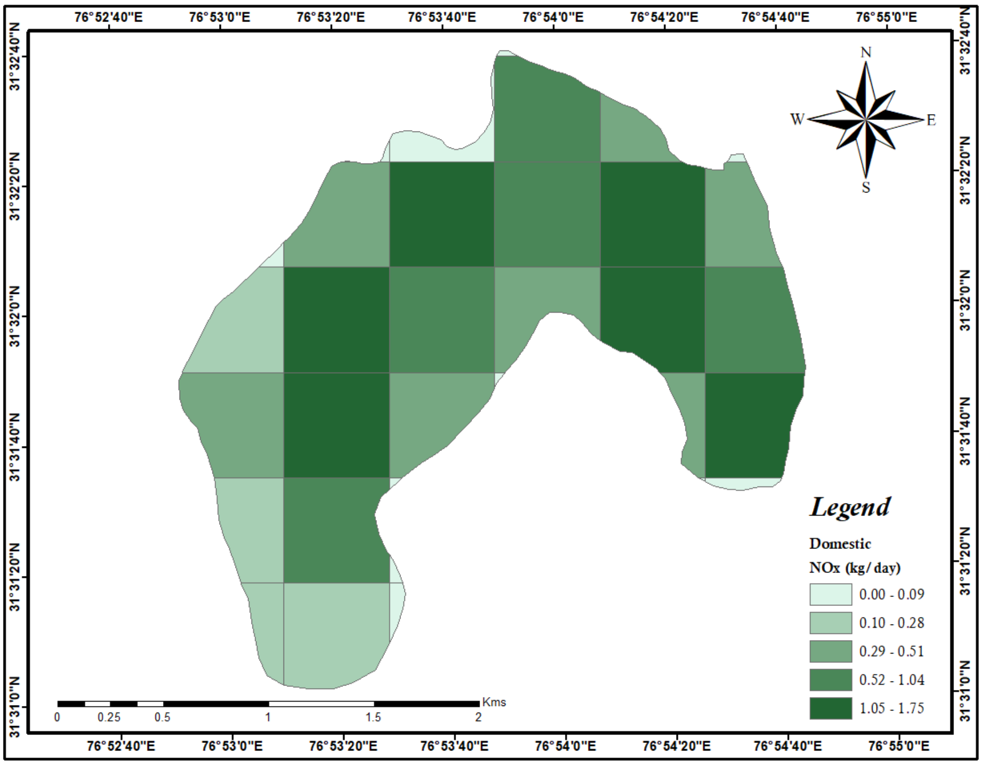


Figure 4.22: **Spatial Distribution of NOx Emissions from Domestic Sector**

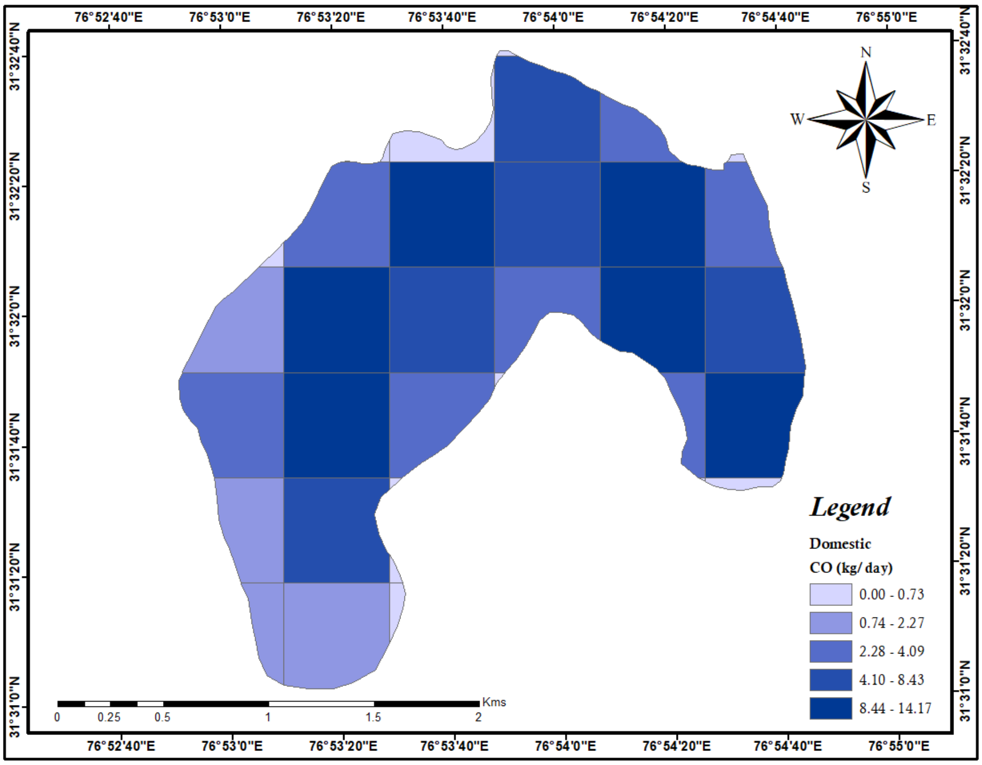


Figure 4.23: **Spatial Distribution of CO Emissions from Domestic Sector**

4.2.6 Construction and Demolition

A detailed survey was undertaken to assess construction and demolition activities. The 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 PWD, CPWD, and a detailed survey was done. Nearly at all the construction sites, the construction material and their debris (lying open, without cover) are being stored outside the construction premises, near the road (Figure 4.24). The areas under construction activities were calculated based on survey data and GIS. The location of construction and demolition sites at Sunder Nagar is given in Figure 4.25. The emission factors given by AP-42 (USEPA, 2000) were used for estimating the construction and demolition emissions.

Figure 4.24:**Construction material and debris near construction sites**

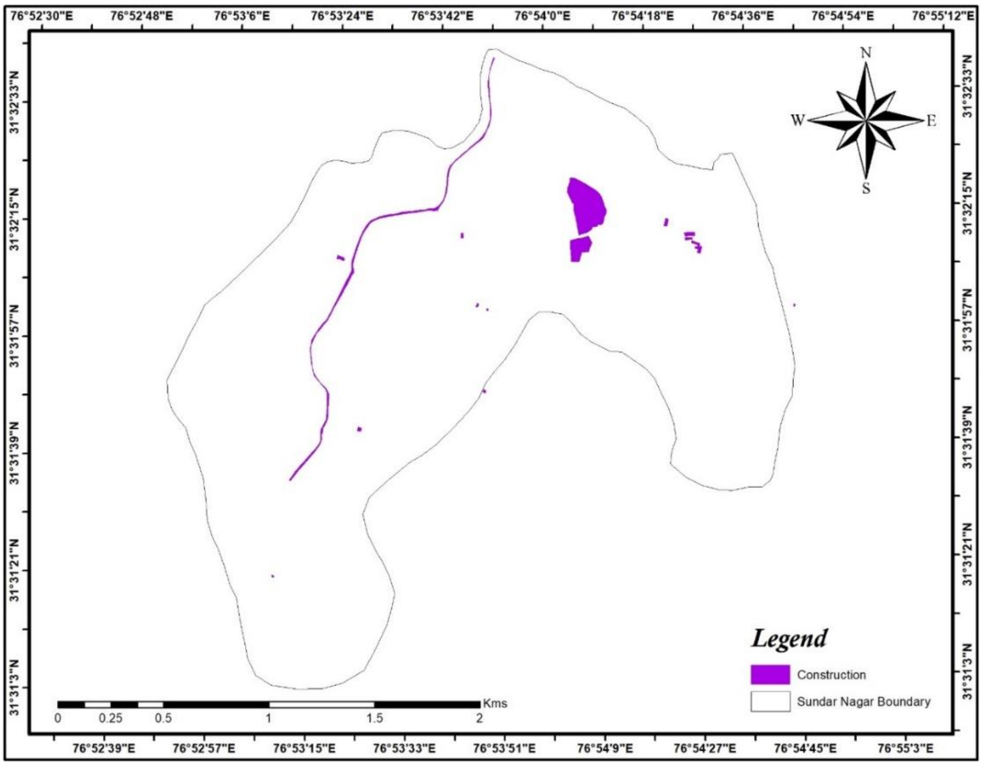
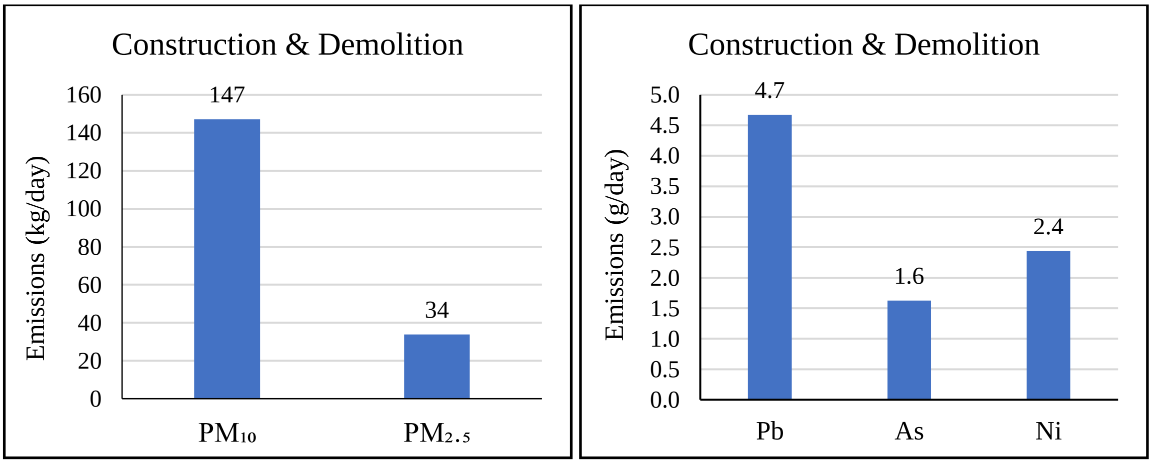


Figure 4.25: Location of Construction and Demolition sites at Sunder Nagar

Total emissions from construction and demolition activities are presented in Figure 4.26 (a) & (b). The spatially resolved map of construction and demolition activities is shown in Figure 4.27 and Figure 4.28. The Emission load of PM_{10} and $PM_{2.5}$ from construction and demolition is 147 kg/day and 34 kg/day.



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

Figure 4.26: Emission Load from Construction and Demolition activities

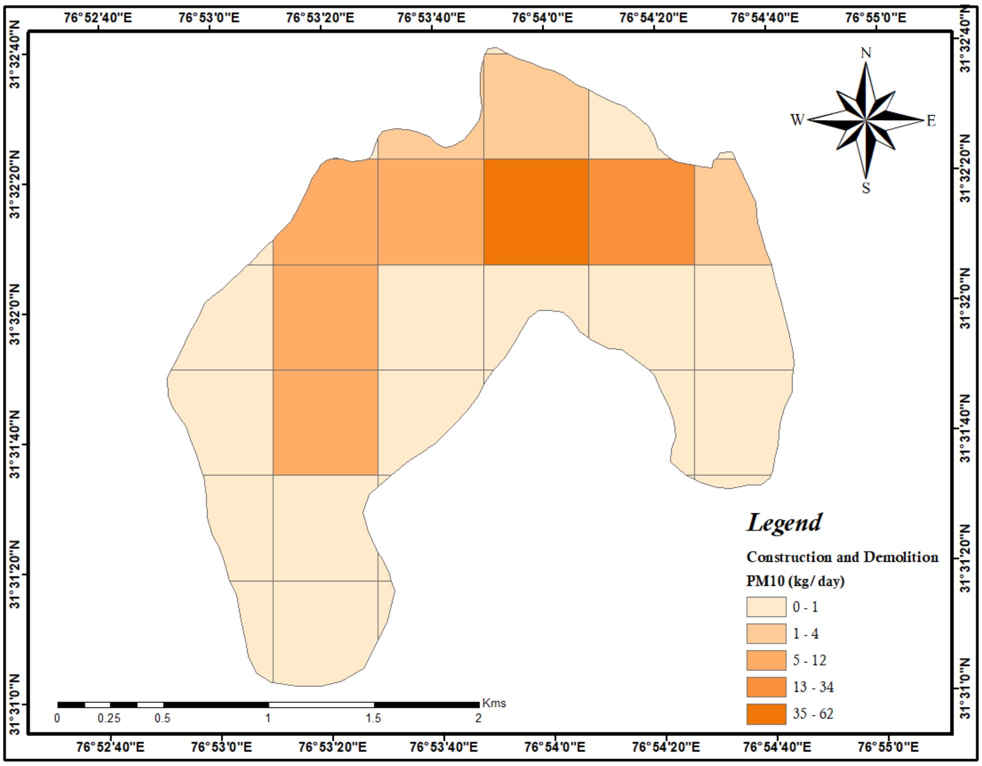


Figure 4.27: **Spatial Distribution of PM_{10} Emissions from Construction/Demolition**

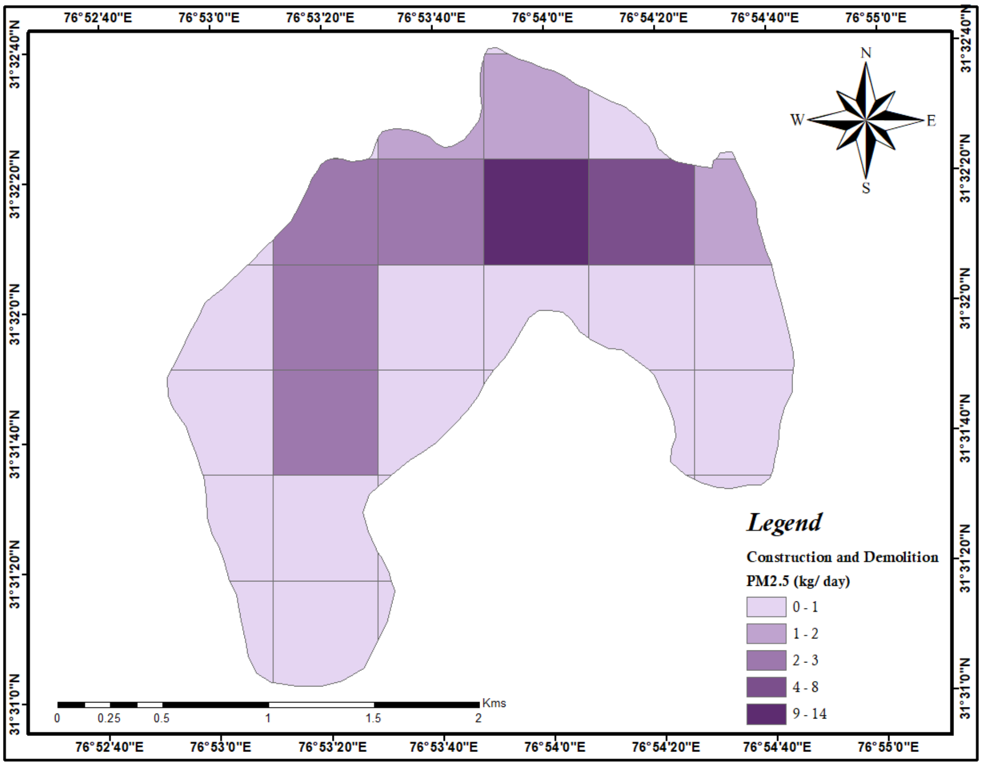


Figure 4.28: **Spatial Distribution of $PM_{2.5}$ Emissions from Construction/Demolition**

4.2.7 Industrial Diesel Generator Sets (DG sets)

The location of the Industrial DG set is shown in Figure 4.29. The industries use DG sets as a backup, approximately 3 Industrial DG sets are operational in industries (source: consent data) out of which only two comes under the city boundary. The capacities of Industrial DG sets are in the range 85 KVA to 100 KVA with the average capacity of 90 KVA. During the industrial survey, it was found out that DG sets operate for two hours per day. Most of the industries use diesel as fuel to 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 all the Industrial DG sets (consent data) are shown in Figure 4.30 (a) & (b), the spatial distribution of emissions from Industrial DG Sets (under city boundary) is shown in Figure 4.31 to Figure 4.35.

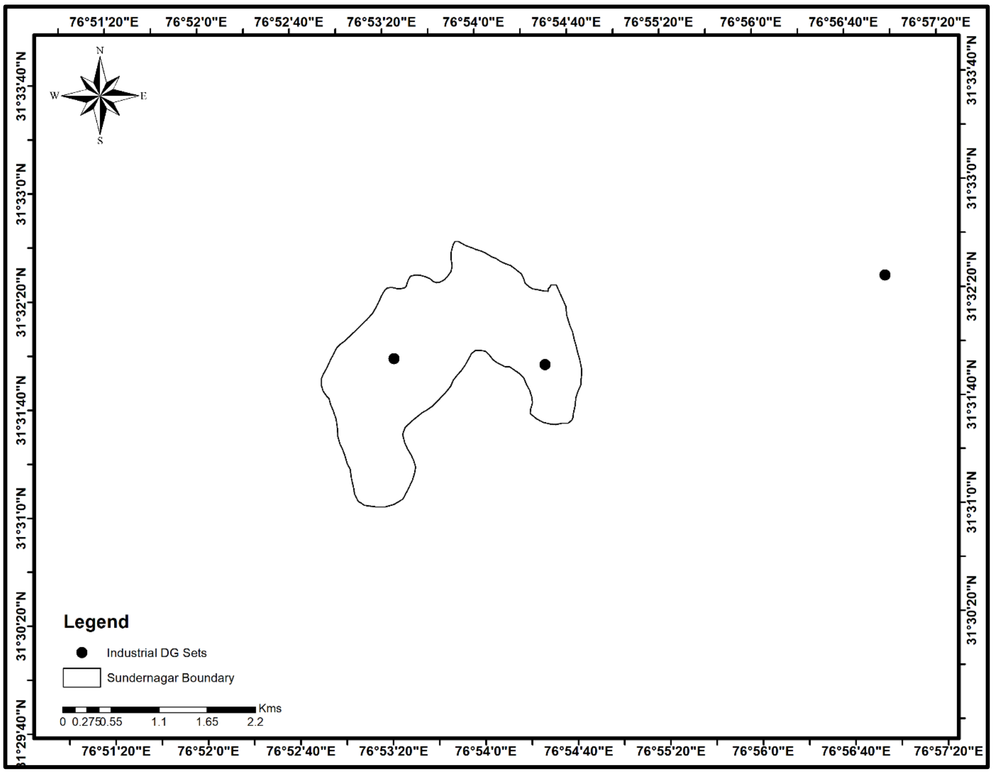
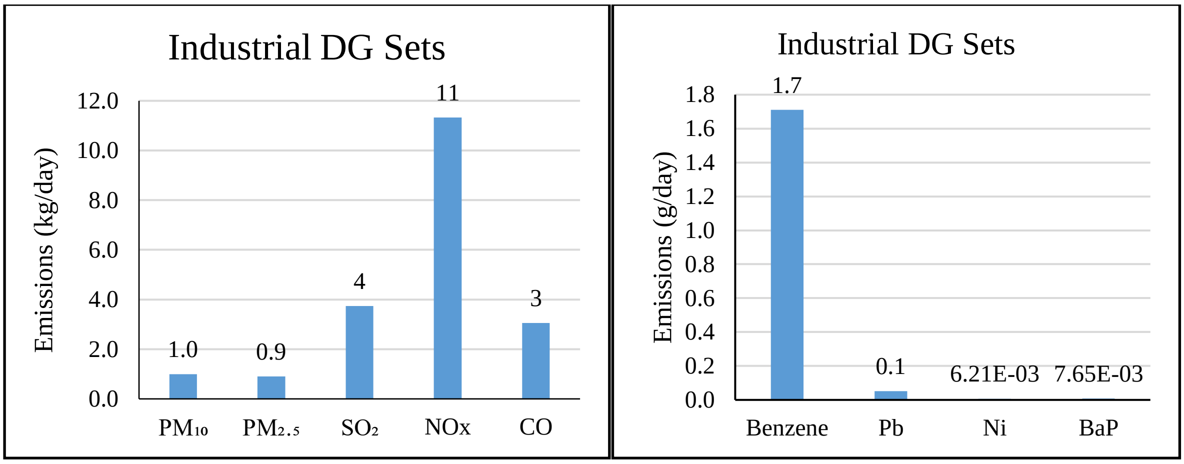


Figure 4.29: **Location of Industrial DG Sets**



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

Figure 4.30: **Emission Load from Industrial DG sets**

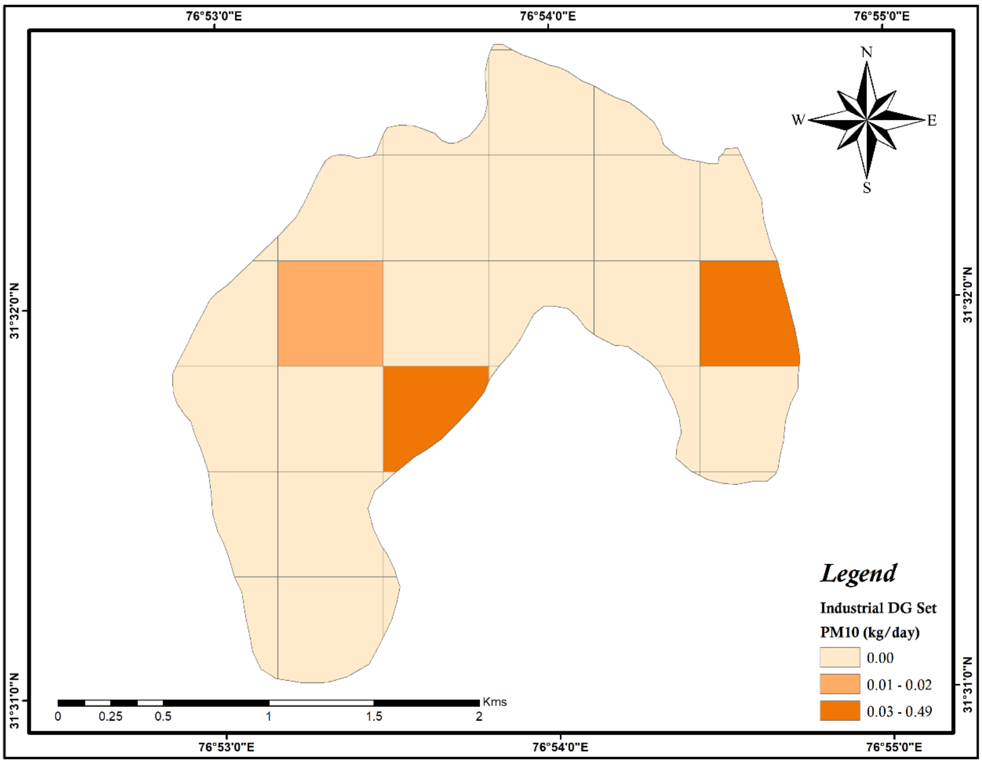


Figure 4.31: **Spatial Distribution of PM_{10} Emissions from Industrial DG Sets**

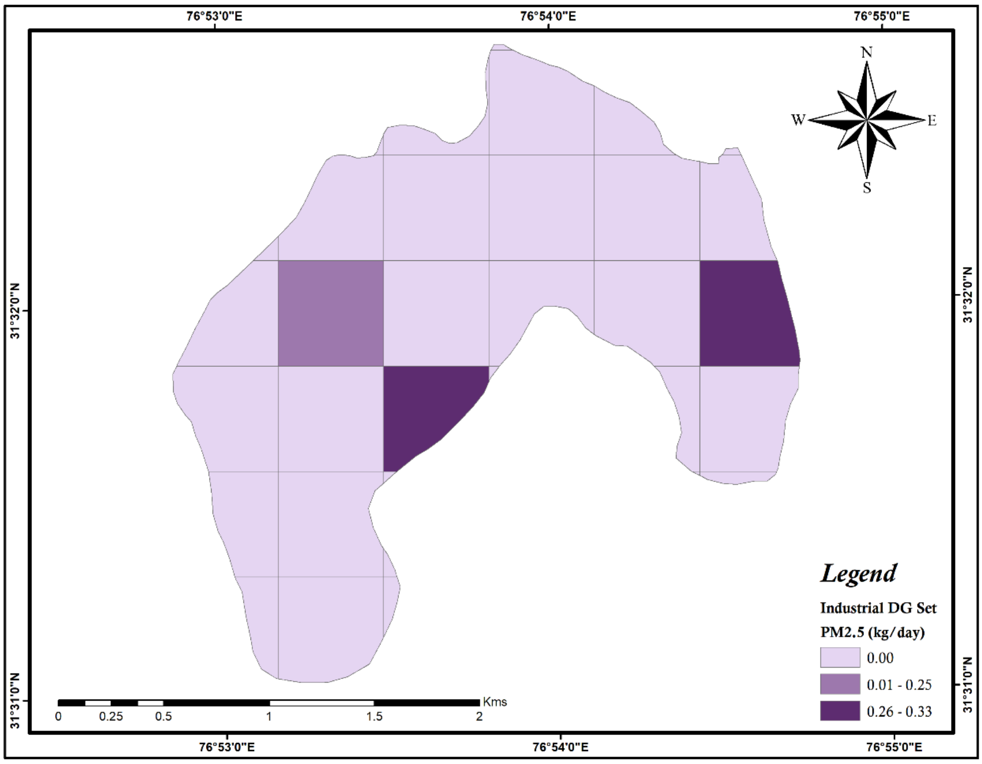


Figure 4.32: **Spatial Distribution of $PM_{2.5}$ Emissions from Industrial DG Sets**

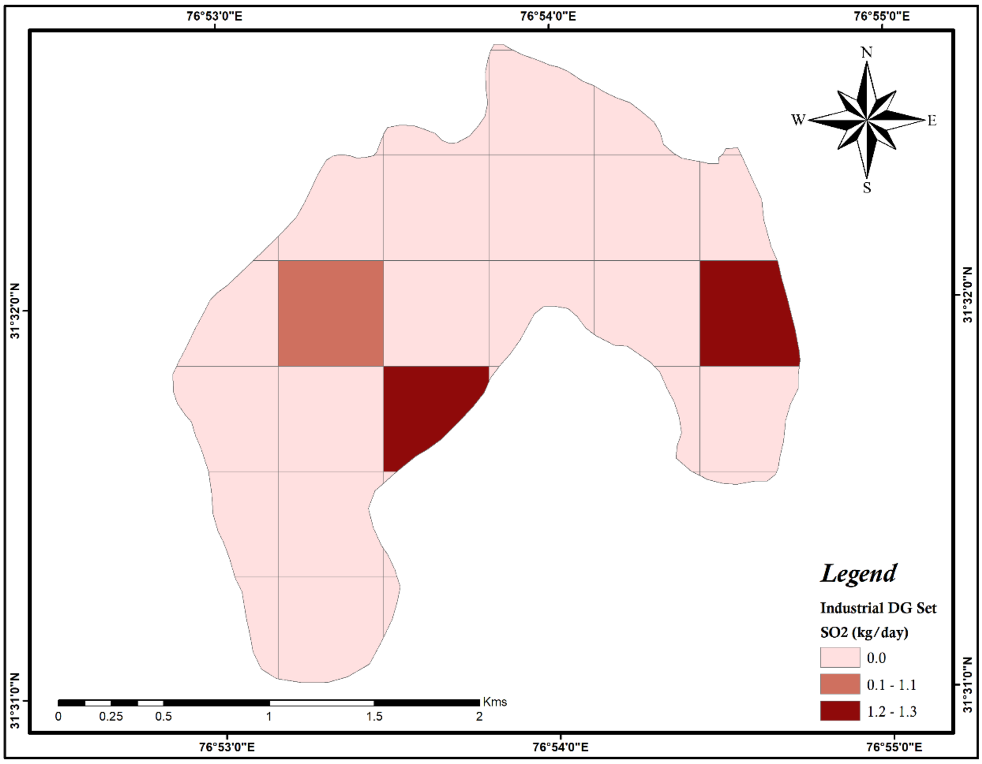


Figure 4.33: **Spatial Distribution of SO_2 Emissions from Industrial DG Sets**

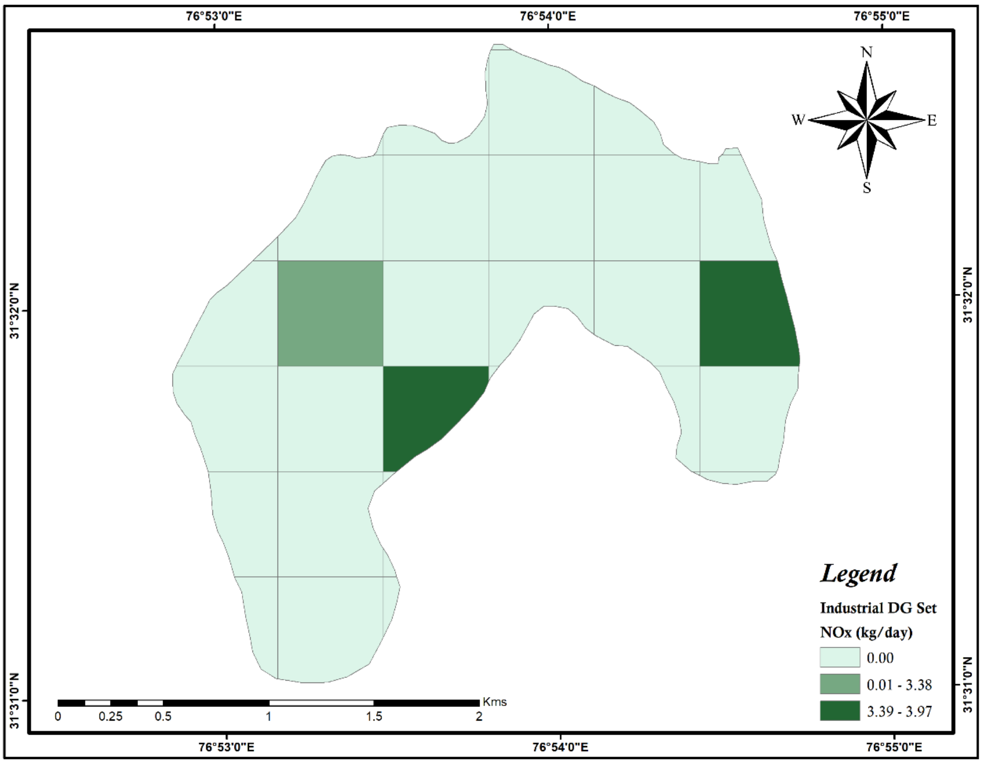


Figure 4.34: **Spatial Distribution of NOx Emissions from Industrial DG Sets**

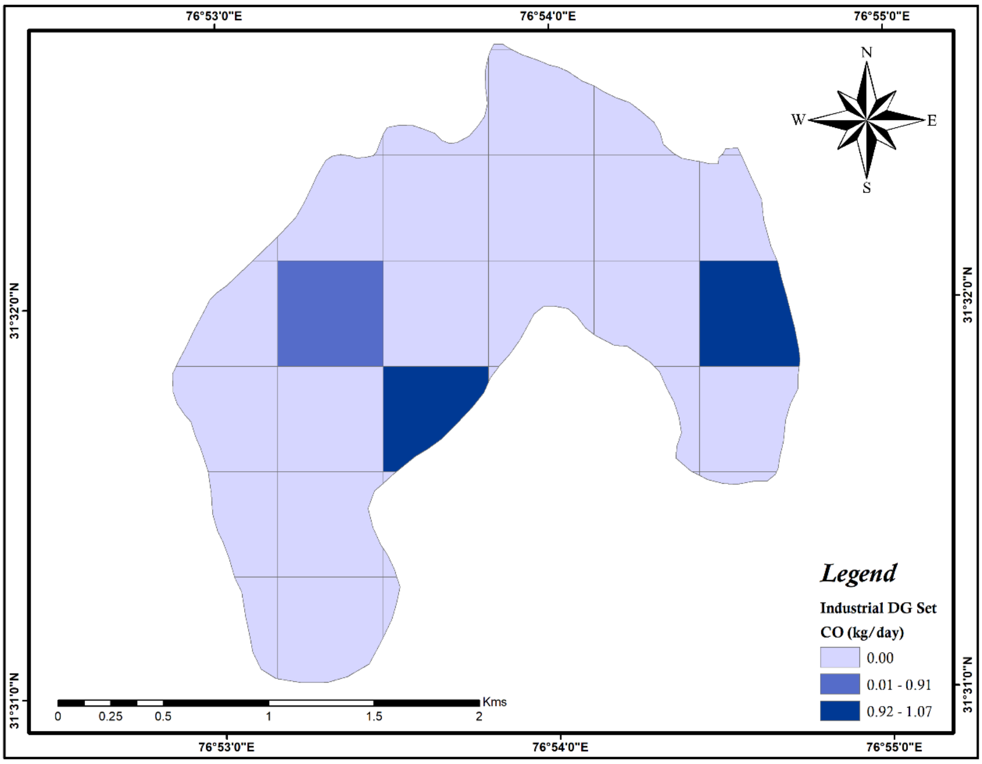


Figure 4.35: Spatial Distribution of CO Emissions from Industrial DG Sets

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 15 persons and other eating joints.

During the field survey (Figure 4.36), it was observed that hotels, restaurants, etc use coal as fuel in tandoors. The total number of Hotels, Restaurants, Guest Houses (GHs), and Banquet Halls (BHs) is found to be approximately 41 (Figure 4.37). 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 at 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 were 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 4.38 (a) & (b). The spatial distribution of emissions from Hotels, Restaurants, GHs & BHs is shown in Figure 4.39 to Figure 4.43.

Figure 4.36: Field Survey of Hotels and Restaurants

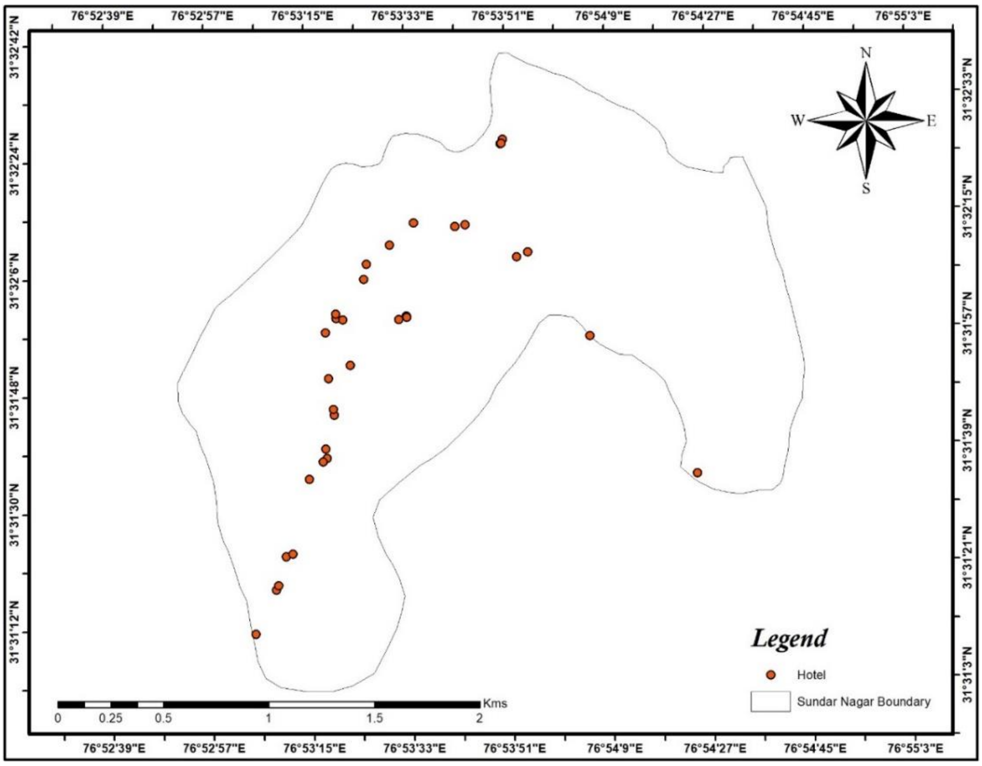
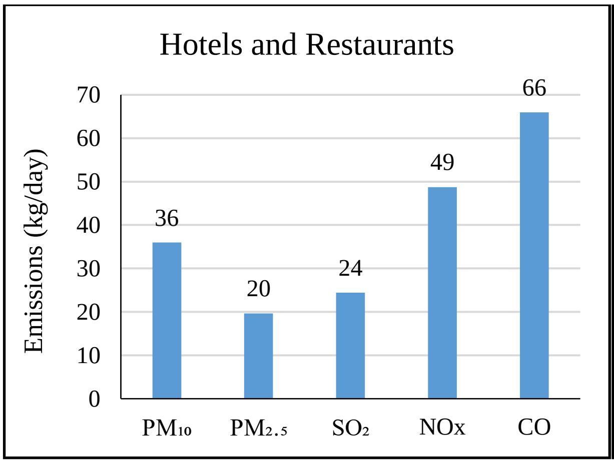
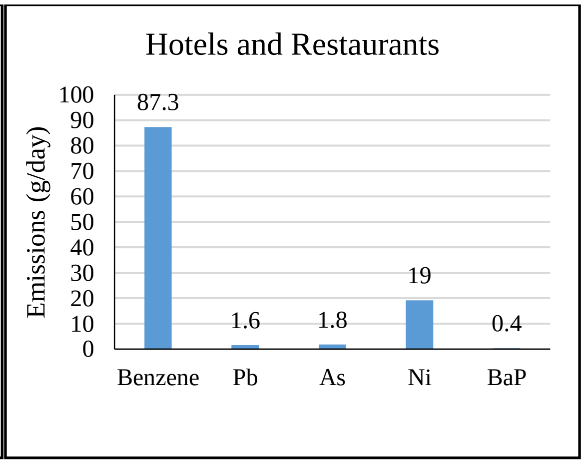


Figure 4.37: **Location of Hotels, Restaurants, GHs and BHs**



a) PM and Gaseous Emission in kg/day



b) Other Pollutants Emission in g/day

Figure 4.38: Emission Load from Hotels, Restaurants, GHs and BHs

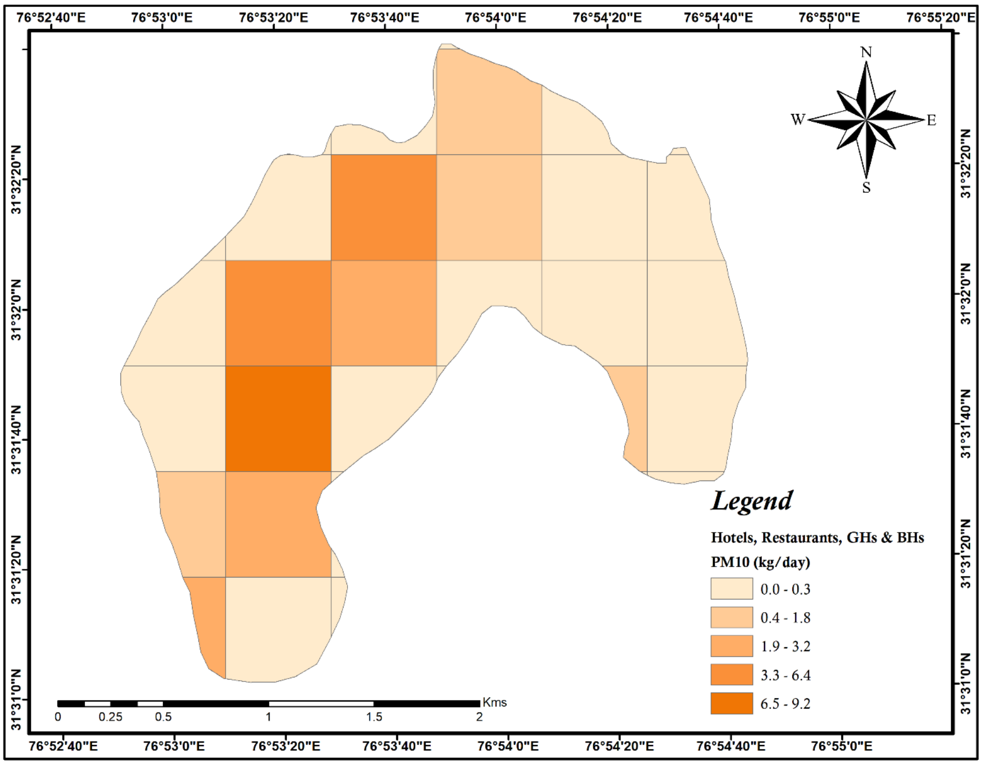


Figure 4.39: **Spatial Distribution of PM_{10} Emissions from Hotels, Restaurants, GHs and BHs**

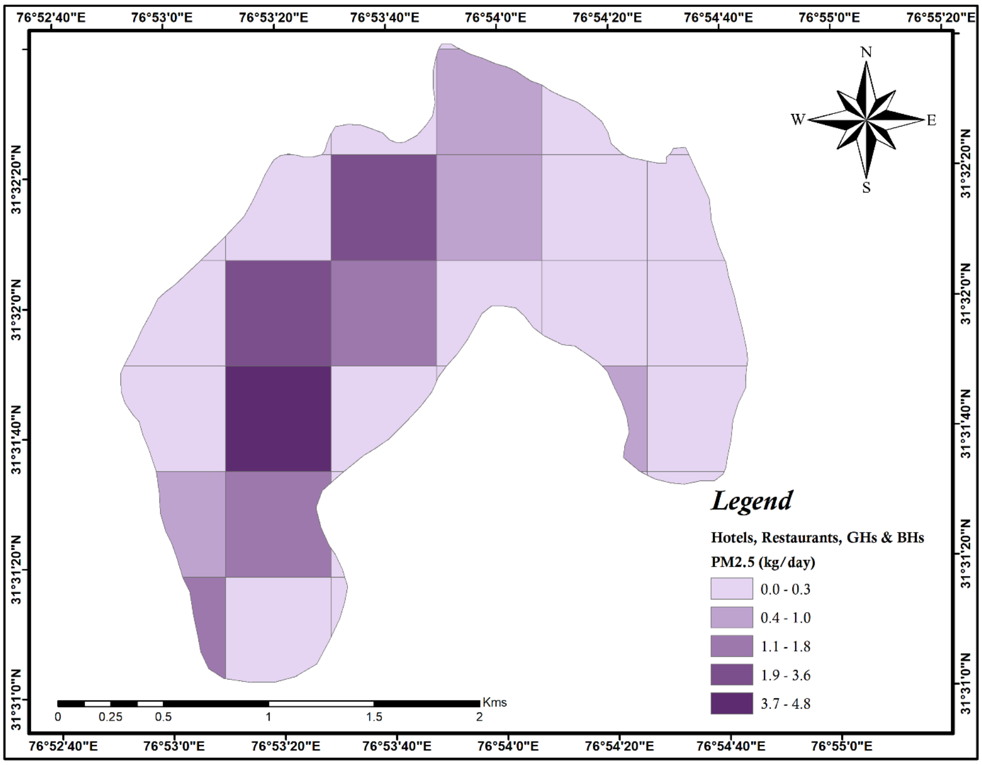


Figure 4.40: **Spatial Distribution of $PM_{2.5}$ Emissions from Hotels, Restaurants, GHs and BHs**

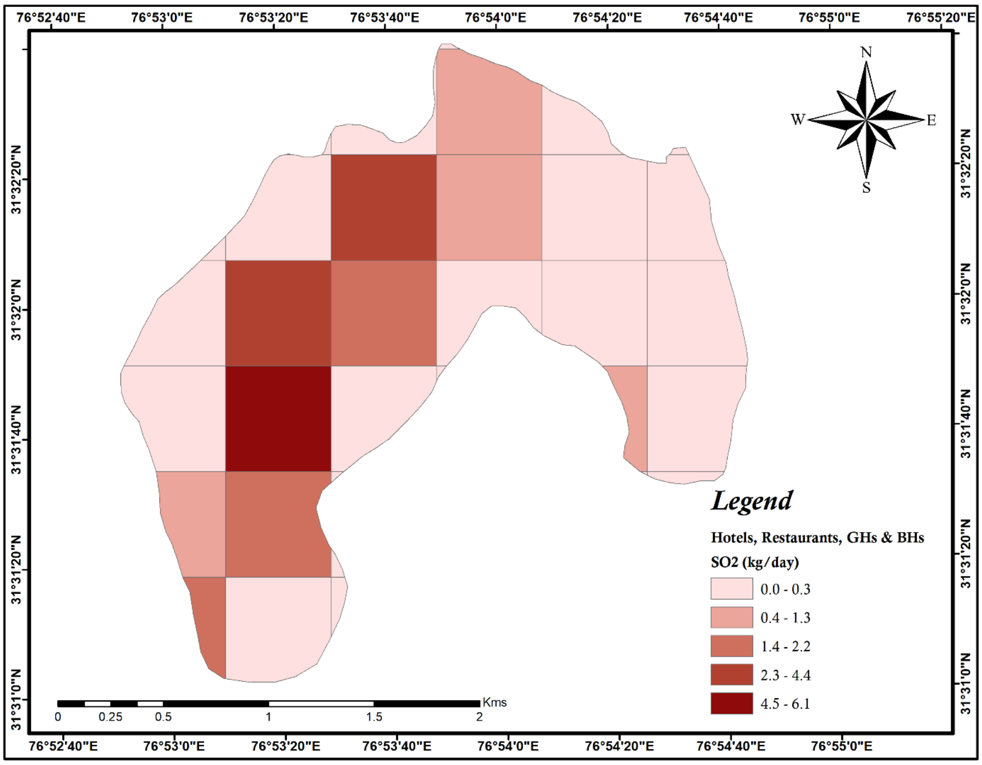


Figure 4.41: **Spatial Distribution of SO_2 Emissions from Hotels, Restaurants, GHs and BHs**

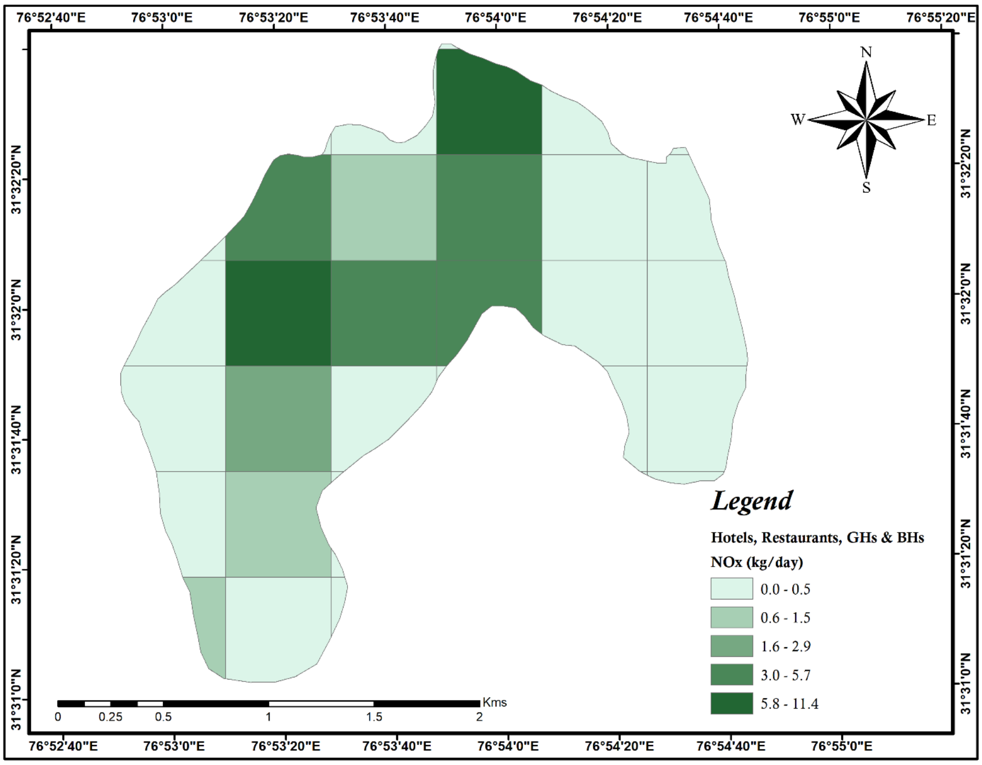


Figure 4.42: **Spatial Distribution of NO_X Emissions from Hotels, Restaurants, GHs and BHs**

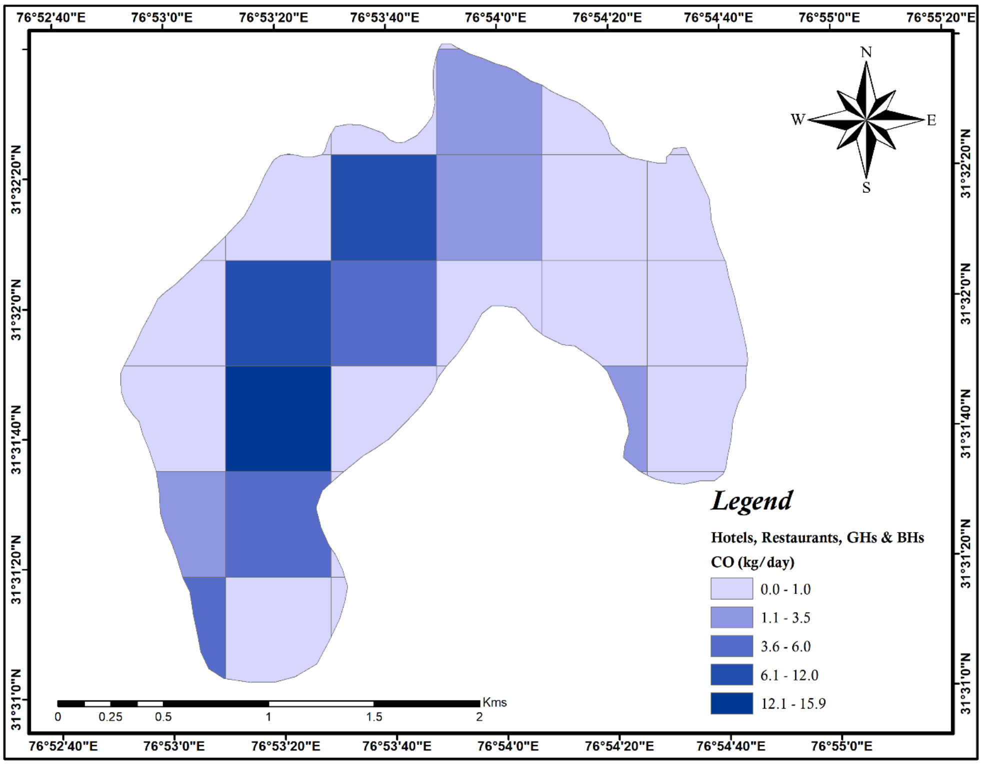


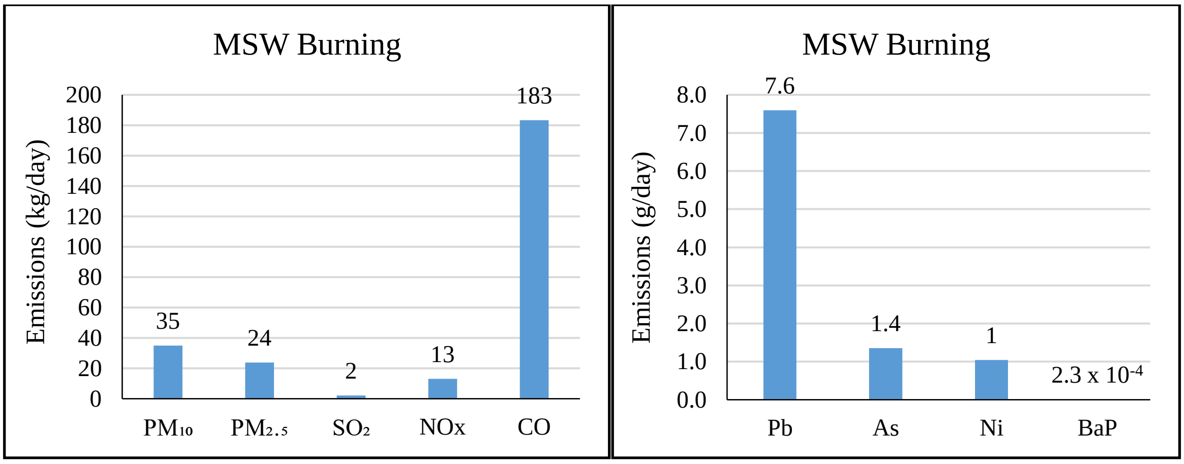
Figure 4.43: **Spatial Distribution of CO Emissions from Hotels, Restaurants, GHs and BHs**

4.2.9 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 10.91 MT/day and the waste collected is approx. 6.54 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 Sunder Nagar (Sharma et al., 2018). Several events of MSW burning have been observed during the city survey conducted for weekdays and weekends. The MSW burning at different location of Sunder Nagar is shown in Figure 4.44.

Figure 4.44: MSW Burning in several parts of Sunder Nagar

The emission factors are given by CPCB (2011) and AP-42 (USEPA, 2000) were used for estimating the emission from MSW burning using the same procedure of emission density in a ward or village. The emissions from MSW burning are presented in Figure 4.45 (a) & (b) and spatial distribution in Figure 4.46 to Figure 4.50.



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

Figure 4.45: Emission Load from MSW Burning

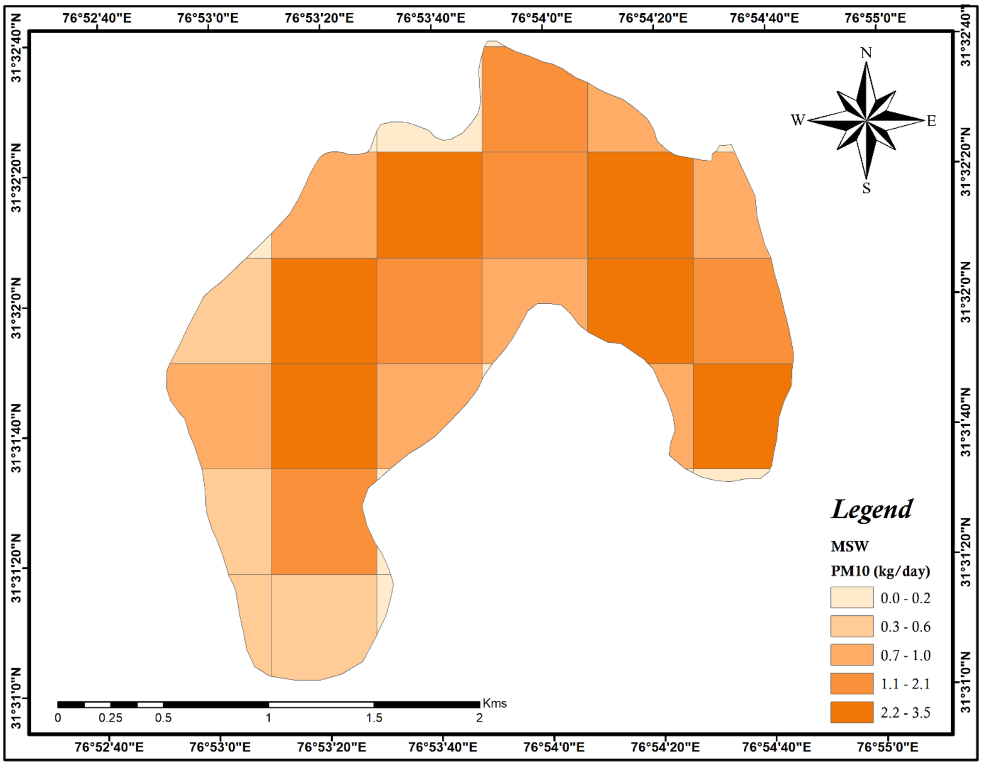


Figure 4.46: **Spatial Distribution of PM_{10} Emissions from MSW Burning**

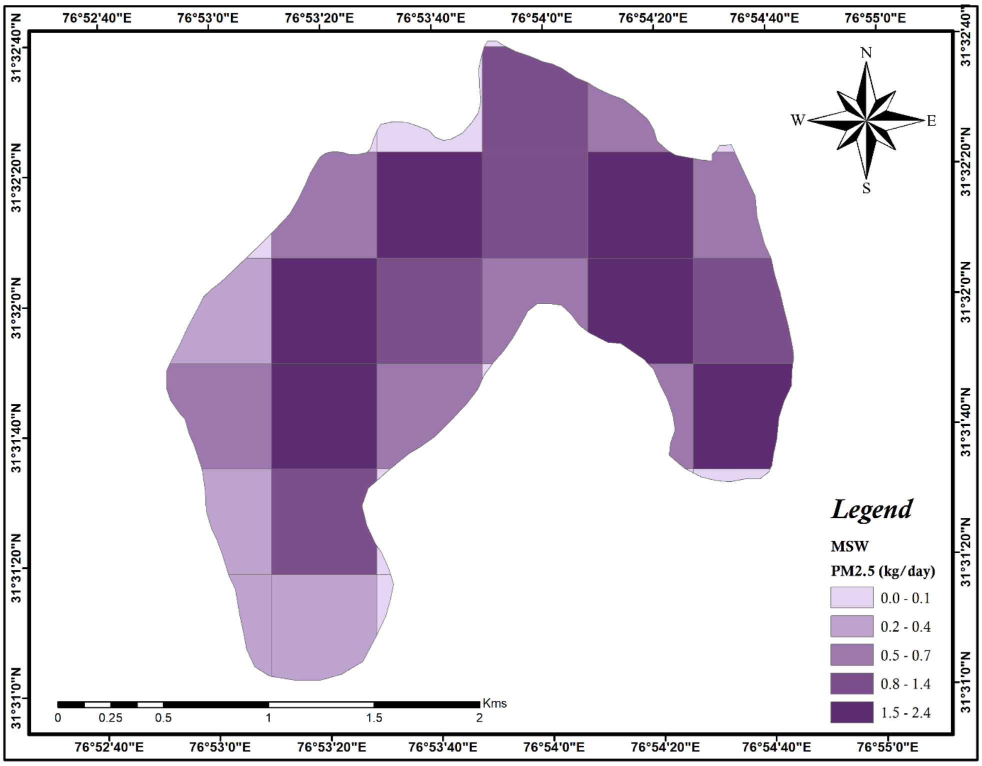


Figure 4.47: **Spatial Distribution of $PM_{2.5}$ Emissions from MSW Burning**

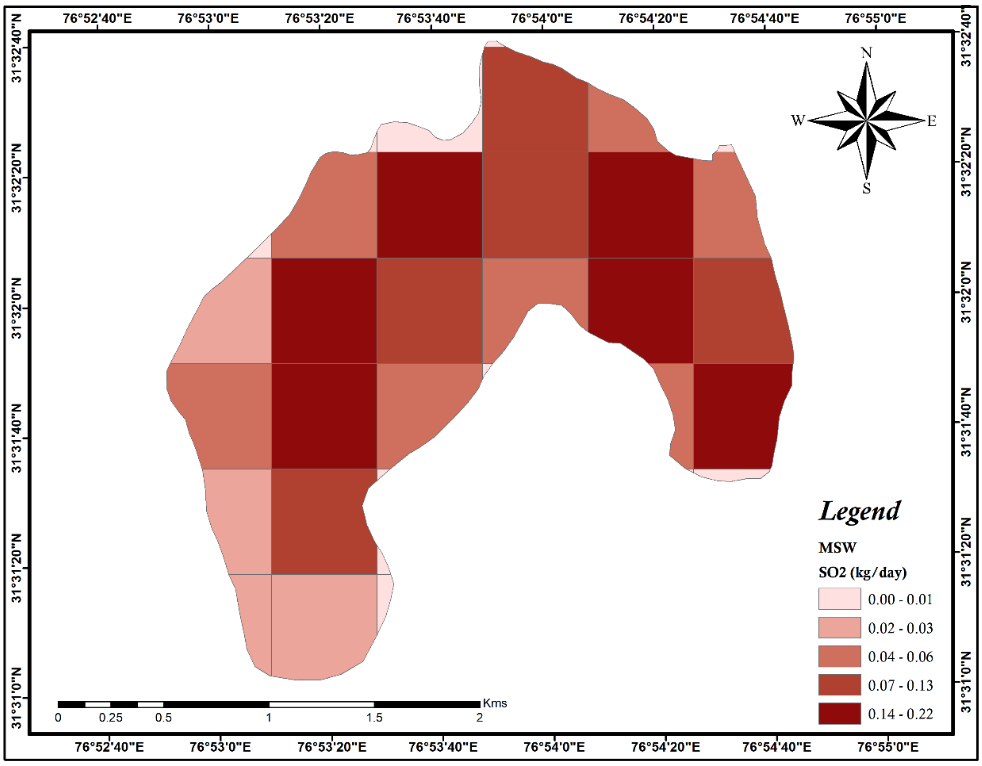


Figure 4.48: **Spatial Distribution of SO_2 Emissions from MSW Burning**

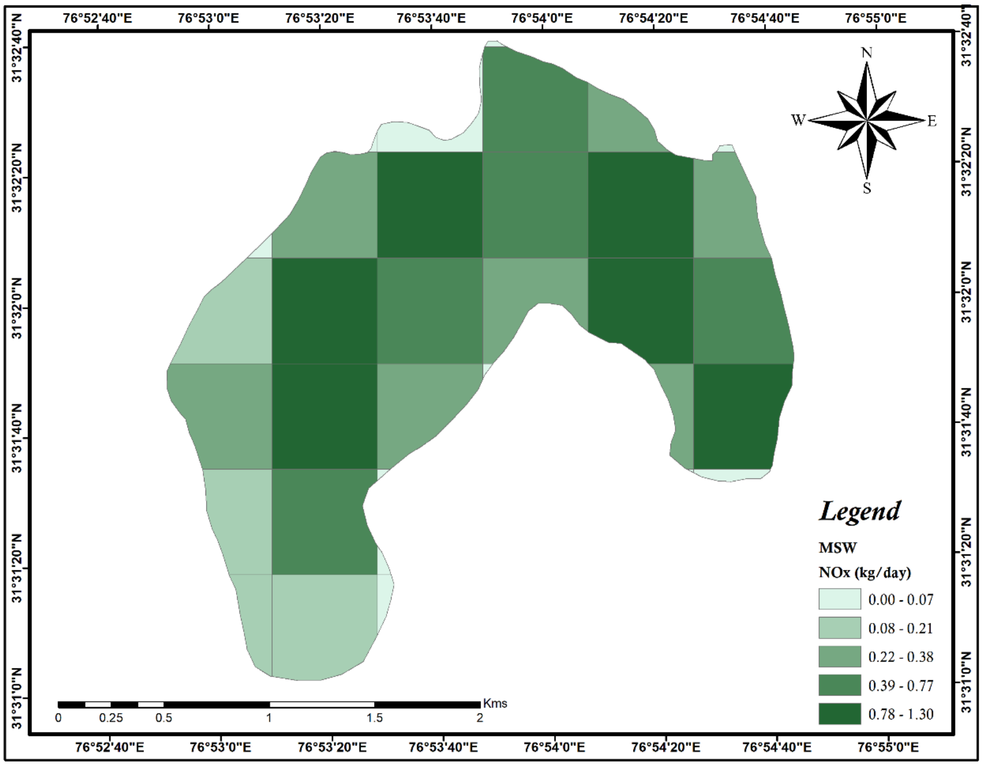


Figure 4.49: **Spatial Distribution of NO_x Emissions from MSW Burning**

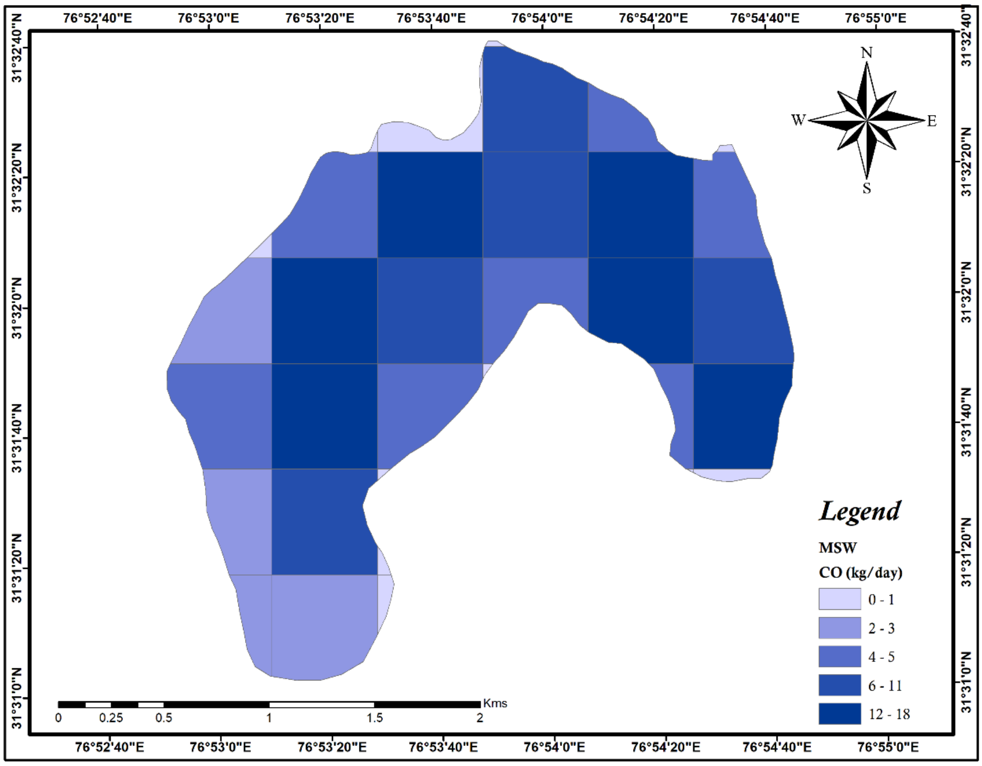


Figure 4.50: **Spatial Distribution of CO Emissions from MSW Burning**

4.2.10 Hospitals

A detailed survey was undertaken to estimate the emission from hospitals in Sunder Nagar. There are approximately 17 hospitals present in the city. The locations of Hospitals in Sunder Nagar are given in Figure 4.51. The emission load from hospitals is given in Figure 4.52 (a) & (b). The overall emissions from hospitals along with their average DG set capacity and running hours are presented in Table 4.1.

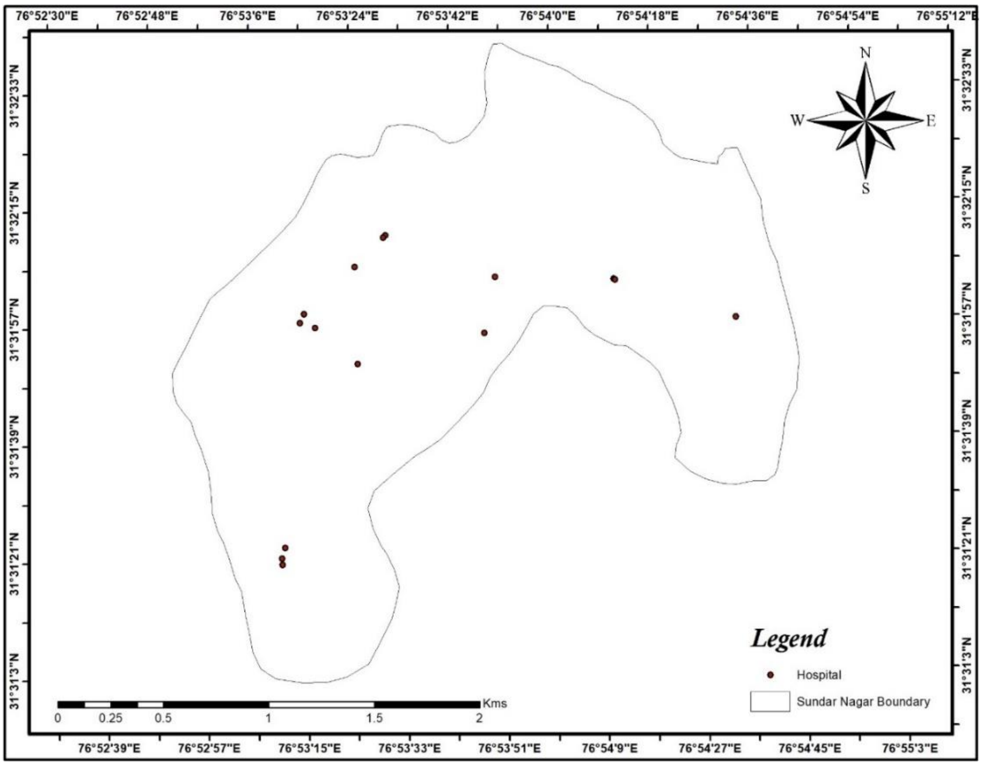
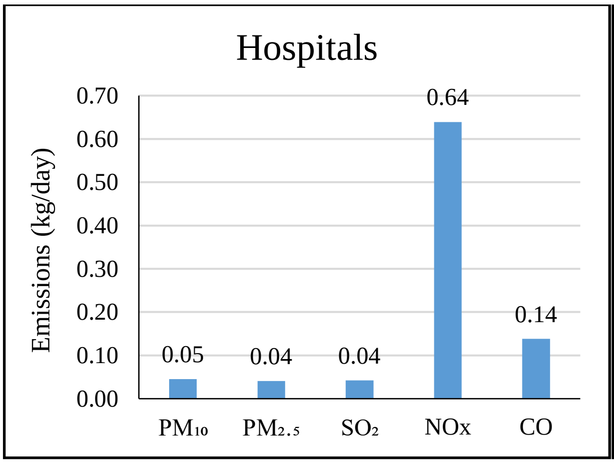


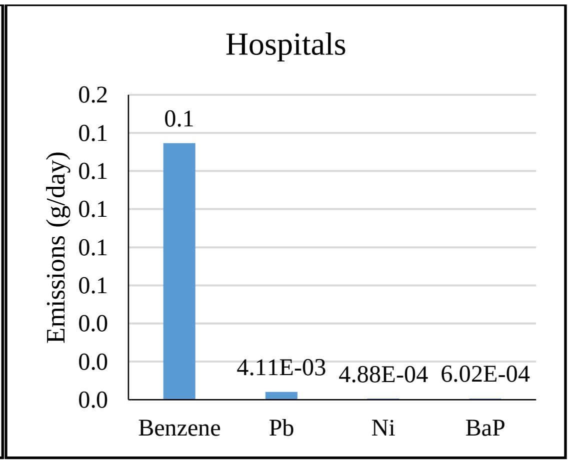
Figure 4.51: Locations of Hospitals in Sunder Nagar

Table 4.1: Hospitals Details in Sunder Nagar (emissions in kg/day and g/day)

No. of Hospitals	DG set Average Capacity		PM_{10}	$PM_{2.5}$	SO_2	NOx	CO	Benzene	Pb	As	Ni	BaP
	KVA	Running Hour	(kg/d)	(kg/d)	(kg/d)	(kg/d)	(kg/d)	(g/d)	(g/d)	(g/d)	(g/d)	(g/d)
17	62.5	2	0.05	0.04	0.04	0.64	0.14	0.1	0.004	0	0.0005	0.0006
Data Source: Consent Data												



a) PM and Gaseous Emission in kg/day



b) Other Pollutants Emission in g/day

Figure 4.52: Emission Load from Hospitals

4.2.11 Industries

There are approximately 3 industrial units in Sunder Nagar having boilers (Boilers, Hot mix Plants. There are 4 stone crusher units that are present in Sunder Nagar contributing to particulate matter emissions. The overall emissions estimated from the different types of boilers, hot mix plants, etc. are presented in Table 4.2. Major fuels that contribute to emissions are Wood and LDO. The other sources contributing to particulate matter are from stone crushers. The industrial locations are given in Figure 4.53. The information on stacks, fuel, and its consumption was obtained from HPPCB. The AP-42 (USEPA, 2000) emission factors were used to calculate the emission. The emission of pollutants from all the industries (consent data) is shown in Figure 4.54 (a) & (b). The Spatial distribution of emissions from the industries (only 3 industries are under city boundary) is given in Figure 4.55 to Figure 4.59.

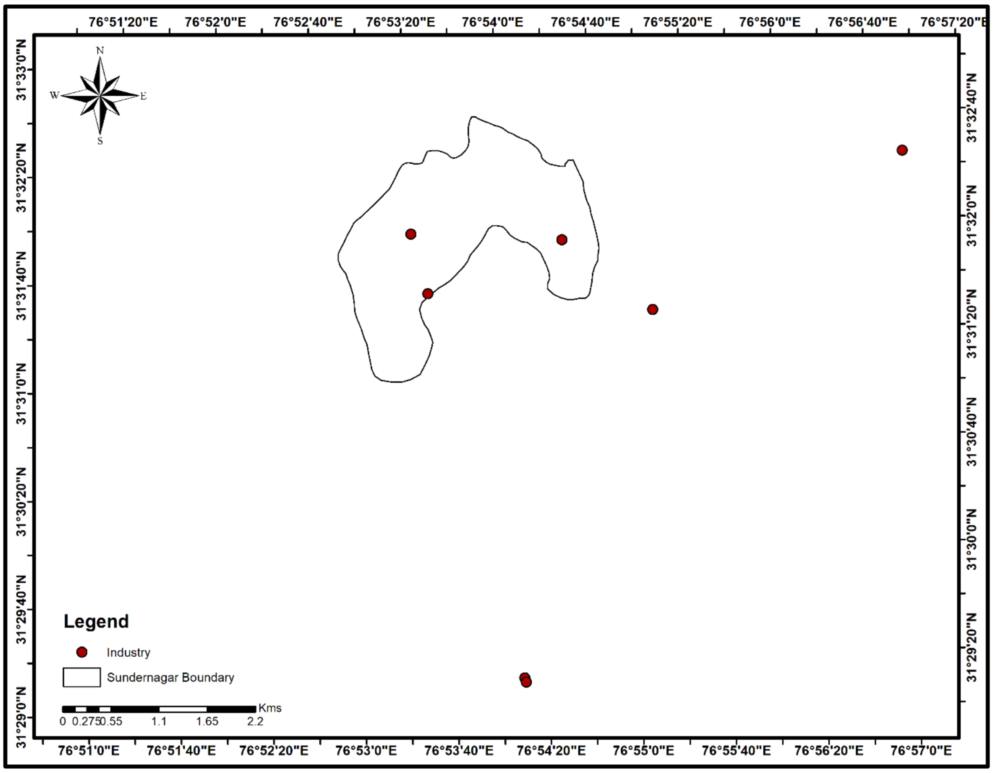
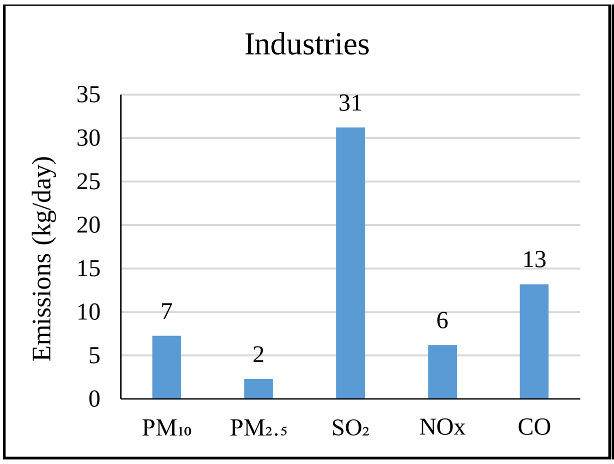
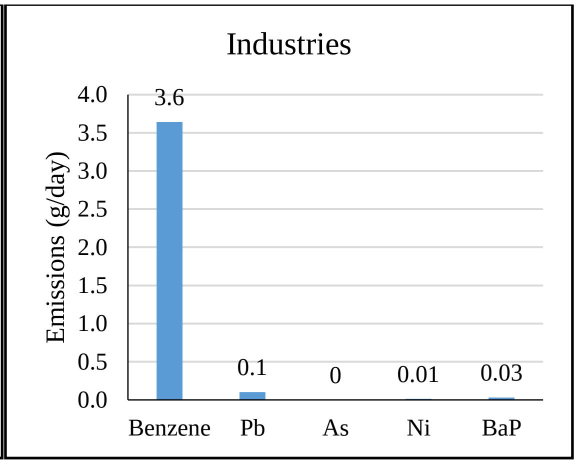


Figure 4.53: **Location of Industries in Sunder Nagar**





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

Figure 4.54: **Emission Load from Industries**

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

Type	Fuel	No. of Furnaces/ Boilers	PM_{10} (kg/d)	$PM_{2.5}$ (kg/d)	SO_2 (kg/d)	NO_X (kg/d)	CO (kg/d)	Benzene (g/d)	Pb (g/d)	As (g/d)	Ni (g/d)	BaP (g/d)
Boiler	Wood	1	0.87	0.78	0.02	0.13	13	0	4.67×10^{-3}	0	1.56×10^{-3}	1.87×10^{-4}
Hot Mix Plant	LDO	2	1.09	0.98	31	6.1	0.55	3.64	9.9×10^{-2}	0	1.18×10^{-2}	2.9×10^{-2}
Total		**3**	**2**	**1.8**	**31**	**6.2**	**13.6**	**3.64**	**0.1**	**0**	**0.01**	**0.03**
Source: Consent Data												

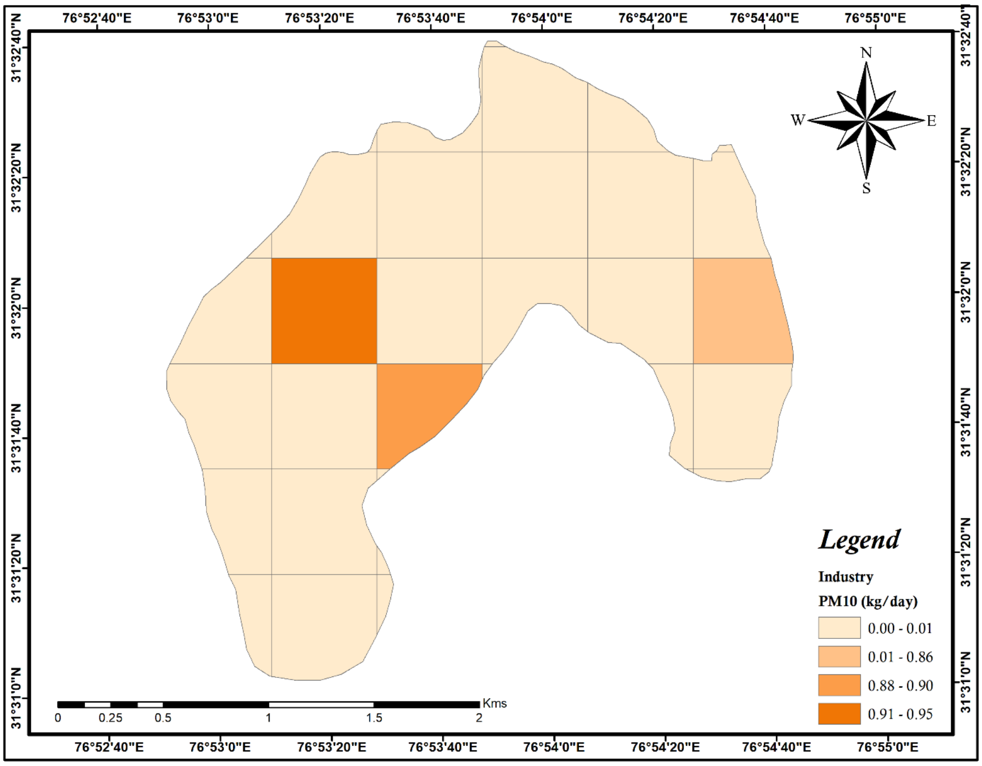


Figure 4.55: **Spatial Distribution of PM_{10} Emissions from Industries**

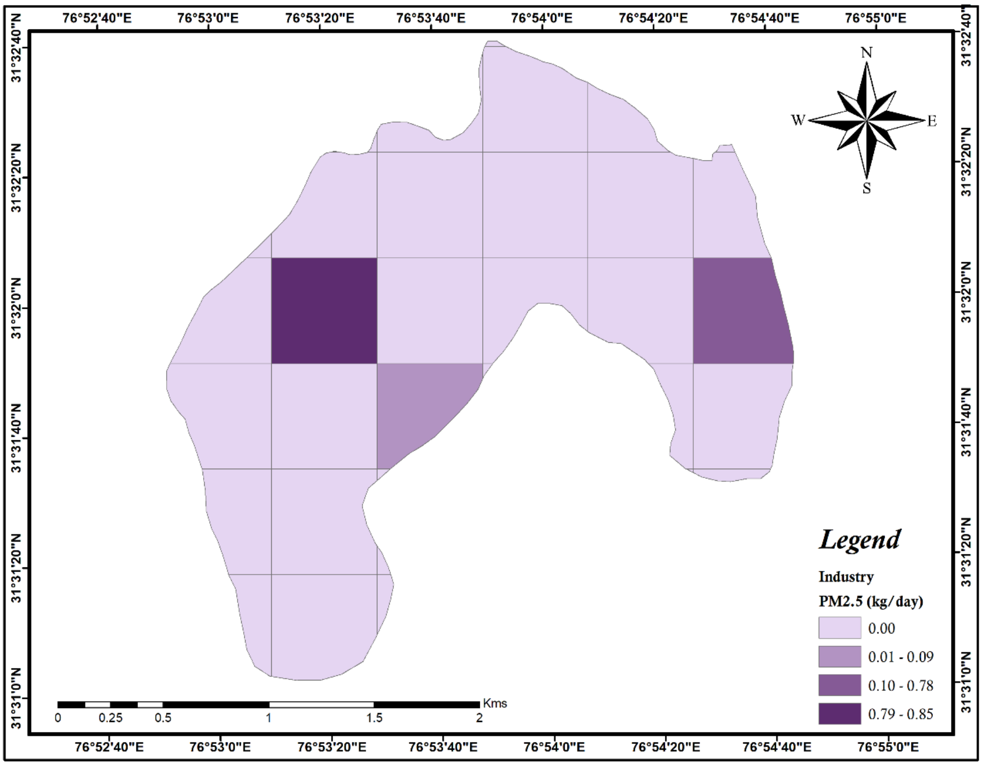


Figure 4.56: **Spatial Distribution of $PM_{2.5}$ Emissions from Industries**

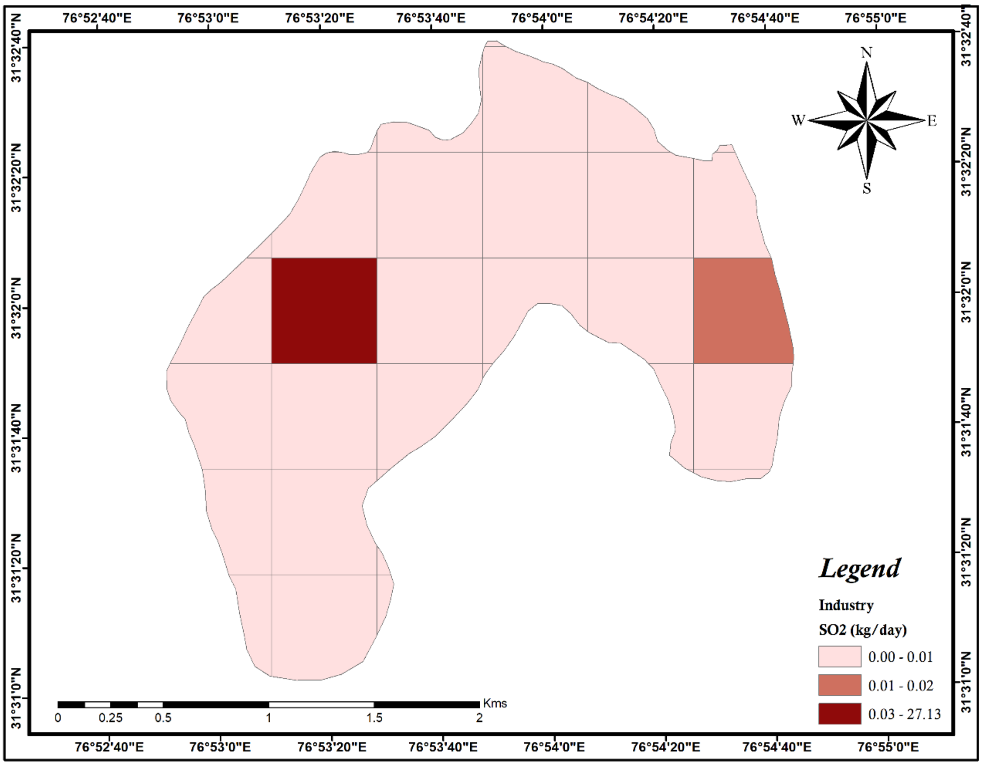


Figure 4.57: **Spatial Distribution of SO_2 Emissions from Industries**

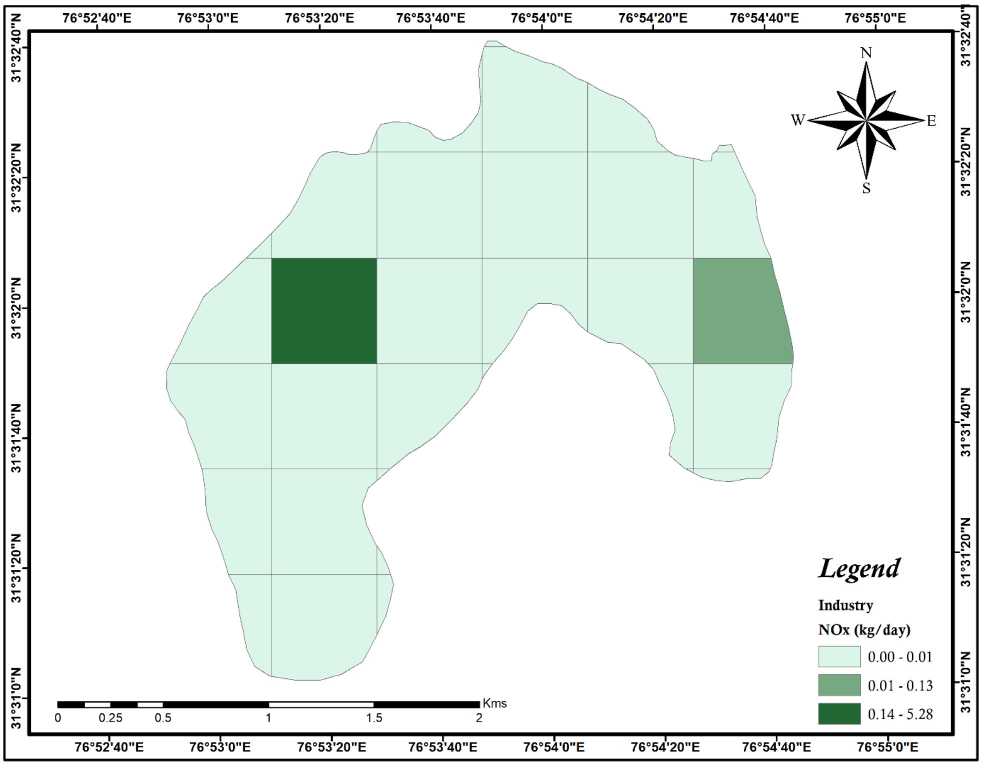


Figure 4.58: **Spatial Distribution of NO_x Emissions from Industries**

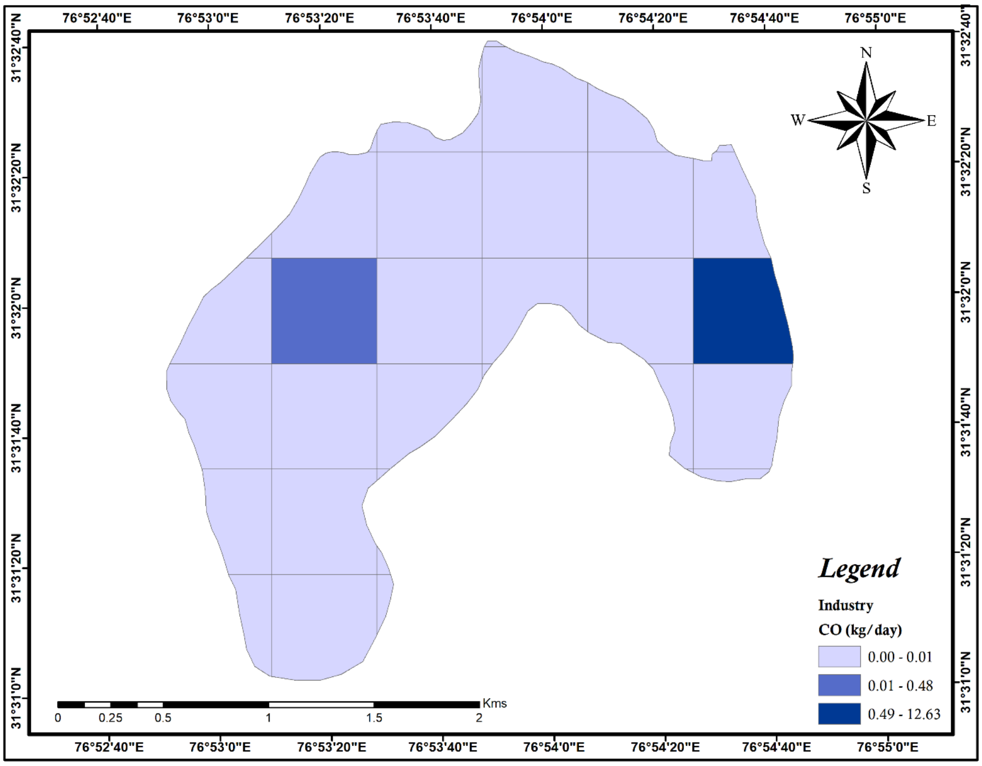


Figure 4.59: **Spatial Distribution of CO Emissions from Industries**

4.2.12 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 3 locations (Naresh Chawk Bus Stand, Sunder Nagar Bus Stand, Bhojpur Road (NH20)) in the city of Sunder Nagar. ARAI (2011) and CPCB (2011) emission factors were used to calculate the emissions. Figure 4.60 and Figure 4.61 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 uses, and age of the vehicles.

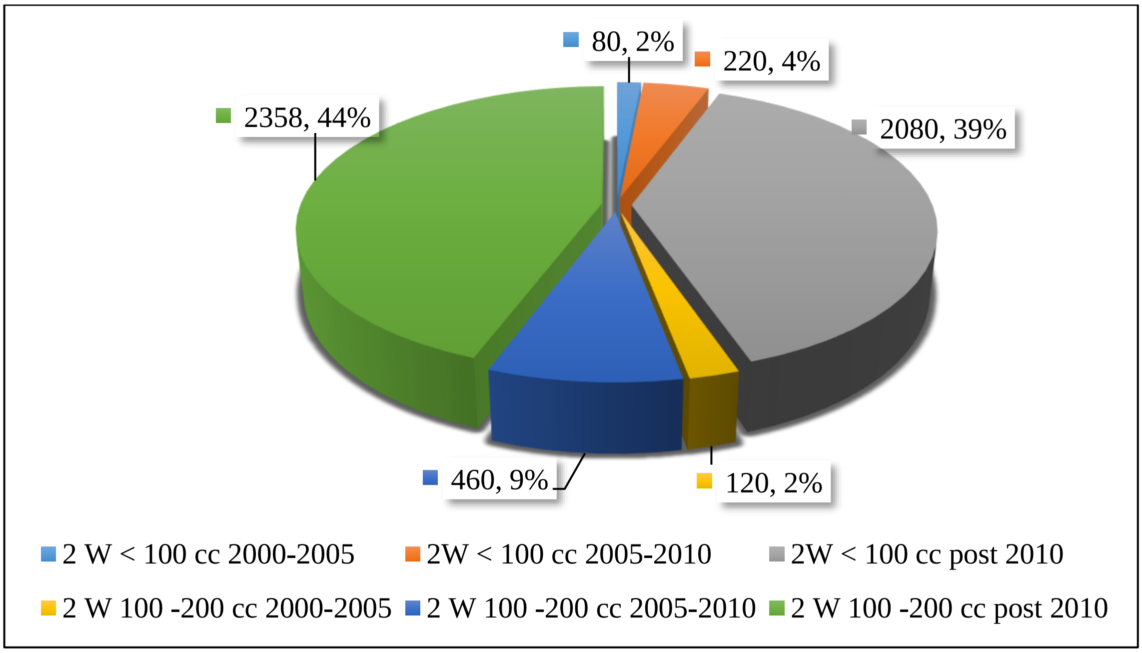


Figure 4.60: **Distribution of 2-Ws in the study area (parking lot survey)**

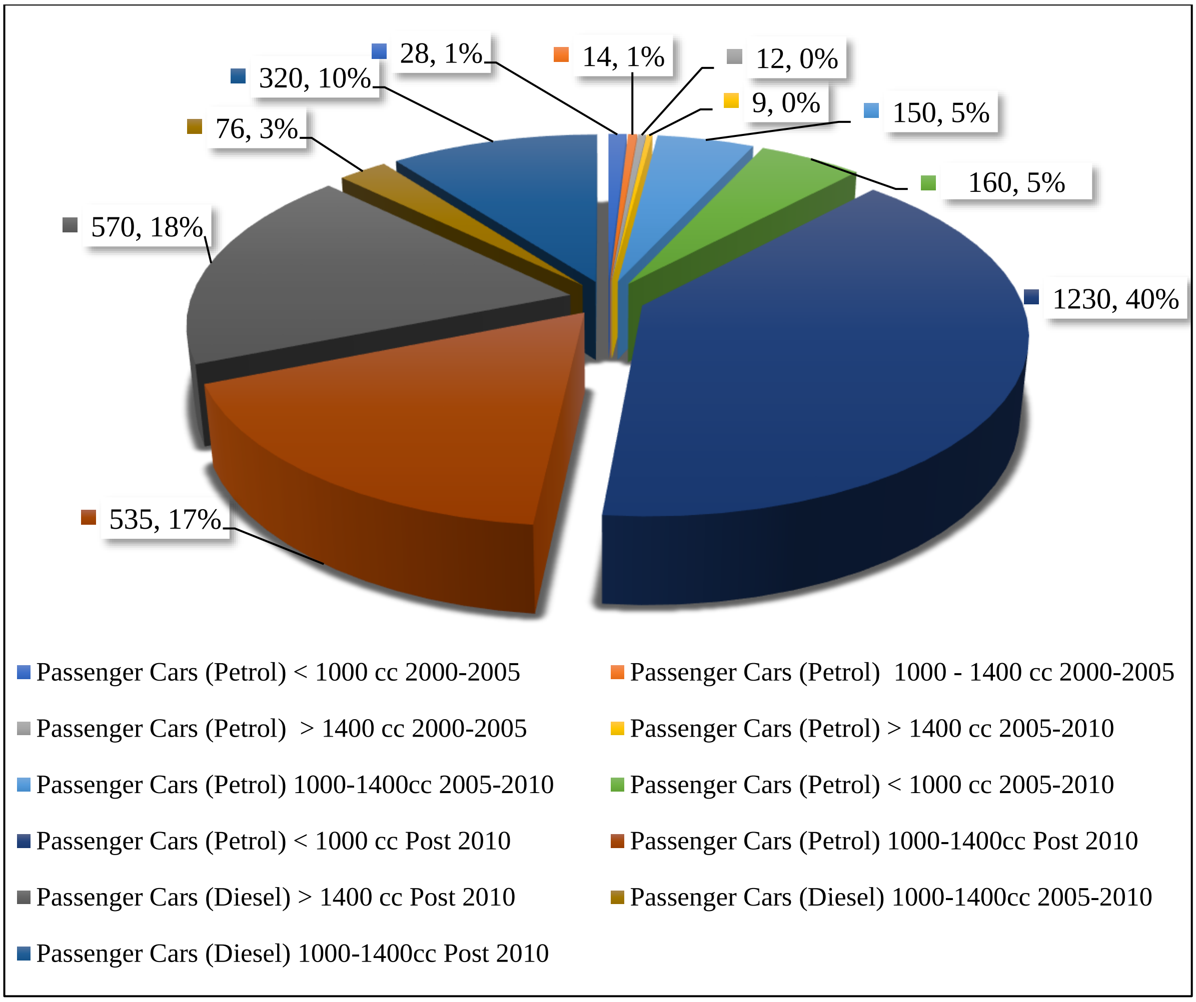


Figure 4.61: **Distribution of 4-Ws in the study area (parking lot survey)**

4.2.13 Vehicular-Line Sources

The average daily flow of vehicles in each hour for 2Ws, 3Ws, 4Ws, LCVs, Buses, and Trucks at 3 locations were obtained by video recording at crossings (Figure 4.62). From these 3 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 is estimated and summed up.

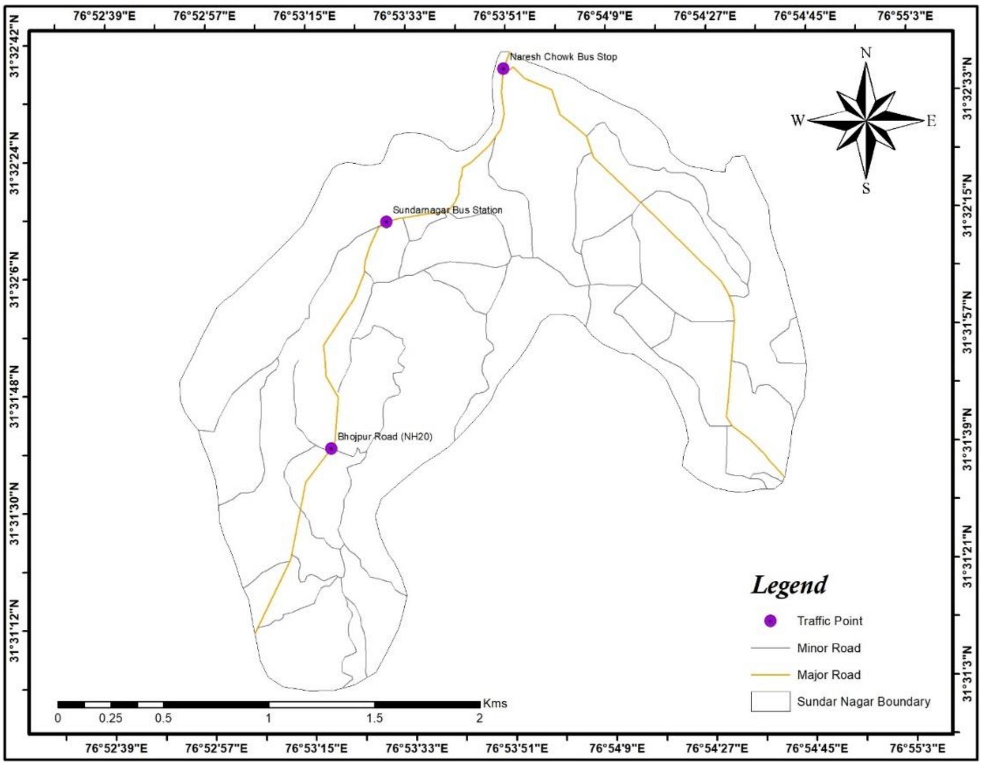
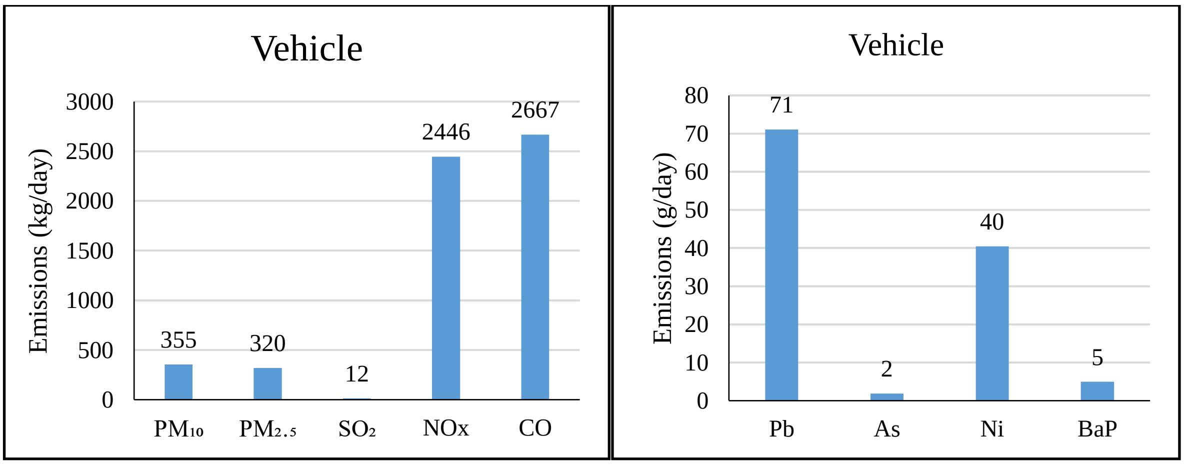


Figure 4.62: **Traffic location considered for vehicle emission in the city of Sunder Nagar**

The emissions from railway locomotives are not taken into considerations, as the emissions are negligible in comparison with the vehicles and other sources.

The emission from vehicles is shown in Figure 4.63 (a) & (b). The emission contribution of each vehicle type in the city of Sunder Nagar is presented in Figure 4.64 to Figure 4.68.

The spatial distribution of emissions from vehicles is presented in Figure 4.69 to Figure 4.73.



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

Figure 4.63: **Emission Load from Vehicles**

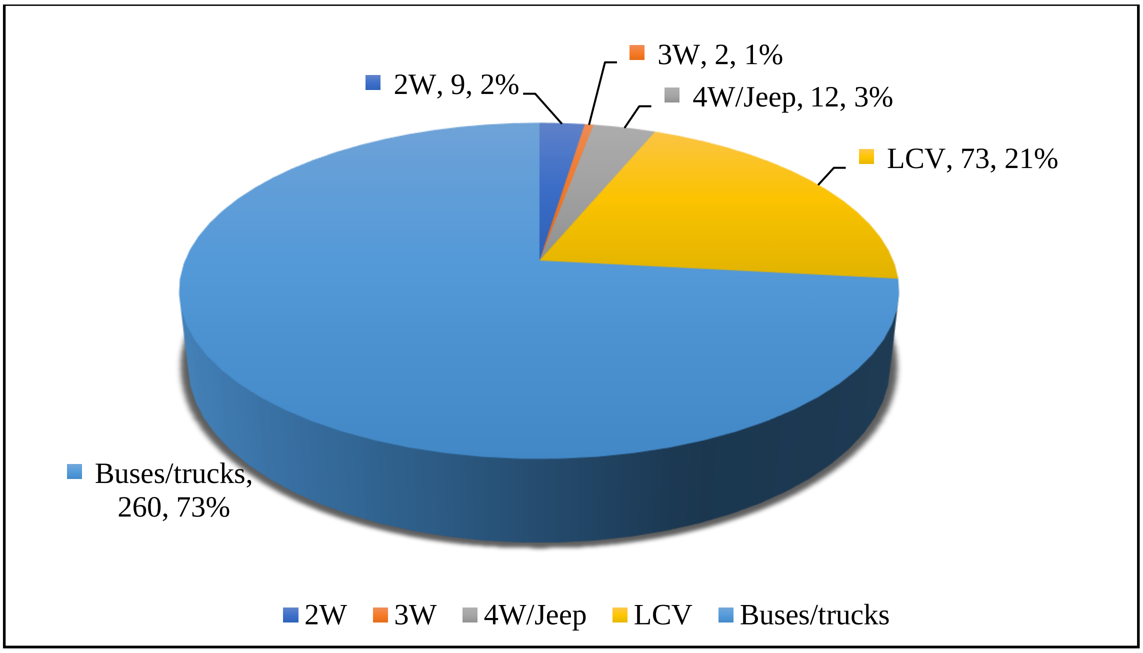


Figure 4.64: **PM_{10} Emission Load contribution of each vehicle type (kg/day)**

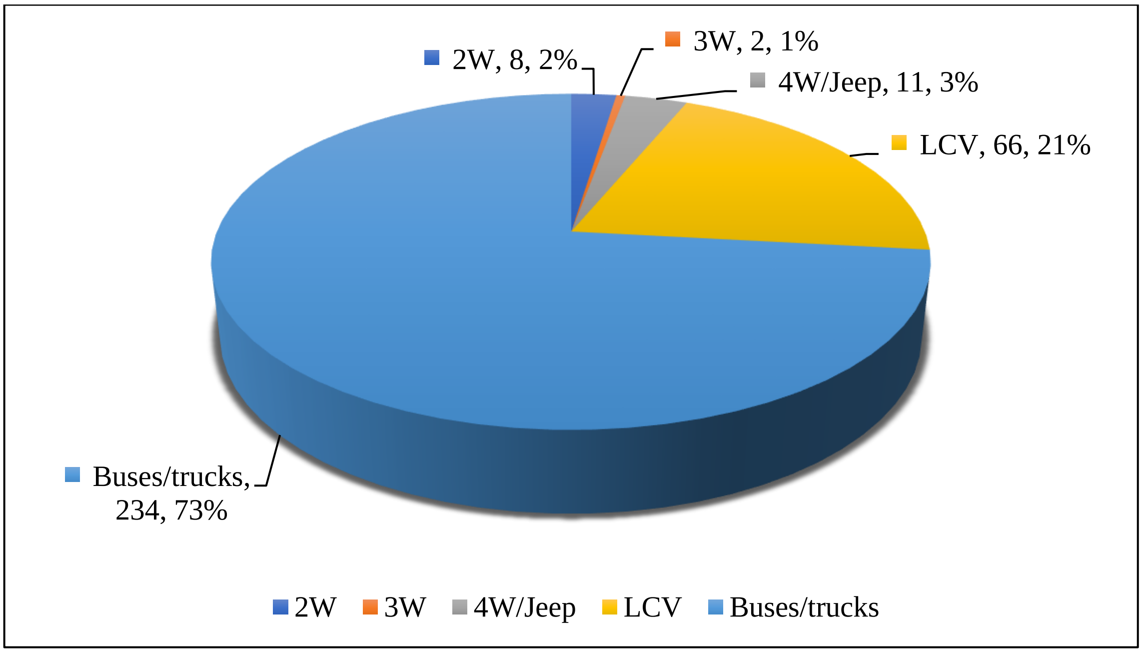


Figure 4.65: **$PM_{2.5}$ Emission Load contribution of each vehicle type (kg/day)**

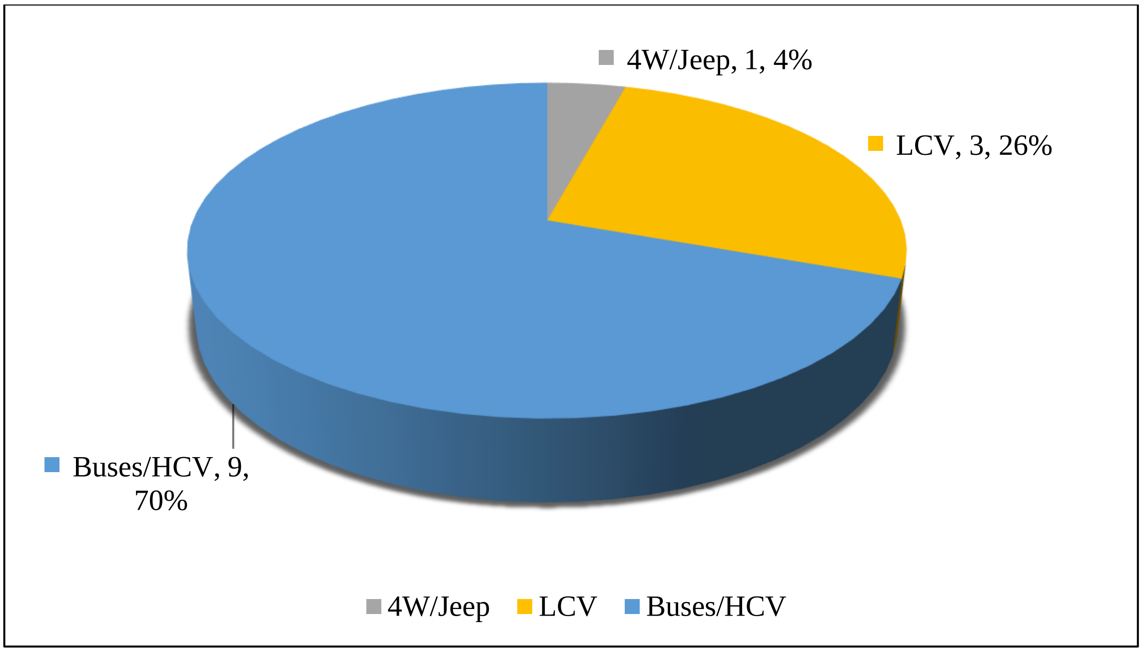


Figure 4.66: **SO_2 Emission Load contribution of each vehicle type (kg/day)**

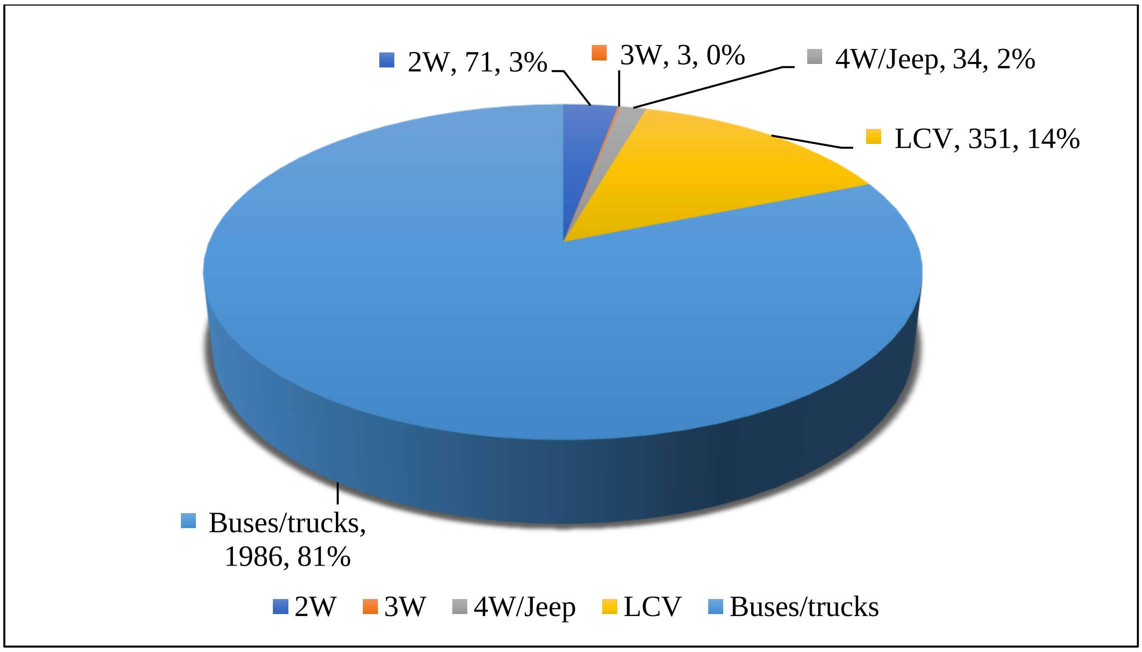


Figure 4.67: NO_x Emission Load contribution of each vehicle type (kg/day)

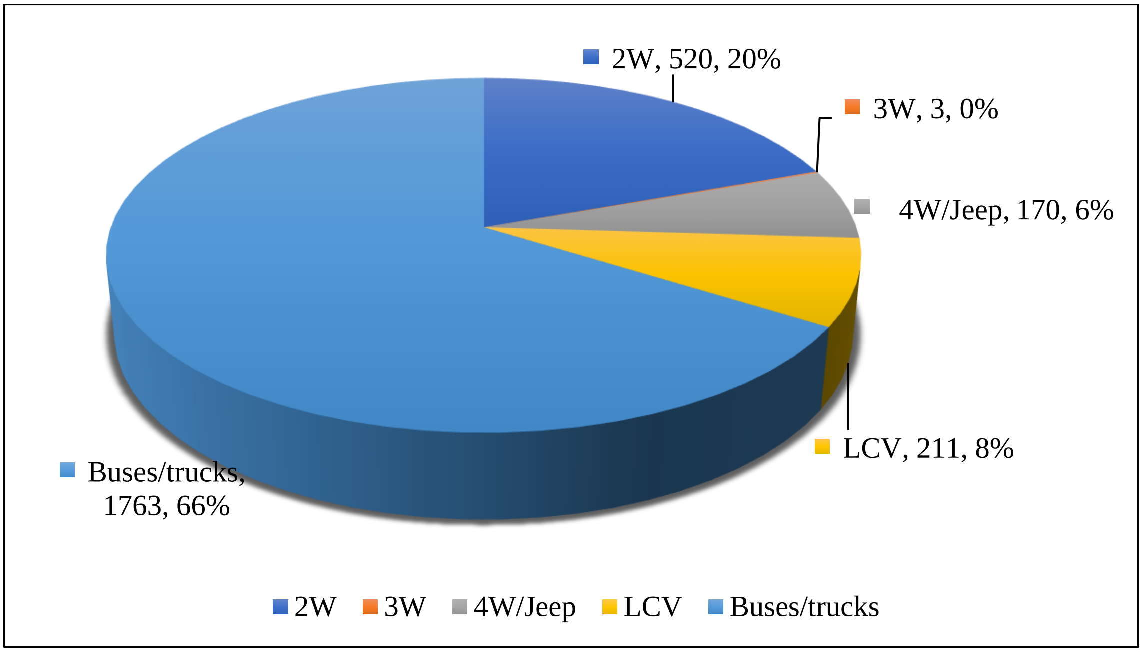


Figure 4.68: **CO Emission Load contribution of each vehicle type (kg/day)**

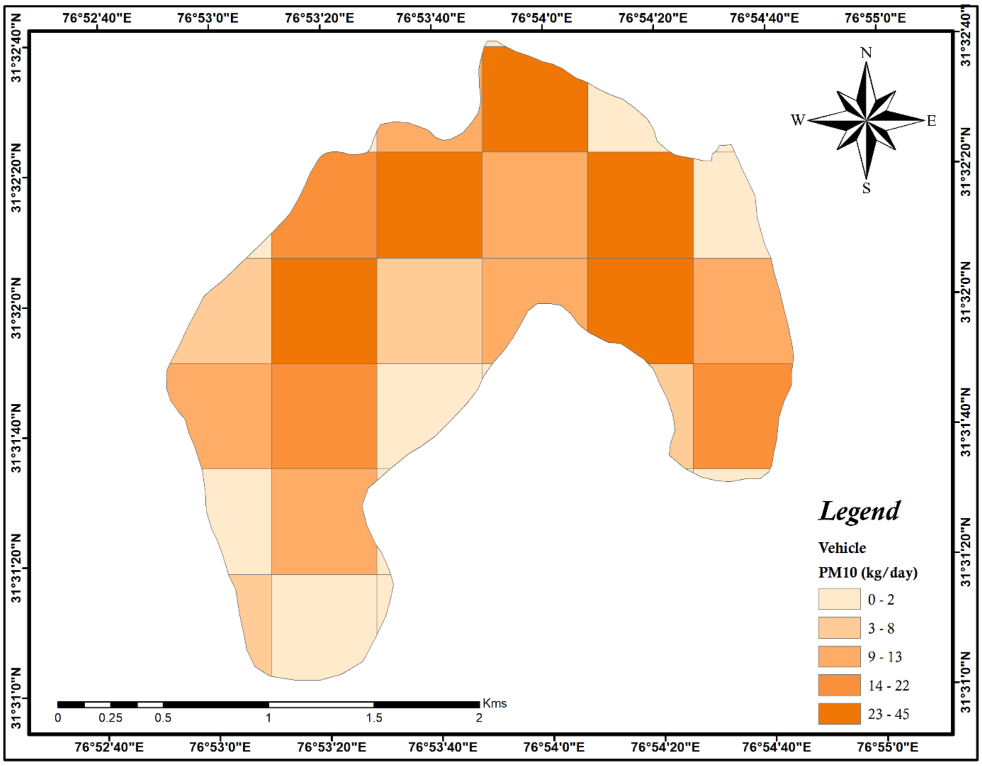


Figure 4.69: **Spatial Distribution of PM_{10} Emissions from Vehicles**

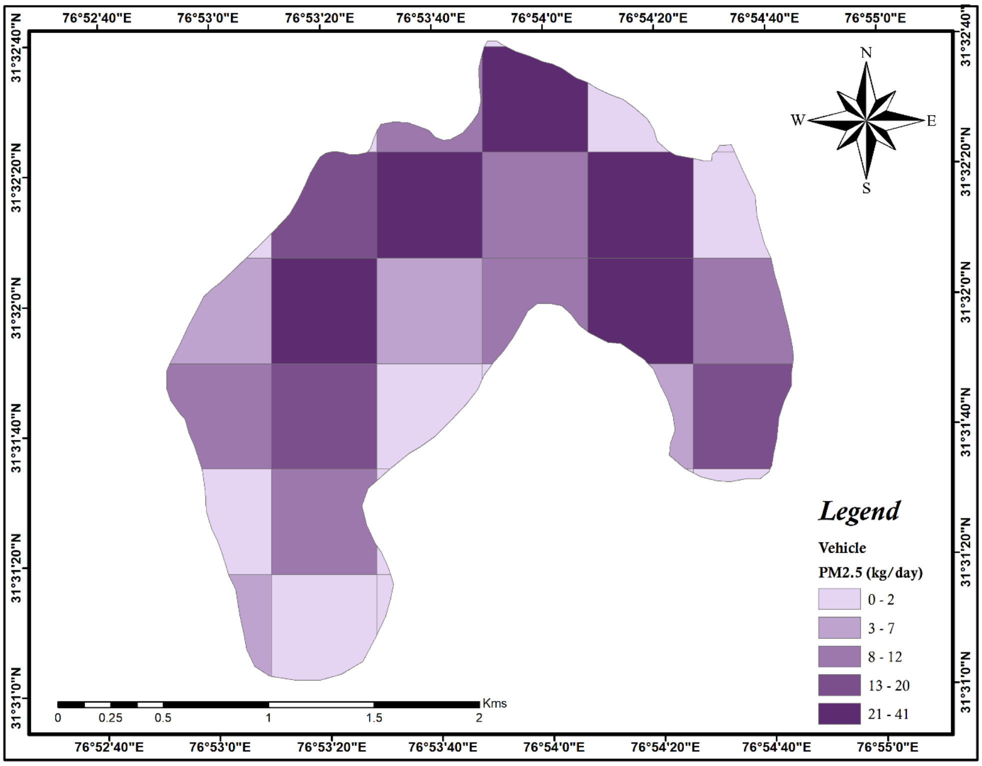


Figure 4.70: **Spatial Distribution of $PM_{2.5}$ Emissions from Vehicles**

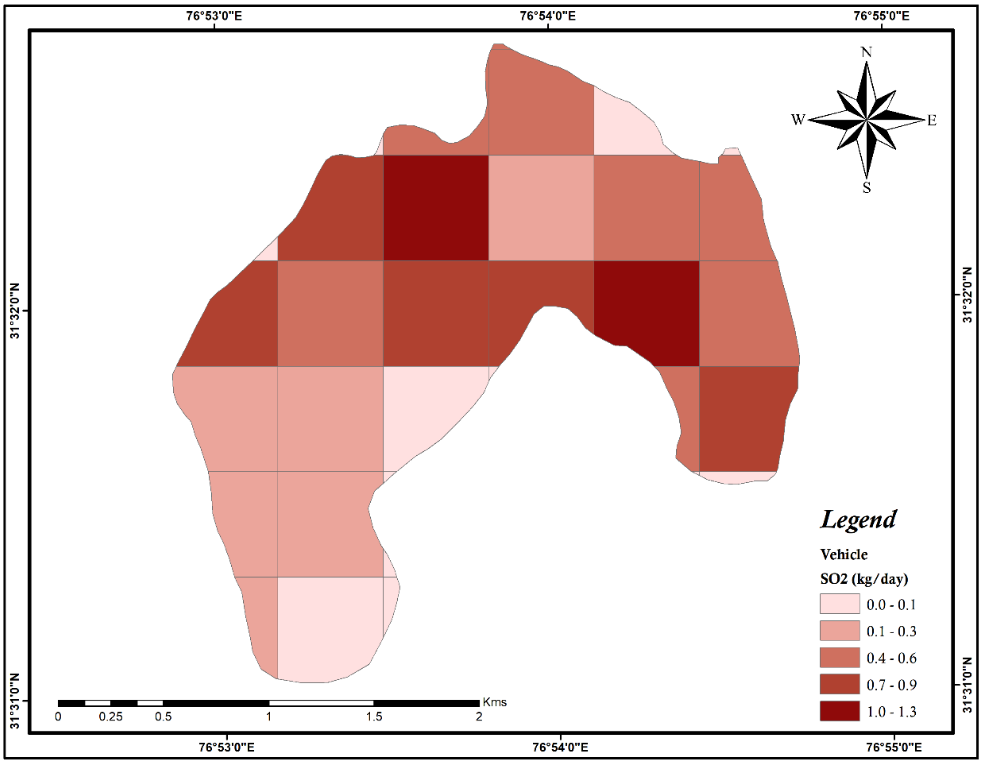


Figure 4.71: **Spatial Distribution of SO_2 Emissions from Vehicles**

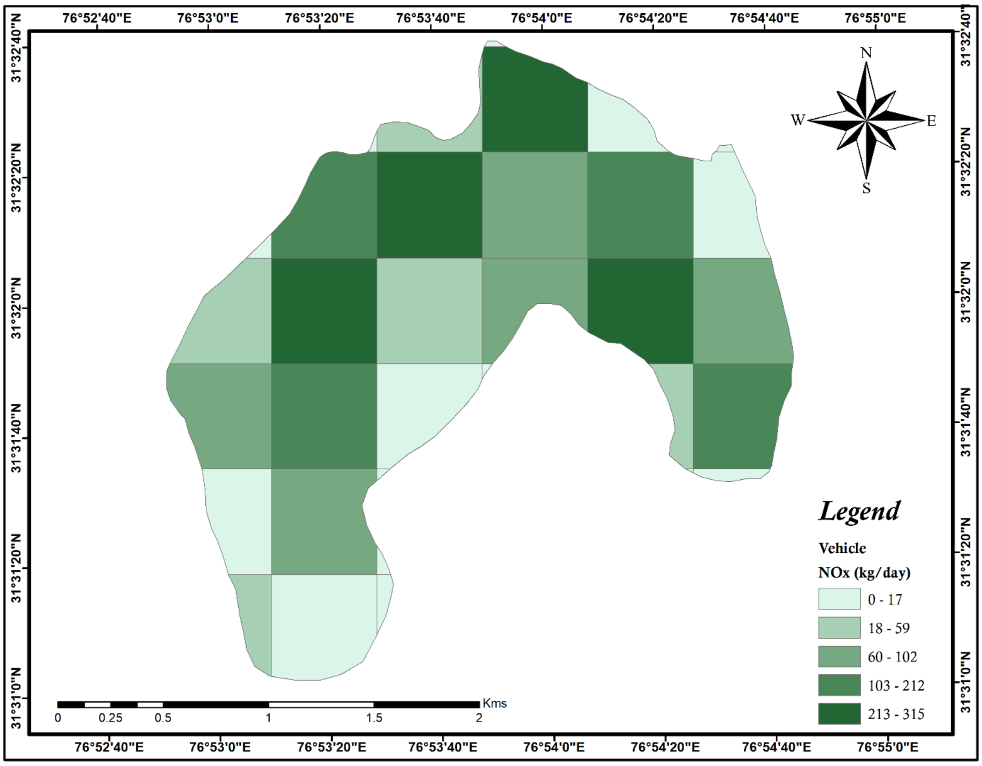


Figure 4.72: Spatial Distribution of NOx Emissions from Vehicles

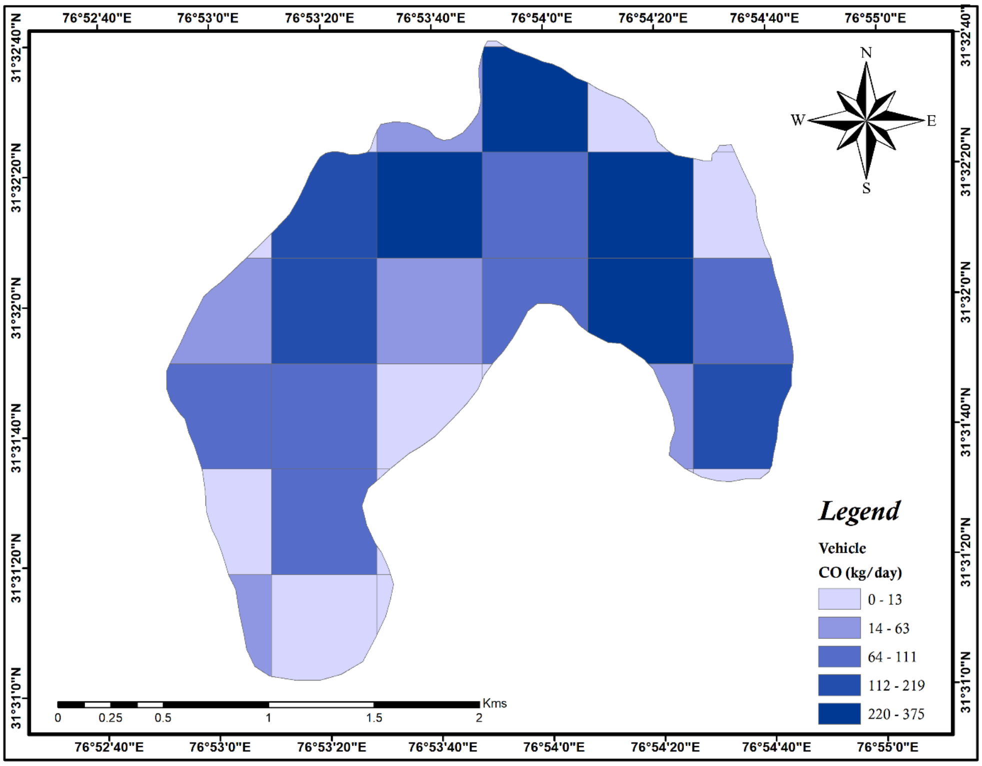


Figure 4.73: Spatial Distribution of CO Emissions from Vehicles

4.2.14 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:

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

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 4.74. 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 out by using Eq (4.4). There is a need to clean the road on regular basis, it can be seen the roads are broken in patches causing higher road dust emissions (Figure 4.75). In the winter and monsoon season, it is less due to moisture and dew atmospheric conditions. The emission load from road dust in Sunder Nagar is given in Figure 4.76 (a) & (b). The Spatial distribution of Emissions from Road Dust Re-suspension is presented in Figure 4.77 and Figure 4.78.

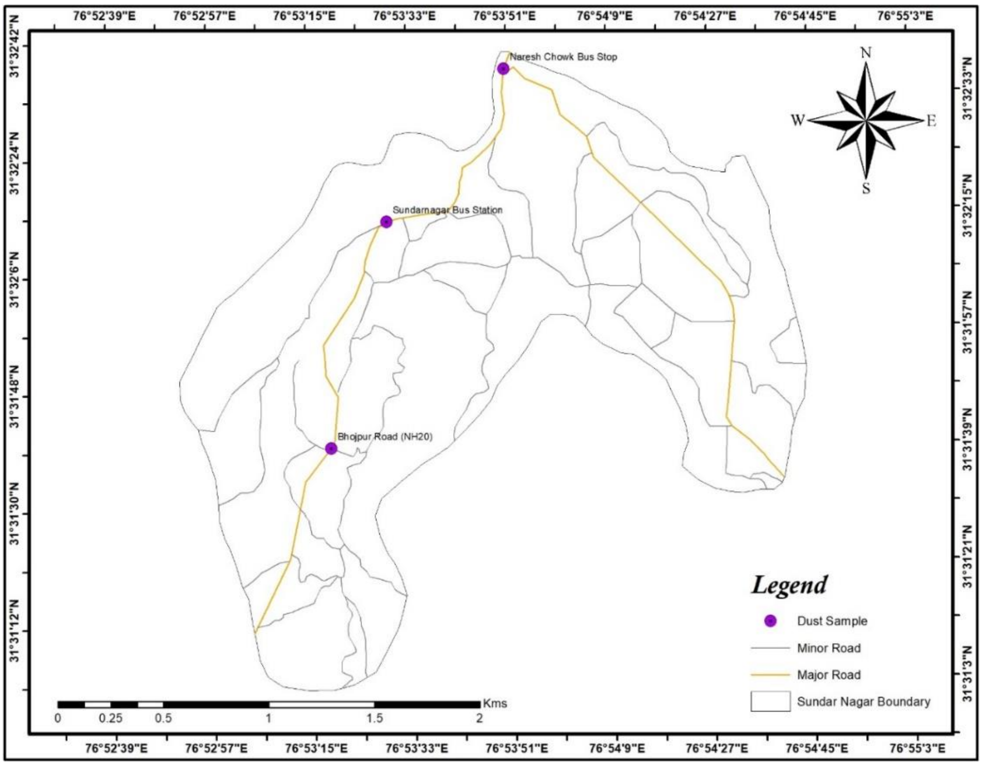
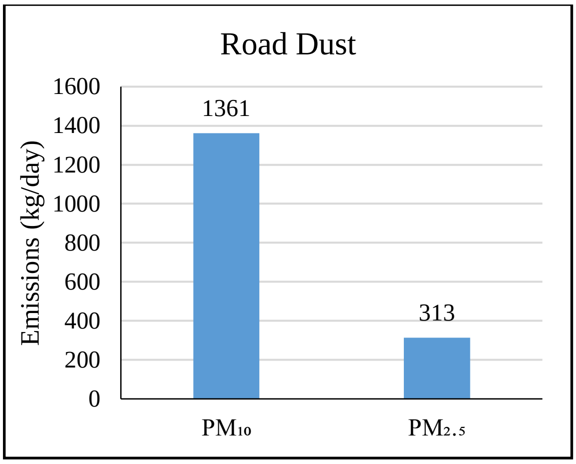
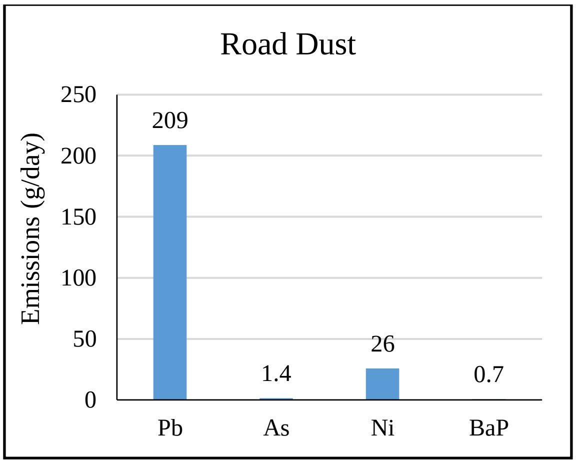


Figure 4.74: Road Dust Sampling Location

Figure 4.75: **Road dust deposition on road/broken roads**



a) PM Emission in kg/day



b) Other Pollutants Emission in g/day

Figure 4.76: Emissions from Road Dust in Sunder Nagar

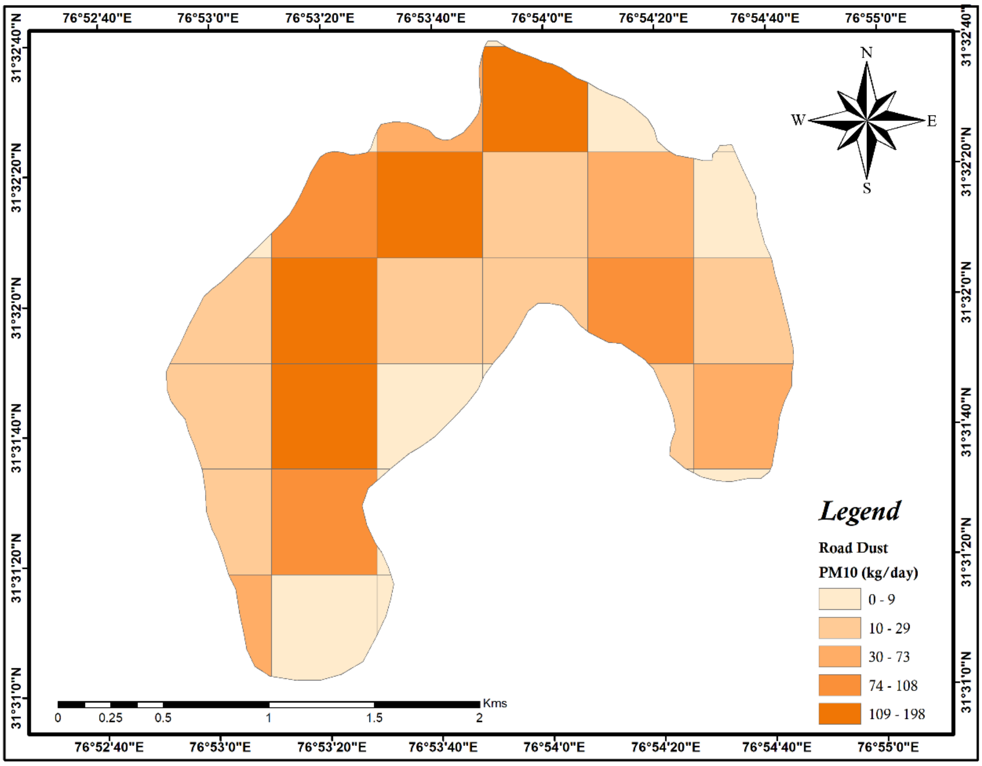


Figure 4.77: Spatial Distribution of PM_{10} Emissions from Road Dust Re-suspension

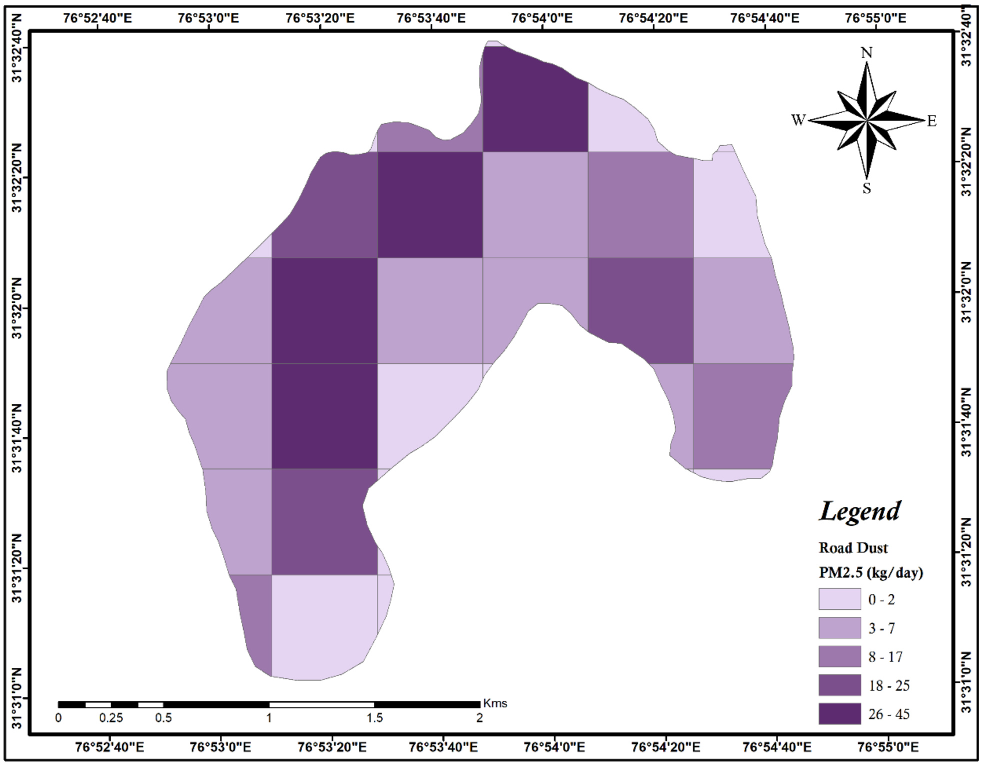


Figure 4.78: Spatial Distribution of $PM_{2.5}$ Emissions from Road Dust Re-suspension

4.3 City Level Emission Inventory

The overall baseline emission inventory for the entire city is presented in Table 4.3. The pollutant wise contribution is shown in Figure 4.79 to Figure 4.83. The spatial distribution of pollutant Emissions from all sources is presented in Figure 4.84 to Figure 4.88. The pollutant wise gridded emissions are provided in Annexure 2.

The total PM_{10} emission load in the city is estimated to be 1976 kg/day. The top three contributors to PM_{10} emissions are Road Dust (69%), Vehicles (18%), and Construction & Demolition (7 %); these are based on annual emissions. Seasonal and daily emissions could be highly variable. The estimated emission suggests that industrial emissions is a major source 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 738 kg/day. The top three contributors to $PM_{2.5}$ emissions are Vehicles (43%), Road Dust (43%), and Construction & Demolition

(5%); 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 81 kg/day. The majority of sources which contribute for SO_2 emissions are Industries (38%) and Hotels, Restaurants, GHs & BHs (30%).

NOx emissions load in the city is estimated to be 2544 kg/day. Majority of total emissions are attributed to Vehicles (96%), Hotels, Restaurants, GHs & BHs (2%), and Domestic (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 3075 kg/day. The major contributors to CO emissions are Vehicles (87%), MSW Burning (6%), Domestic (5%). Vehicles could be the main target for controlling CO for improving air quality concerning CO.

The estimated emissions are for benzene: 93 g/d, Pb: 295 g/d, As: 9 g/d, Ni: 96 g/d and BaP: 6 g/d from all sources.

Table 4.3: Sunder Nagar City Level Inventory (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)
Domestic	33	25	7	18	142		0.2	0.6	0.73	7.4	0.1
MSW Burning	35	24	2.2	13	183		0	7.6	1.4	1	2.37×10^{-4}
Hotels, Restaurants, GHs & BHs	36	20	24	49	66		87	1.6	1.8	19	0.37
Construction & Demolition	147	34						4.7	1.6	2.4	0
Industrial DG Sets	1.0	0.9	4	11	3		1.7	0.1	0	6.21×10^{-3}	7.65×10^{-3}
Hospitals	0.05	0.04	0.04	0.64	0.14		0.1	4.11×10^{-3}	0	4.88×10^{-4}	6.02×10^{-4}
Industries	7	2.3	31	6	13		4	0.1	1.56×10^{-3}	0.01	0.03
Vehicle	355	320	623	2446	2667		0	71	1.9	40	4.98
Road Dust	1361	313						209	1.4	26	0.07
Agriculture						184					
Livestock						192					
Total	**1976**	**738**	**81**	**2544**	**3075**	**376**	**93**	**295**	**9**	**96**	**6**

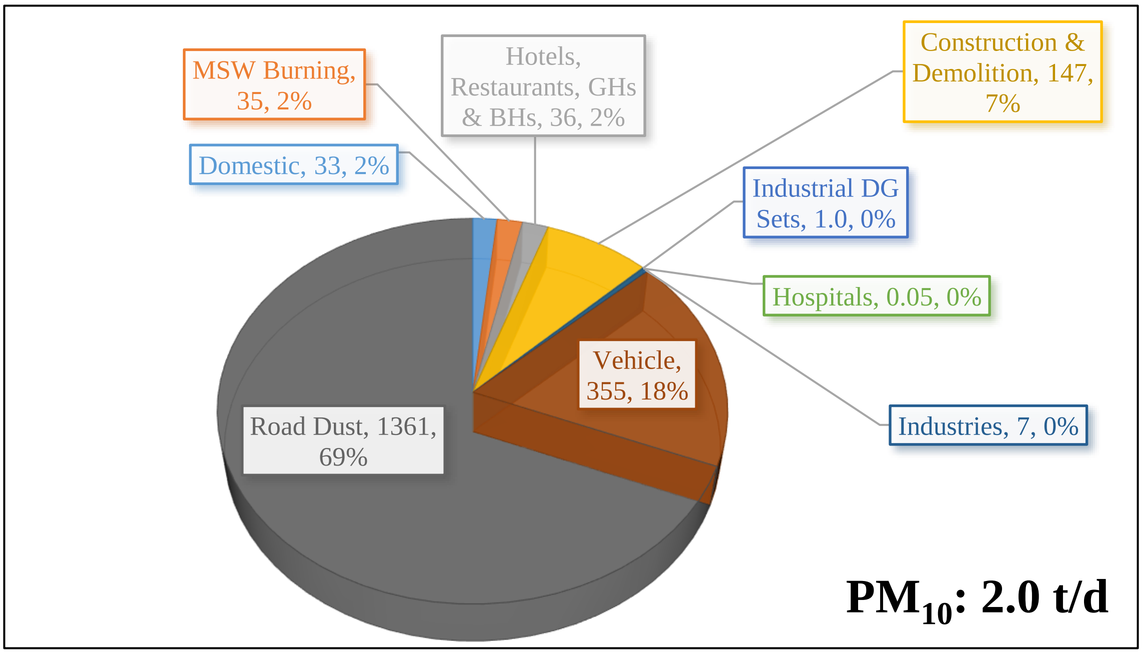


Figure 4.79: PM_{10} Emission Load Contribution of Different Sources

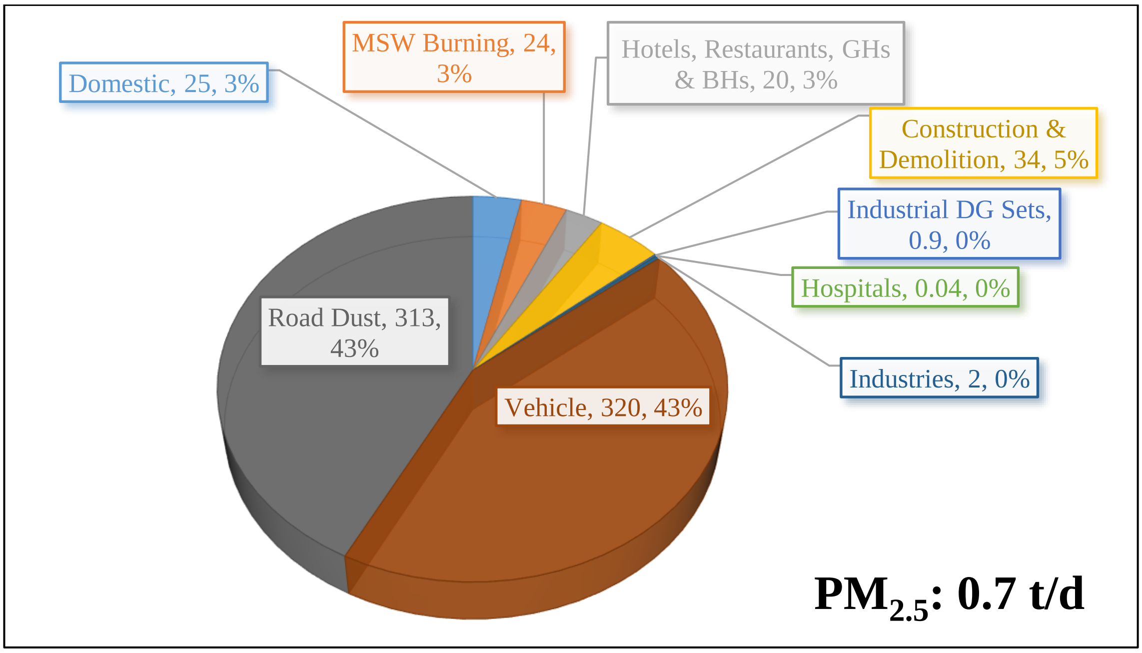


Figure 4.80: $PM_{2.5}$ Emission Load Contribution of Different Sources

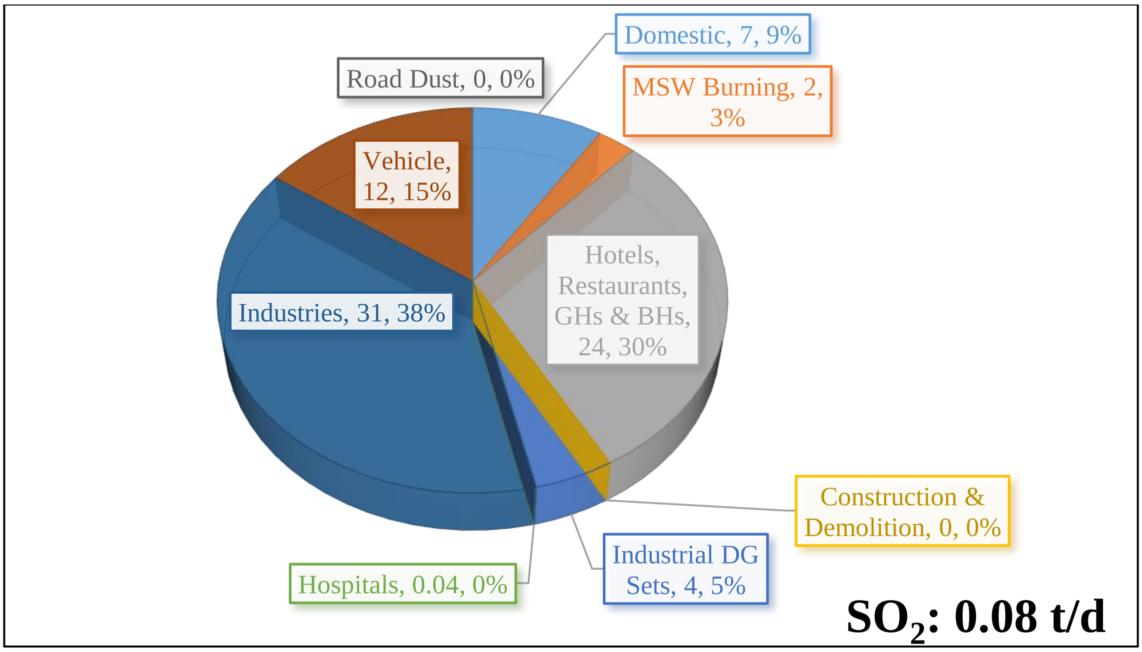


Figure 4.81: **SO_2 Emission Load Contribution of Different Sources**

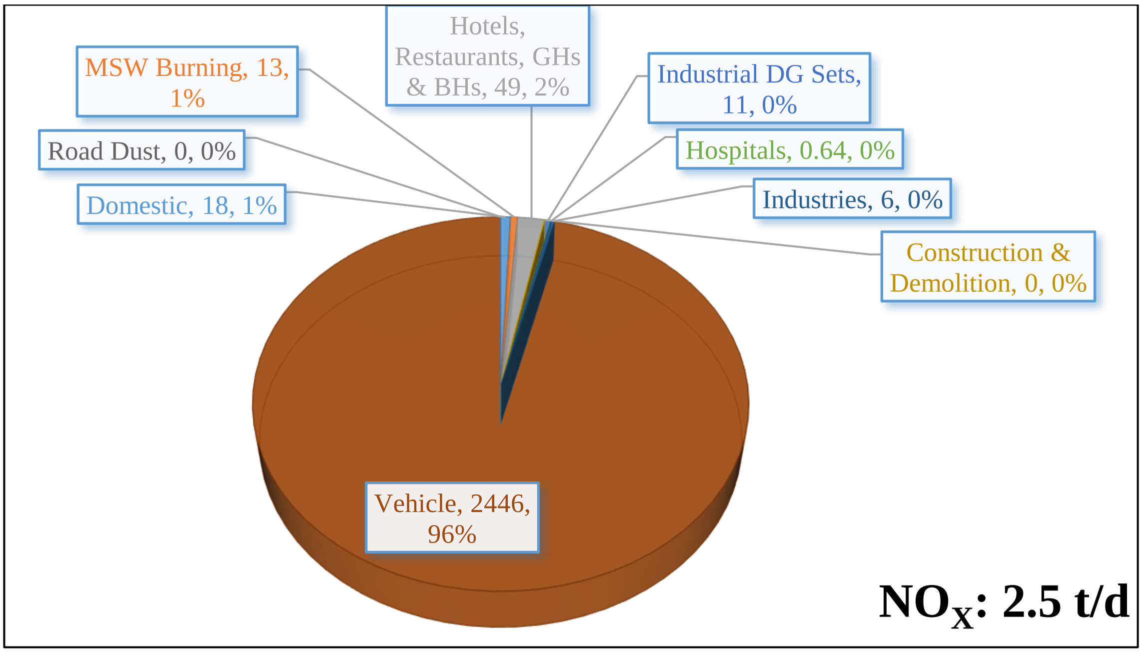


Figure 4.82: **NOx Emission Load Contribution of Different Sources**

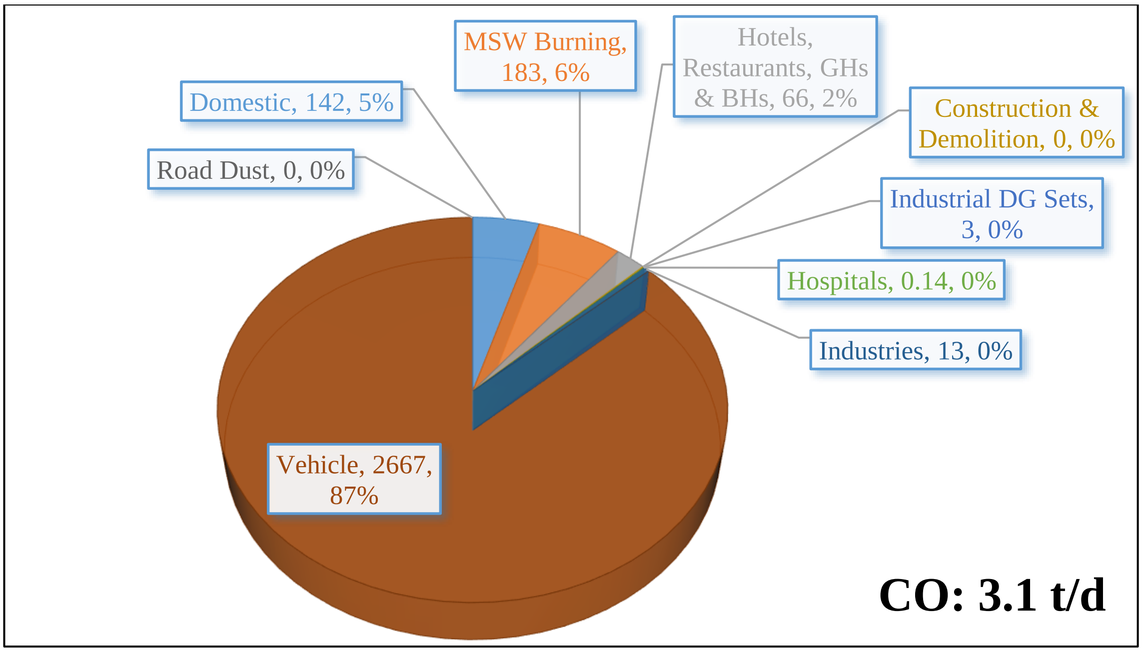


Figure 4.83: **CO Emission Load Contribution of Different Sources**

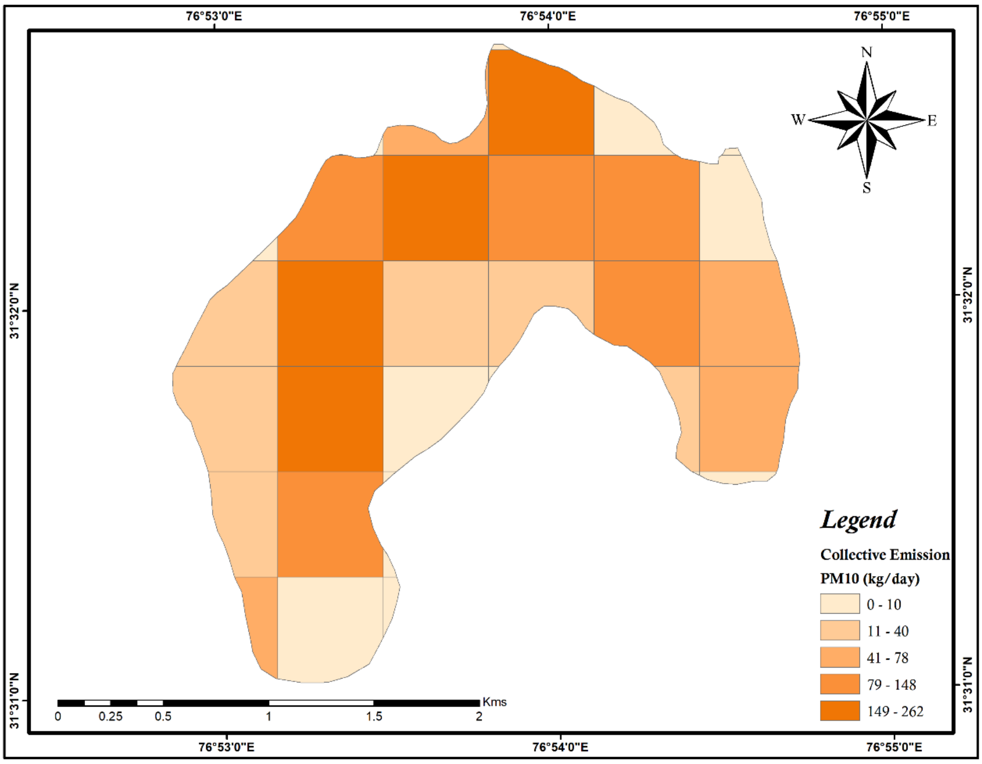


Figure 4.84: Spatial Distribution of PM$_{10}$ Emissions in the City of Sunder Nagar

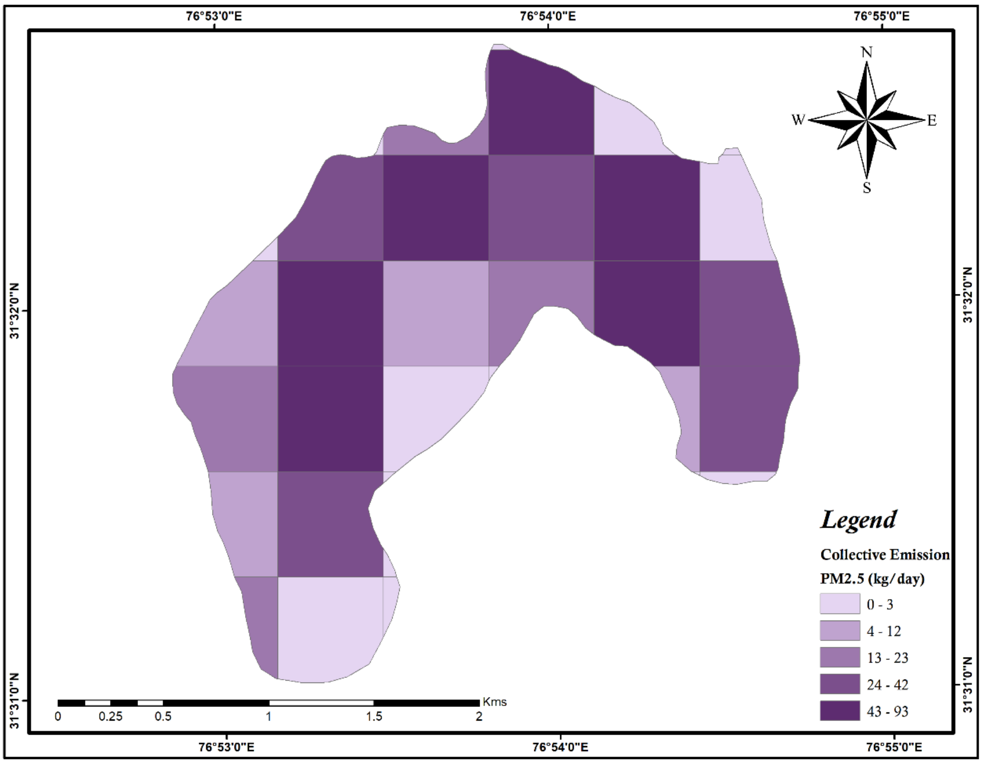


Figure 4.85: **Spatial Distribution of $PM_{2.5}$ Emissions in the City of Sunder Nagar**

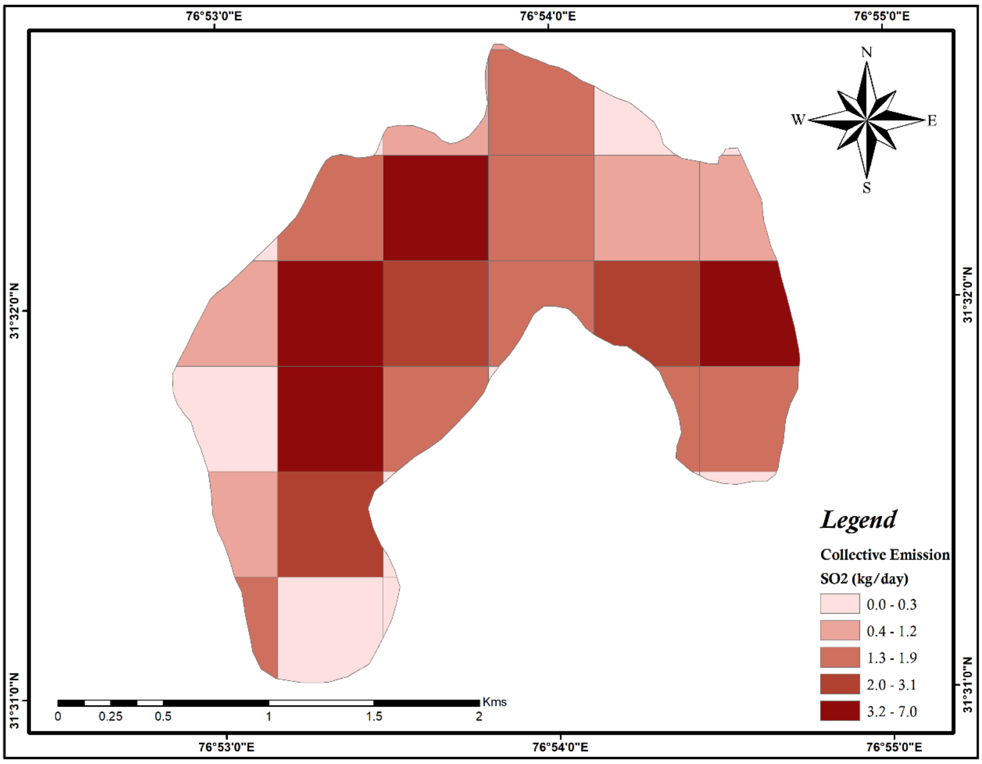


Figure 4.86: **Spatial Distribution of SO_2 Emissions in the City of Sunder Nagar**

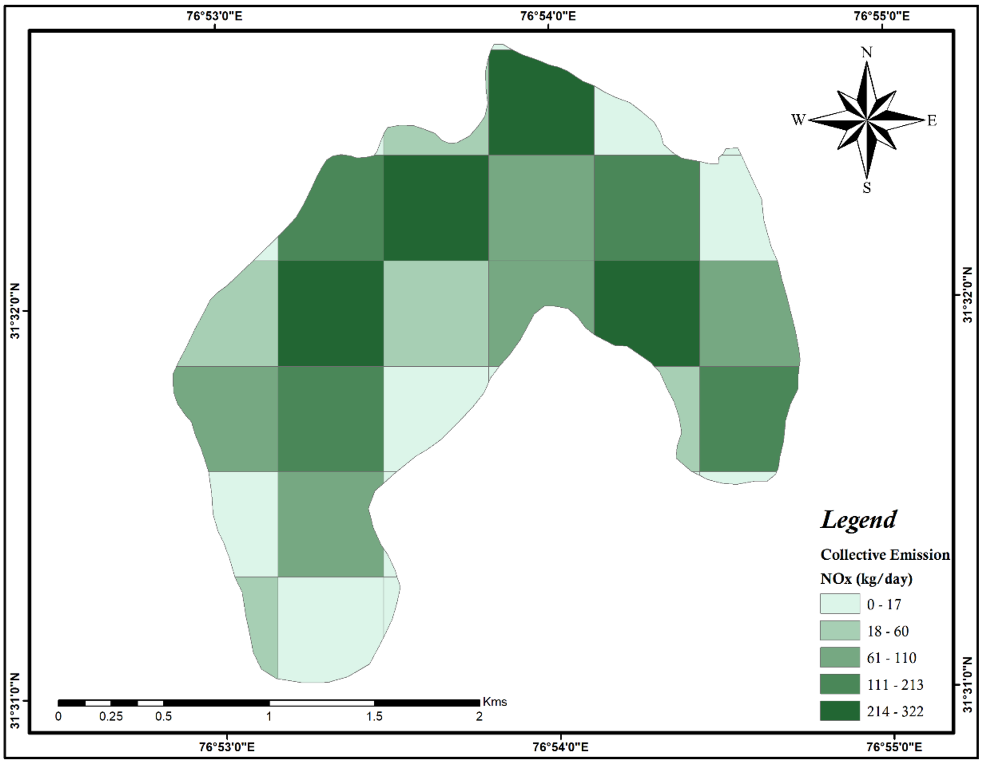


Figure 4.87: **Spatial Distribution of NOx Emissions in the City of Sunder Nagar**

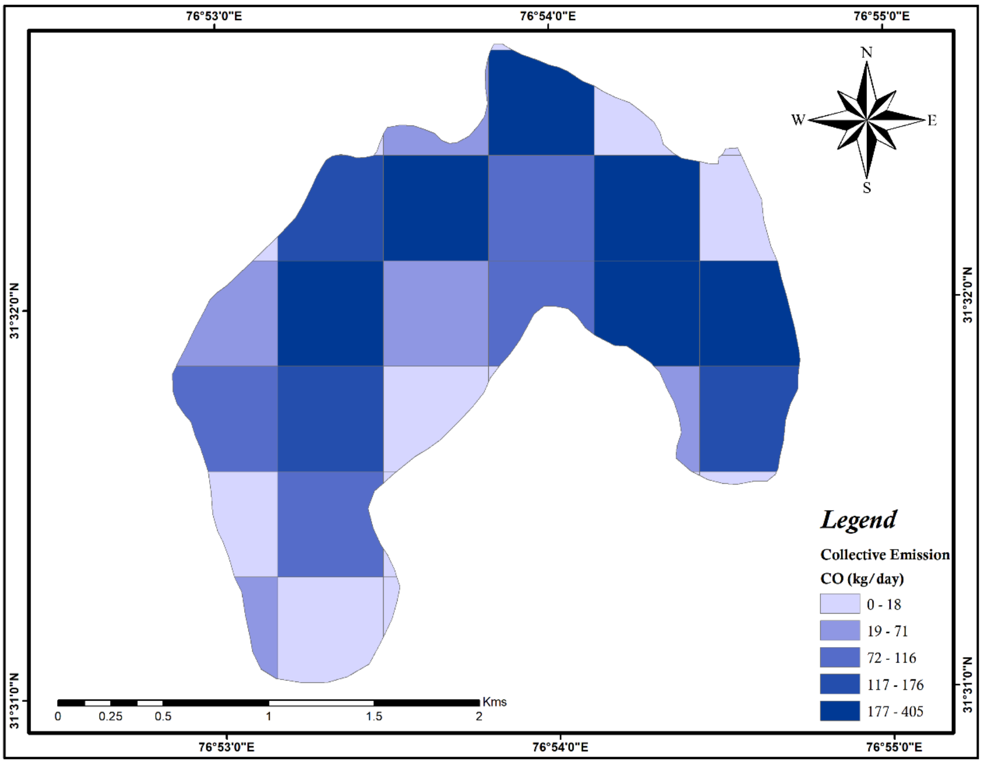


Figure 4.88: **Spatial Distribution of CO Emissions in the City of Sunder Nagar**

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 January 31 - February 06, 2020 during winter at three sites in Sunder Nagar.

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 Sunder Nagar are described in the next section.

5.3 PMF Modeling Results and interpretation (Sunder Nagar)

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 $PM_{2.5}$.

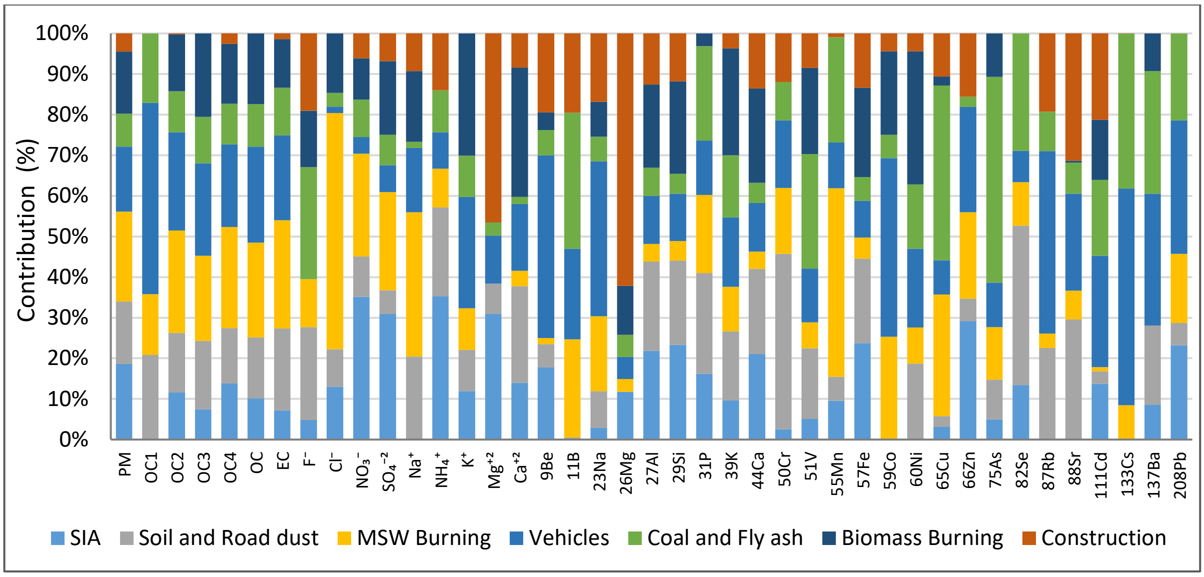
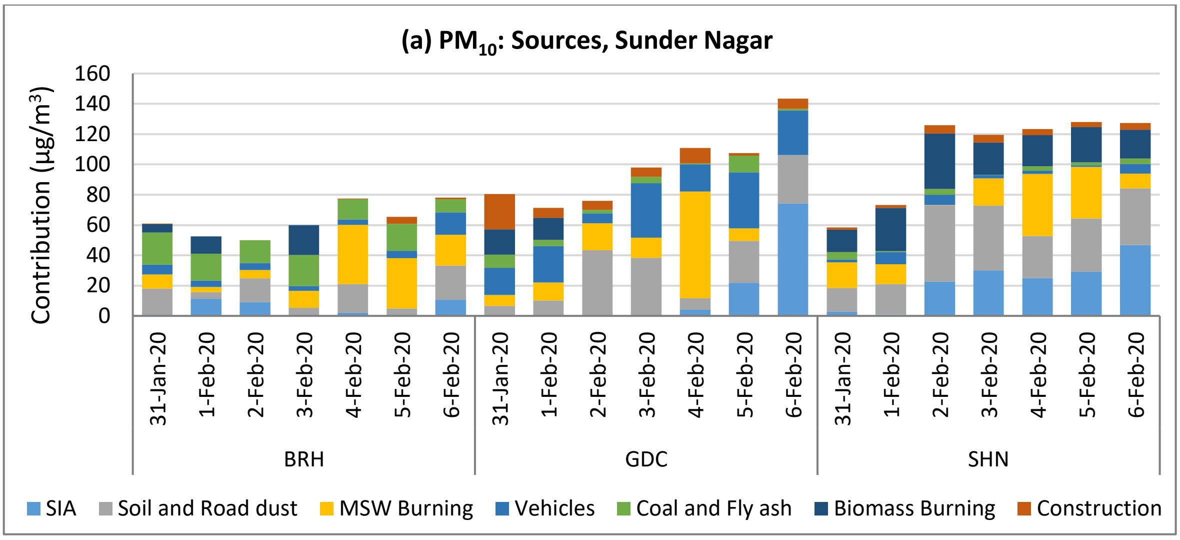


Figure 5.1: PMF-based Source profiles for PM_{10} and $PM_{2.5}$



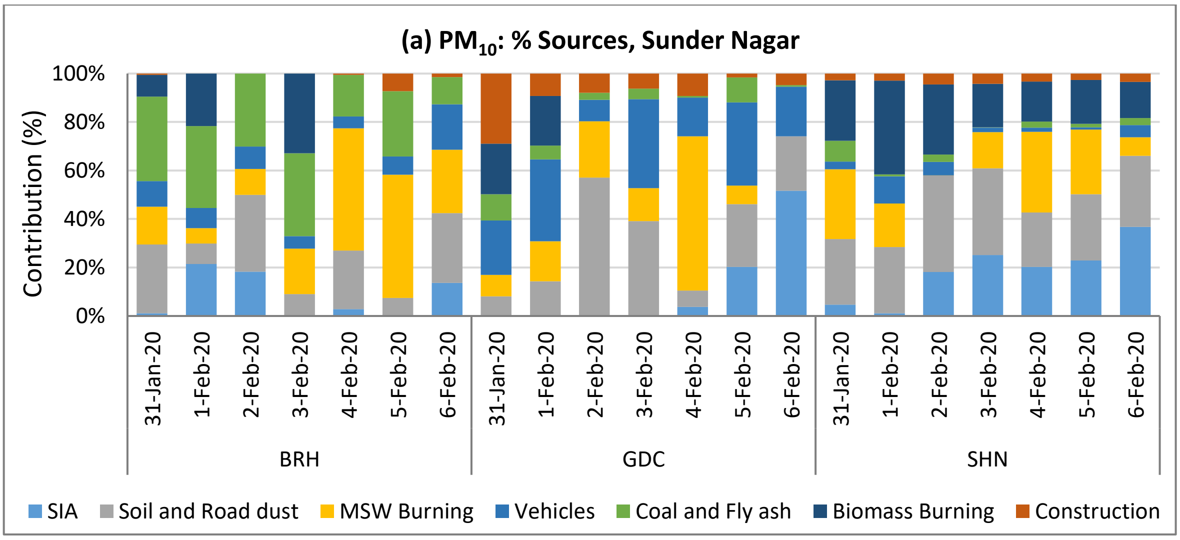


Figure 5.2: PMF modeling Results for PM_{10} at all sites

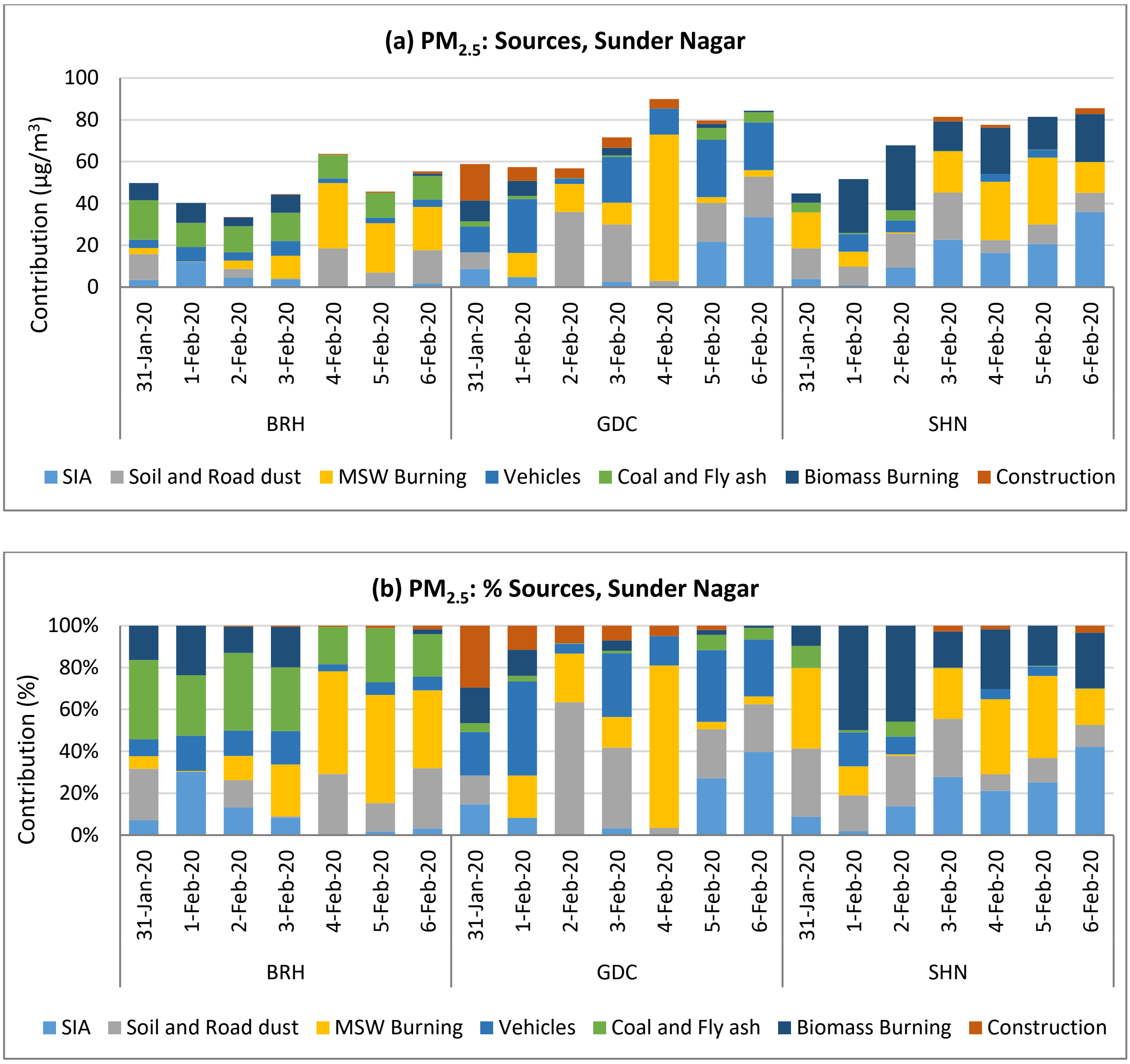


Figure 5.3: PMF modeling Results for $PM_{2.5}$ at all sites

5.3.1 BRH

PM_{10}

The average PM_{10} concentration was 59 µg/m^3. Figure 5.2 represents PM_{10} contribution of sources in terms of concentration, and percent contribution of sources at all sites (BRH 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 municipal solid waste (MSW) burning (28%) followed by coal combustion and fly ash (26%). The other sources are soil and road dust (20%), vehicular emission (9%), biomass burning (8%), secondary inorganic aerosols (SIA; 8%) and construction activities (1%).

$PM_{2.5}$

The average $PM_{2.5}$ concentration was 44 µg/m^3 (i.e., about 0.75 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 (BRH represented in 1st 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 MSW burning (28%) followed by coal combustion and fly ash (27%). The other sources are soil and road dust (17%), biomass burning (10%), vehicular emission (9%), SIA (8%) and construction activities (1%).

HYSPLIT back trajectories (Figure 5.5) indicate that wind is flowing mostly from NW direction and sometimes from other 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 MSW burning contribution is most significant in $PM_{2.5}$ and PM_{10} at 28%. 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.

- The contribution of coal combustion including fly ash is the second most significant source in PM_{10} (26%) and $PM_{2.5}$ (27%). It may be possible that restaurants and dhabas were using coal in the nearby areas.

- Soil and road dust contribution is also significant in $PM_{2.5}$ (17%) and PM_{10} (20%). The high contribution in emissions during sampling period may be due to bad/unpaved roads.

- The biomass contribution has significant. Biomass burning emission are expected to be large from regions of economically lower strata that uses of biomass as a solid fuel for cooking and heating.

- Vehicle contribution is consistent in $PM_{2.5}$ and PM_{10} at 9%. It could be moderate to high traffic on NH-154 in the nearby areas.

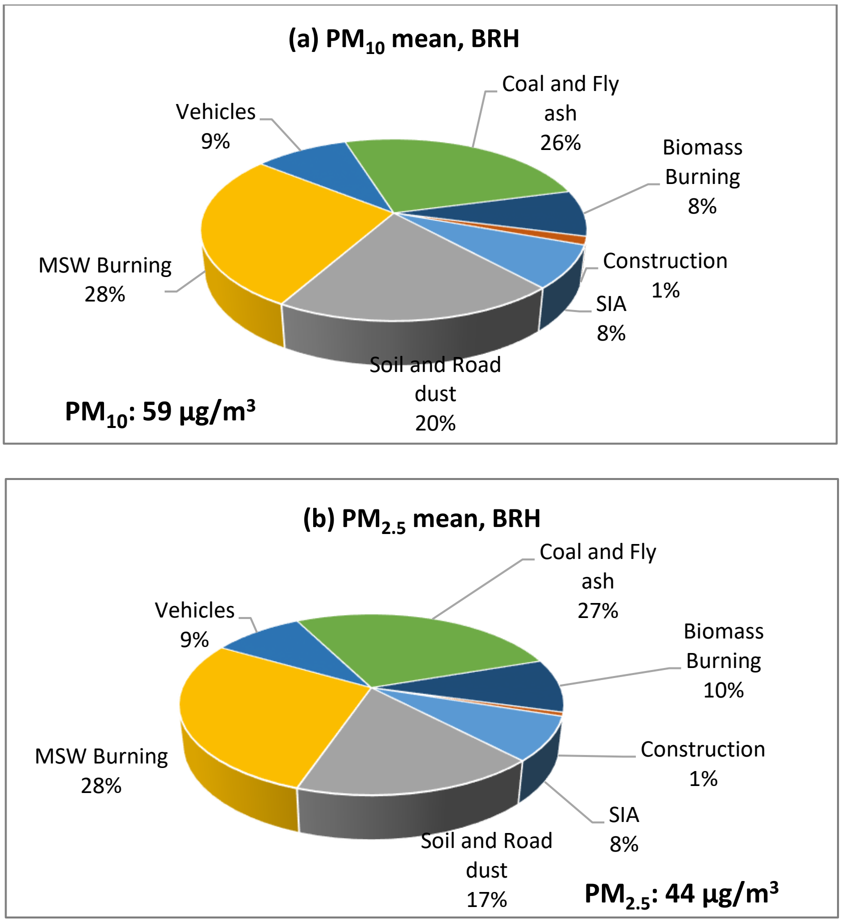


Figure 5.4: PMF modeling for (a) PM_{10} and (b) $PM_{2.5}$ at BRH

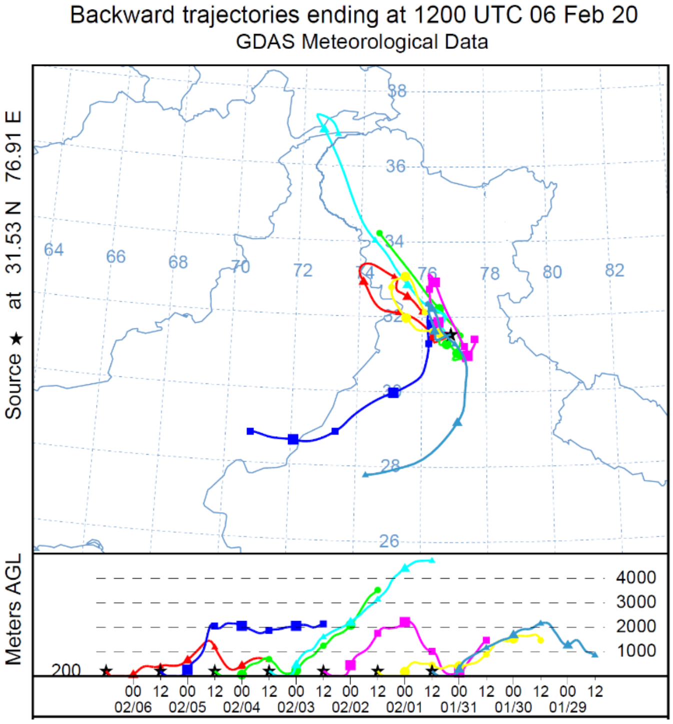


Figure 5.5: Backward trajectories at BRH

5.3.2 GDC

PM_{10}

The average PM_{10} concentration was 92 µg/m^3. Figure 5.2 represents PM_{10} contribution of sources in terms of concentration, and percent contribution of sources at all sites (GDC 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 vehicular emission (25%) followed by soil and road dust (24%). The other sources are MSW burning (19%), SIA (14%), construction activities (9%), coal combustion and fly ash (5%) and biomass burning (4%).

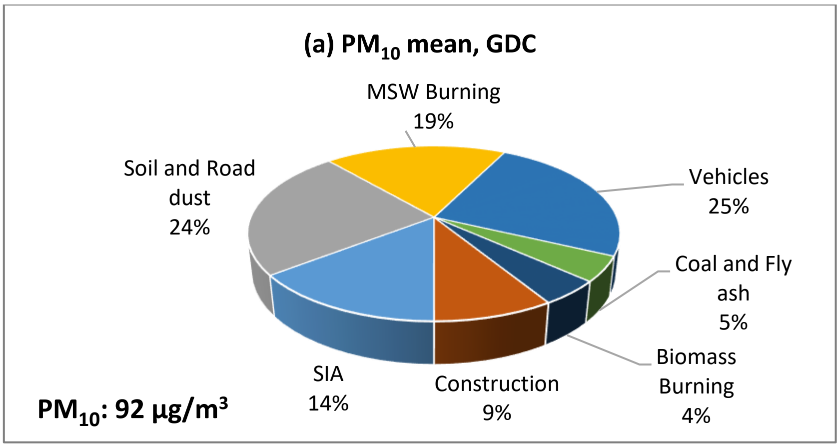
$PM_{2.5}$

The average $PM_{2.5}$ concentration was 69 µg/m^3 (i.e., about 0.76 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 (GDC 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 vehicular emission (25%) followed by soil and road dust (23%). The other sources are MSW burning (22%), SIA (14%), construction activities (8%), biomass burning (5%) and coal combustion and fly ash (3%).

HYSPLIT back trajectories (Figure 5.7) indicate that wind is flowing mostly from NW direction and sometimes from other 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

Vehicles contribution was highest about 25% in $PM_{2.5}$ and PM_{10}. Vehicles source combines diesel, gasoline uses in DG sets industries and commercial offices, vehicles. It could be moderate to high traffic on NH-154 and traffic congestion in commercial area. Soil and road dust is the second most significant source contributing about 24% in PM_{10} and 23% in $PM_{2.5}$. MSW burning is also significant source contributing about 22% in $PM_{2.5}$ and 19% in PM_{10}. SIA contribution is also significant in PM_{10} and $PM_{2.5}$ at 14%.



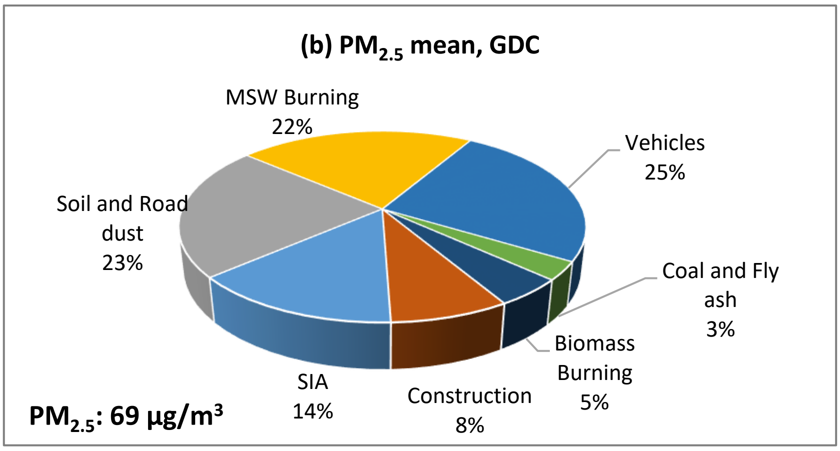


Figure 5.6: PMF modeling for (a) PM_{10} and (b) $PM_{2.5}$ at GDC

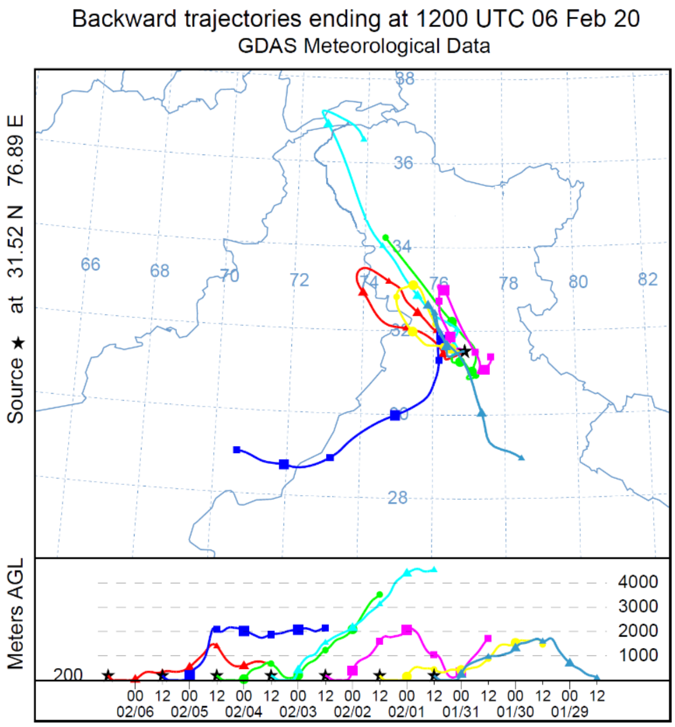


Figure 5.7: Backward trajectories at GDC

5.3.3 SHN

PM_{10}

The average PM_{10} concentration was 108 µg/m^3. Figure 5.2 represents PM_{10} contribution of sources in terms of concentration, and percent contribution of sources at all sites (SHN 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 (30%) followed by biomass burning (22%). The other sources are SIA (21%), MSW burning (18%), vehicular emission (4%), construction activities (3%) and coal combustion and fly ash (2%).

$PM_{2.5}$

The average $PM_{2.5}$ concentration was 66 µg/m^3 (i.e., about 0.62 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 (SHN 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 biomass burning (28%) followed by MSW burning (24%). The other sources are SIA (23%), soil and road dust (18%), vehicular emission (4%), coal combustion and fly ash (2%) and construction activities (1%).

HYSPLIT back trajectories (Figure 5.9) indicate that wind is flowing mostly from NW direction and sometimes from other 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 30% in PM_{10} and reduced to 18% in $PM_{2.5}$. It was observed during sampling that road condition was bad and broken with high silt loads. Biomass burning is very high at 28% in $PM_{2.5}$ and 22% in PM_{10}. MSW contribution is also significant contributor source at 18% in PM_{10} and 24% in $PM_{2.5}$. vehicles contribution is low in PM_{10} and $PM_{2.5}$ at this site.

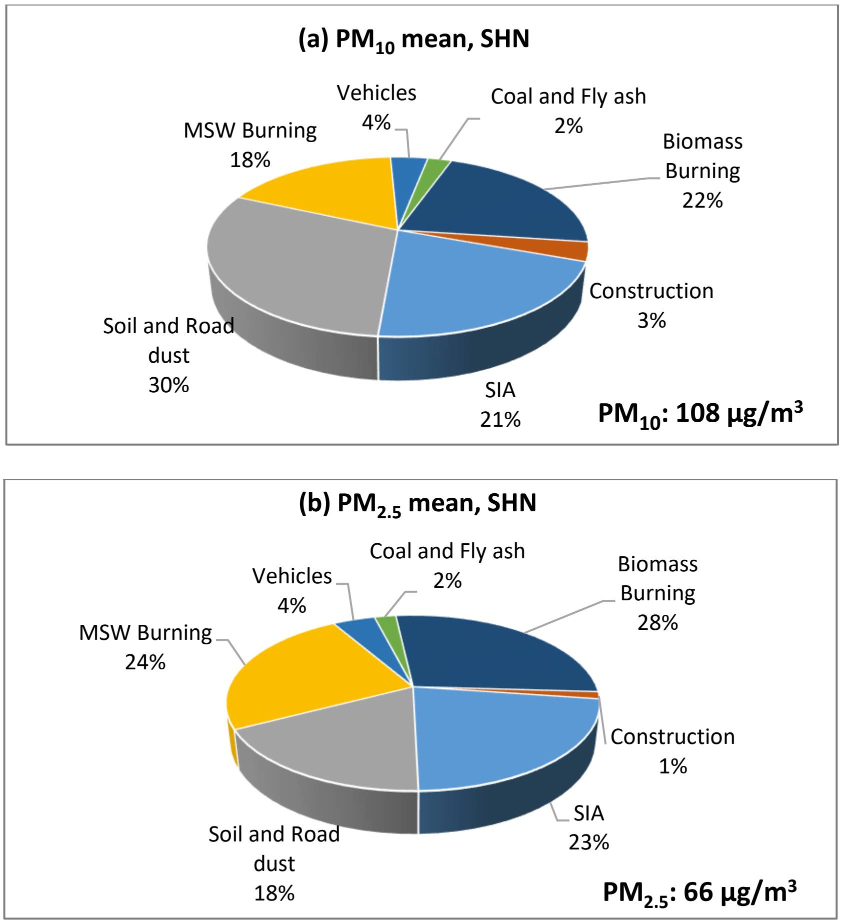


Figure 5.8: PMF modeling for (a) PM_{10} and (b) $PM_{2.5}$ at SHN

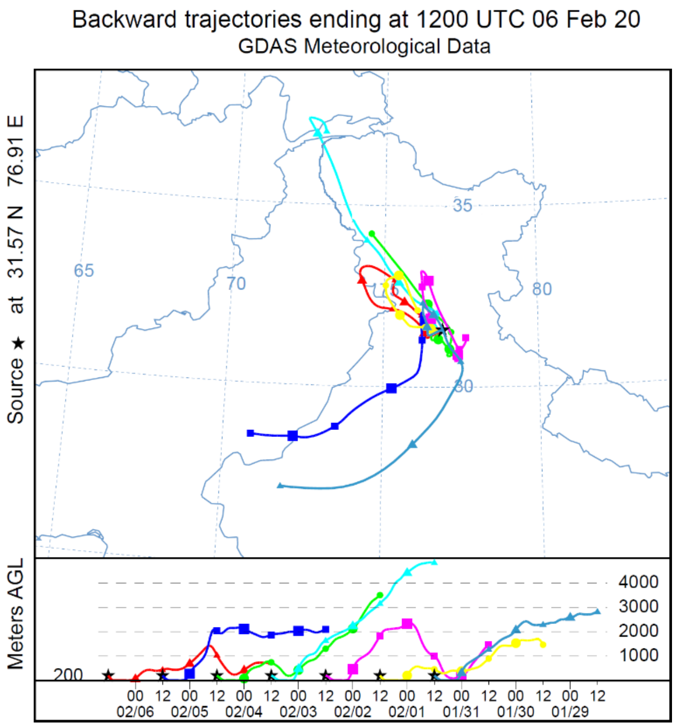


Figure 5.9: Backward trajectories at SHN

5.3.4 Overall

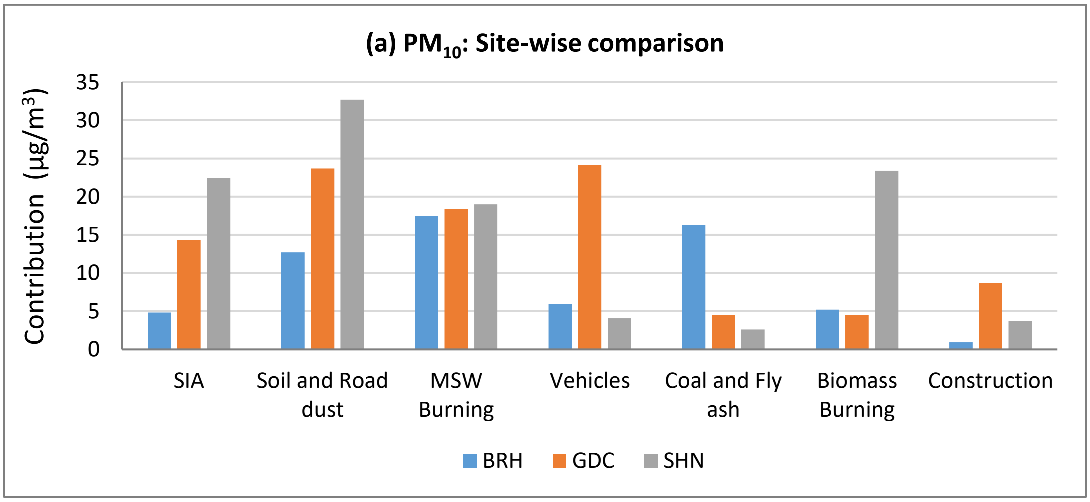
The overall summary of PMF modeling results is shown in Figures 5.10 – 5.11. Tables 5.1 – 5.2 provide a summary of overall statistics.

PM_{10}

The average PM_{10} concentration was 86 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 Sunder Nagar. It is observed that the major source contributing to PM_{10} was soil and road dust (23 µg/m^3 ~ 26%) followed by MSW burning (18 µg/m^3 ~ 20%). The other major sources are SIA (14 µg/m^3 ~ 15%), vehicular emission (11 µg/m^3 ~ 13%), biomass burning (11 µg/m^3 ~ 12%), coal combustion and fly ash (8 µg/m^3 ~ 9%) and construction activities (4 µg/m^3 ~ 5%).

$PM_{2.5}$

The average $PM_{2.5}$ concentration was 60 µg/m^3 (i.e., about 0.71 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 MSW burning (15.4 µg/m^3 ~ 25%) followed by soil and road dust (12.2 µg/m^3 ~ 19%). The other major sources are SIA (9.9 µg/m^3 ~ 16%), biomass burning (9.1 µg/m^3 ~ 14%), vehicular emission (8.4 µg/m^3 ~ 13%), coal combustion and fly ash (5.6 µg/m^3 ~ 9%) and construction activities (2.3 µg/m^3 ~ 4%).



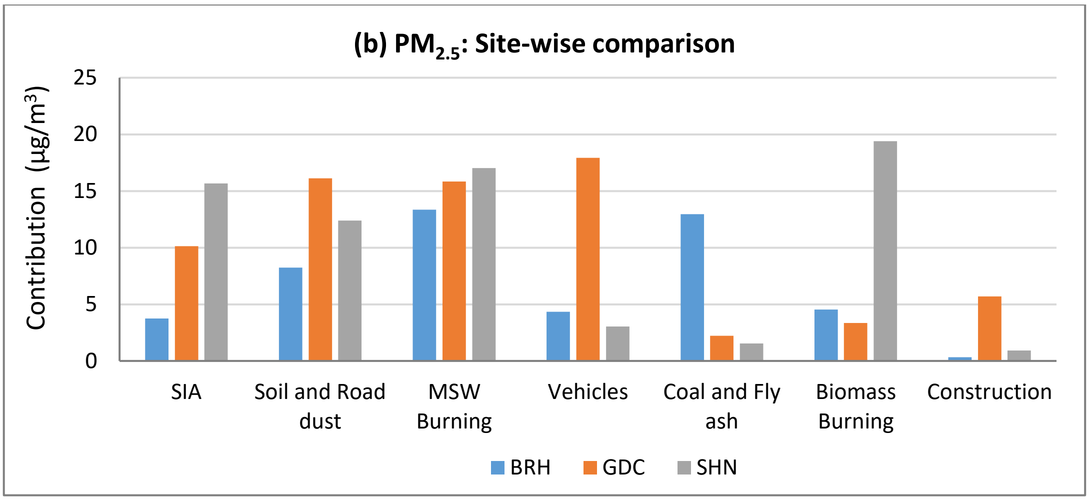
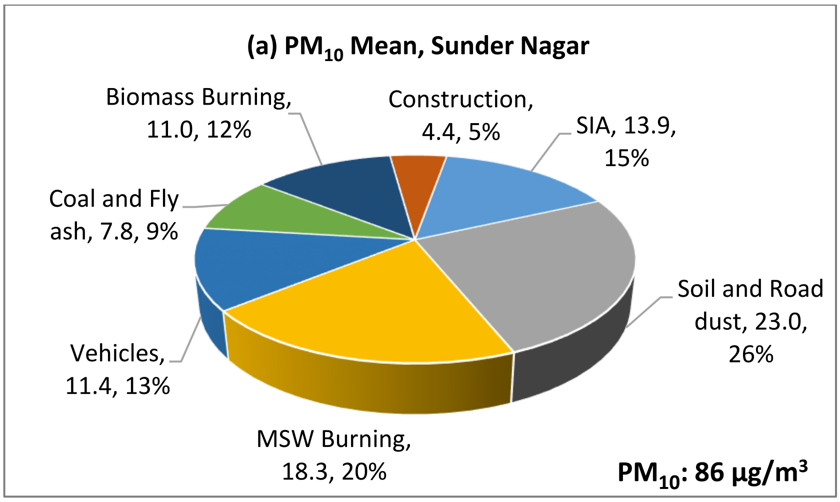


Figure 5.10: source concentration comparison for (a) PM_{10} and (b) $PM_{2.5}$ at all sites



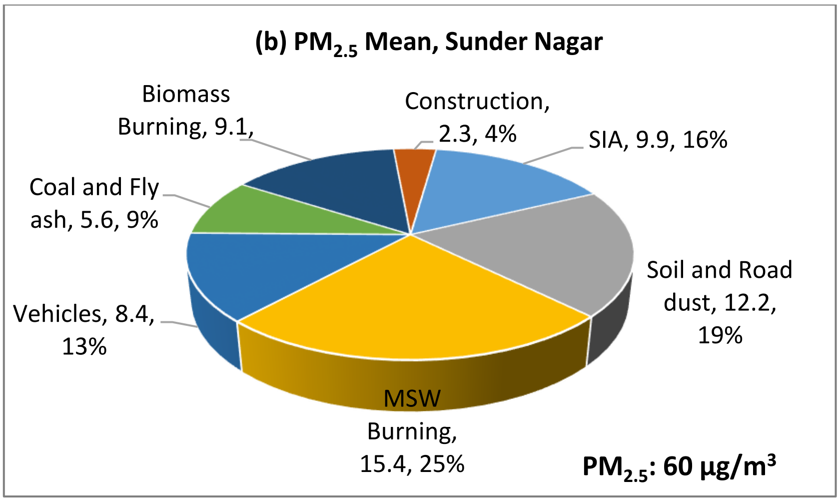


Figure 5.11: PMF modeling for (a) PM_{10} and (b) $PM_{2.5}$

Table 5.1: Summary of source concentration of PM_{10}: Sunder Nagar

Site	Parameter	Measured PM_{10}	Calculated PM_{10}	% Mass	% Source Contribution						
					SIA	Soil and Road dust	MSW Burning	Vehicles	Coal and Fly ash	Biomass Burning	Construction
BRH	Mean	59.38	63.43	107.45	8.19	19.70	25.56	9.18	26.92	9.07	1.37
	SD	12.13	11.11	4.69	9.29	10.86	18.22	4.68	9.27	13.23	2.62
GDC	Mean	91.94	98.23	107.78	10.81	24.79	19.10	24.67	5.04	5.91	9.68
	SD	25.45	25.22	7.18	19.50	18.11	20.94	10.61	4.17	10.09	8.91
SHN	Mean	107.58	108.00	100.45	18.41	29.89	18.50	4.16	2.76	22.90	3.38
	SD	28.76	29.21	3.91	12.19	5.94	12.00	3.52	2.74	8.59	0.72
OVERALL	Mean	86.30	89.89	105.22	15.44	25.63	20.35	12.68	8.70	12.27	4.94
	SD	30.16	29.46	6.21	14.29	12.75	16.89	11.14	12.56	12.74	6.26
	CV	0.35	0.33	0.06	0.93	0.50	0.83	0.88	1.44	1.04	1.27
	MAX	129.40	143.40	117.21	51.73	57.09	63.59	36.75	34.84	38.74	28.93
	MIN	45.37	49.87	95.20	0.00	6.77	0.00	0.91	0.17	0.00	0.00

Table 5.2: Summary of source concentration of $PM_{2.5}$: Sunder Nagar

Site	Parameter	Measured $PM_{2.5}$	Calculated $PM_{2.5}$	% Mass	% Source Contribution						
					SIA	Soil and Road dust	MSW Burning	Vehicles	Coal and Fly ash	Biomass Burning	Construction
BRH	Mean	44.38	47.49	107.85	9.07	15.72	25.80	9.82	28.33	10.62	0.64
	SD	9.81	9.94	12.93	10.34	12.37	20.73	5.24	7.71	9.81	0.63
GDC	Mean	69.23	71.23	103.71	13.31	23.62	20.39	25.20	3.02	5.40	9.06
	SD	15.09	13.82	8.14	15.10	21.88	26.78	13.35	2.77	6.69	9.84
SHN	Mean	66.23	70.01	107.04	20.08	18.77	24.26	4.83	2.81	28.14	1.11
	SD	17.87	16.03	7.19	13.37	9.49	14.53	5.93	4.28	14.85	1.47
OVERALL	Mean	59.95	62.91	106.20	15.66	19.47	24.48	13.40	8.86	14.45	3.67
	SD	17.94	17.01	9.43	13.26	15.09	20.32	12.30	13.28	14.41	6.74
	CV	0.30	0.27	0.09	0.85	0.77	0.83	0.92	1.50	1.00	1.84
	MAX	84.67	89.89	126.53	42.09	63.42	77.63	44.85	37.96	49.89	29.57
	MIN	31.74	33.44	85.66	0.00	0.00	0.00	0.00	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 soil and road dust (26 – 19%), MSW burning (20 – 24%), SIA (15 – 16%), vehicles (13 – 13%), biomass burning (12 – 14%), coal combustion and flyash (9 – 9%) and construction activities (5 – 4%).
- The consistent sources for PM_{10} and $PM_{2.5}$ are soil and road dust and MSW burning. 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 coal combustion and fly ash.
- Soil and road dust is the most significant contributor in PM_{10} (26%) and reduced significantly in $PM_{2.5}$ (19%), showing high variability, which infers that the road condition in the town is not up to the mark. It indicates that most parts of roads and kerb-sides were poorly maintained.
- From the uncollected solid waste (plastic waste, packaging material, etc.) the major part is burned. It is seen that MSW burning is a major source that contributes to both PM_{10} (20%) and $PM_{2.5}$ (24%). 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. The dumping and burning of MSW and plastic waste along the roadsides may be a routine practice.
- Vehicles' contribution is significant and consistent at 13% in PM_{10} and $PM_{2.5}$ in the town.
- BRH site was in the commercial area and near the industrial area having major commercial activities and polluting industries in nearby region. Therefore, it has the movement of large trucks ferrying raw material and finished products. Vehicular contribution and soil and road dust is highest at BRH.

- Coal and flyash contribute 15% in PM_{10} and 11% 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.
- The contribution of biomass burning is also significant among all sources at 12% (for PM_{10}) and 14% (for $PM_{2.5}$). Sizeable biomass is consistent in PM, indicating local sources present in Sunder Nagar and nearby areas. Biomass burning is because of arboriculture activities, agricultural residue burning, high energy crop burning for fuel, etc.
- Industrial contribution in the town is negligible in PM_{10} and $PM_{2.5}$. This contribution may be partially merged in coal combustion, biomass and MSW burning. Most of the industrial emissions are from combustion and process emissions.

Directions for PM control

- Industrial and combustion sources

  The industrial units in the Sunder Nagar and nearby region (i.e., Naulakha) must comply with the norms notified by the HPSPCB. There might be some unauthorized industries in the industrial area that must be closed. The polluting industries must shift to bag filters (or equivalent control devices) and in the next two years and wood and coal must be phased out from all industries.

- Construction, Soil and road dust

  These sources contribute about 31% to PM_{10}. The silt load on some of the road is very high and silt can become airborne with the movement of vehicles, especially on turning points/curvatures. The estimated PM_{10} emission from road dust is over 1.4 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.

- 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 fly ash) contributes about 9% of PM_{10} and unless sources contributing to fly ash are controlled, one cannot expect improvement in air quality. It appears these sources are more of fugitive in nature than regular point sources. Fly ash emission from hotels, restaurants, dhabas and tandoors also cause large emissions and requires better housekeeping and fly ash disposal.

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 Sunder Nagar

The city of Sunder Nagar 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 soil and road dust (26 – 19%), MSW burning (20 – 24%), SIA (15 – 16%), vehicles (13 – 13%), biomass burning (12 – 14%), coal combustion and fly ash (9 – 9%) and construction activities (5 – 4%).

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/town

6.2.1 Hotels/Restaurants/Banquet Halls

The Hotels, Restaurants, Guest Houses (GHs), and Banquet Halls (BHs) is found to be approximately 41, mainly situated in the central part of the city and along with the National Highway-154. 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 Sunder Nagar City.

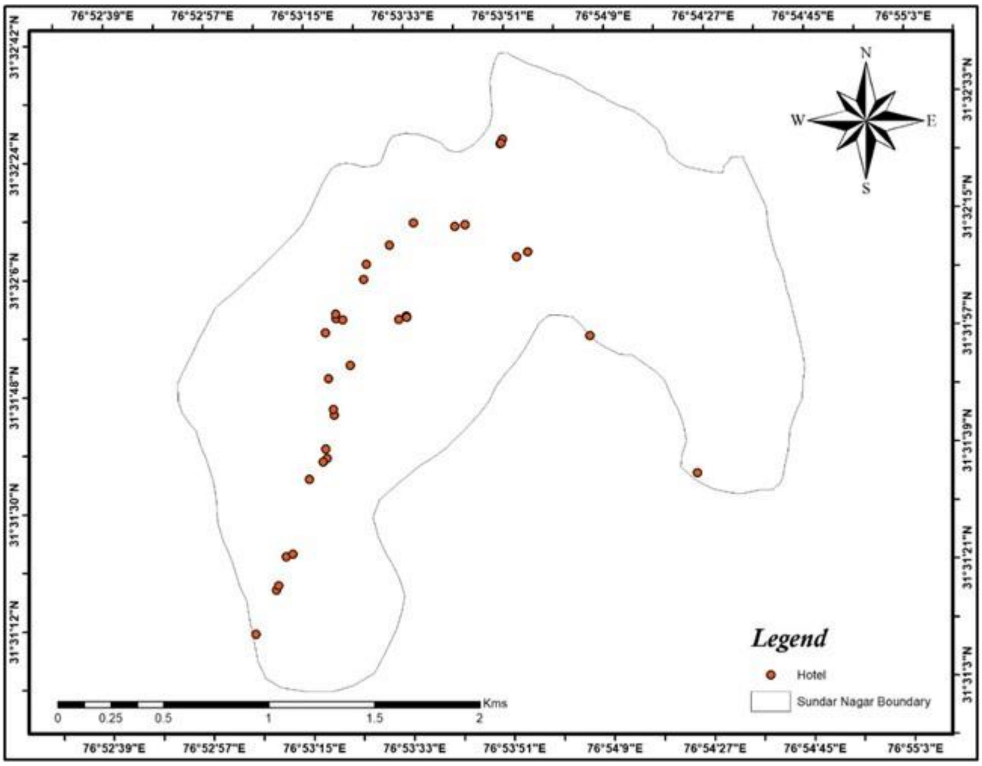


Figure 6.1: Location of Hotels, Restaurants, GHs and BHs in Sunder Nagar City

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 Sunder Nagar 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 Sunder Nagar, Department of Food, Civil Supplies and Consumer Affairs, and oil companies (Indian Oil, HP, etc.). A 70% reduction of PM_{10} (25 kg/d) and $PM_{2.5}$ (14 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 Sunder Nagar (Figure 6.2). In winter, the overall source contribution from MSW burning is 20% in PM_{10} and 24% 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 Sunder Nagar 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 Sunder Nagar

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 Naresh chowk, Old Market and Bhojpur Bazar.

Desilting and cleaning of municipal drains by Municipal Council Sunder Nagar 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 Sunder Nagar, ‘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 Sunder Nagar should prioritize the MSW collection mechanism starting systematically in each ward/section 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 by district administration for Sunder Nagar and nearby region. 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 Sunder Nagar, HPSPCB, NGOs and municipal corporators.

The banning of MSW waste burning can reduce the emissions by 100% of PM_{10} (35 kg/d) and $PM_{2.5}$ (24 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 Construction and Demolition

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

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

- Wet suppression
- wind speed reduction (for large construction sites)
- Waste should be properly disposed of and not stored on the premises or 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 Development Authority, Himachal Pradesh Housing Board, Municipal Council Sunder Nagar, Urban Development Department, PWD, and HPSPCB.

The suggested control measures will reduce the emission by 50% in PM_{10} (74 kg/day) and 72% in $PM_{2.5}$ (24 kg/day). This will also reduce the road dust and fly ash contribution to ambient air concentration.

6.2.4 Domestic sector

The projected population of Sunder Nagar for the year 2020 is approximately 33000 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%) at Sunder Nagar.

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.

This action is expected to reduce 82% of PM_{10} (27 kg/day) and 81% of $PM_{2.5}$ (20 kg/d) emissions from domestic sector.

6.2.5 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 4 to 5 g/m^2 which is slightly high (typical load in developed countries is less than 1 g/m^2). The NH-154 passes through the Sunder Nagar and goes to Kullu and Manali via Mandi that create massive traffic load on NH-154. 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 40% 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 with association with sub-district administration 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}= 572 kg/day and $PM_{2.5}$= 131 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 (NH-154, Bhojpur road, Naresh Chowk, Zero Chowk and Old Market Road) should be carried out at least two 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 Development Authority, Himachal Pradesh Housing Board, Municipal Council Sunder Nagar, 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 Sunder Nagar (Figure 6.3).

❑ Construction of Foot Paths

❑ End to End Development of Roads

Figure 6.3: Quality of dust-free Roads, footpaths and dividers with dust control (Courtesy Greater Hyderabad Municipal Corporation)

6.2.6 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 GDC site have very large vehicle contributions (25% in $PM_{2.5}$ and PM_{10}; Figure 5.11, Chapter 5) with an overall contribution of vehicles in the city is 13% in $PM_{2.5}$ and PM_{10} in winter months. Out of about 320 kg/day 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 town 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 Sunder Nagar are two *(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 Sunder Nagar 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 Sunder Nagar and other destinations) to quickly move towards electric buses.

9. Route rationalization: Improvement of availability by rationalizing routes and fleet enhancement with requisite modifications. Ensure integration of the existing metro system with bus service.
10. 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.
11. 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.
12. There is a need to improve the intersections of roads at many places in Sunder Nagar. Steps shall be taken to install traffic signals on all the major intersections and traffic police shall enforce smooth traffic.
13. 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

A chaotic and poorly managed traffic is normal on Naresh Chowk and Bhojpur 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 NH-154, Naresh Chowk and Zero Chowk road require specific attention including installation of DPF.

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

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

- Heavy encroachment by shopkeepers and street vendors is observed in the commercial area and residential areas, and vehicles are parked on the road. The parked vehicles take up to 40% of the road width, although one-third of the roads are more than 30 m wide. This reduces road utilization by about 50%.
- The unauthorized vehicle service centres located near the road make things worse as the vehicle is parked on-road while servicing and repairing and oil and grease spillage can be seen, some of the areas where these unorganized shops can be seen are service road near Naresh Chowk.
- Heavy-duty vehicles and buses which are destined for other cities pass through major roads within Sunder Nagar city and create heavy congestion. The important points of congestions are Circular and Bhojpur road which meet to NH-154. The city main roads are circular road, BBMB colony road and NH-154 results this having mostly traffic; As a result, this routes within the city will also be congested.
- Areas that are adjacent to the market centers like Naresh chowk, Old Market and Bhojpur Bazar experience traffic congestion due to the unregulated parking and encroachment by local shop owners. The on-street parking has to be removed and if required designated parking is developed.

During the traffic recording and survey done by IIT Kanpur, the following major intersections are identified as traffic bottlenecks (Table 6.1 and Figure 6.4).

Table 6.1: Major Traffic Bottleneck in Sunder Nagar

Sunder Nagar Bus Stop	Bhojpur Road (NH)	Naresh Chowk

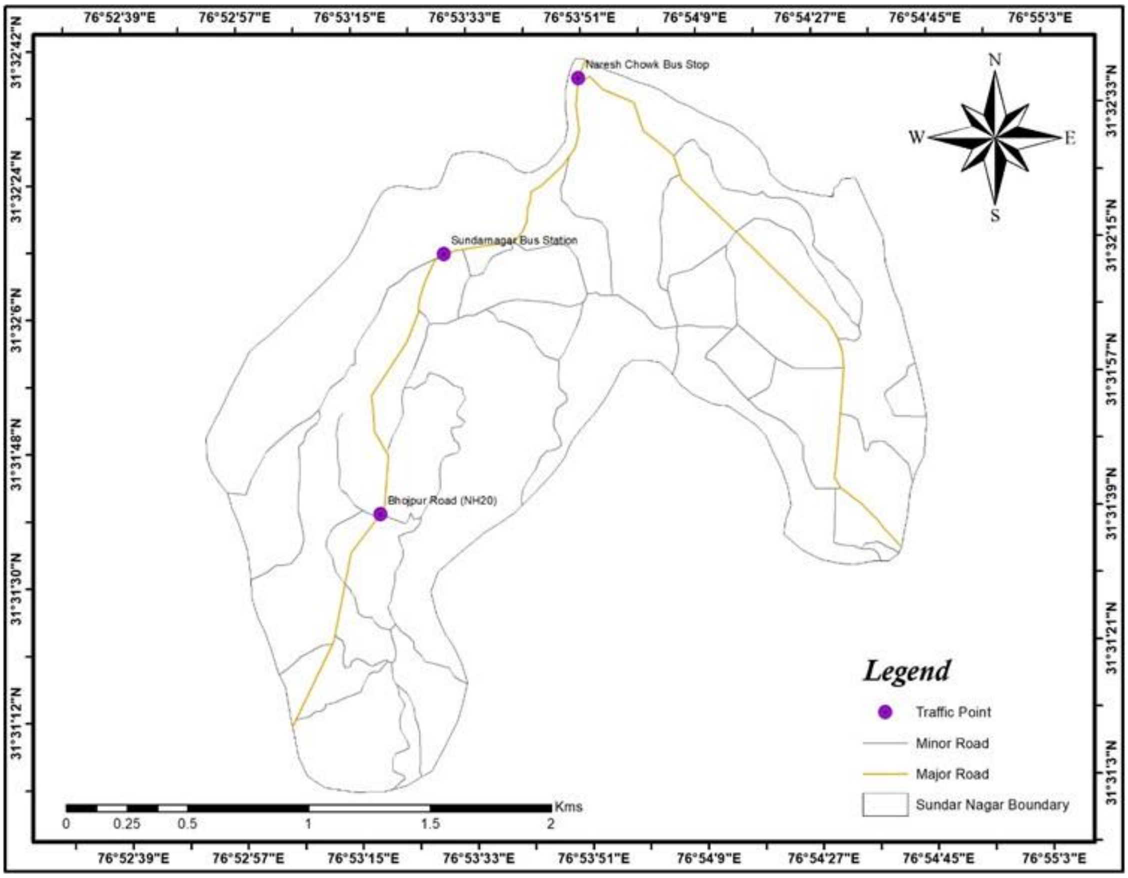


Figure 6.4: Location of traffic bottlenecks

Parking spaces

There must be no parking zone (up to 50 m including auto, electric and hand-pulled rickshaw) near the intersections (Figure 6.5) 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.

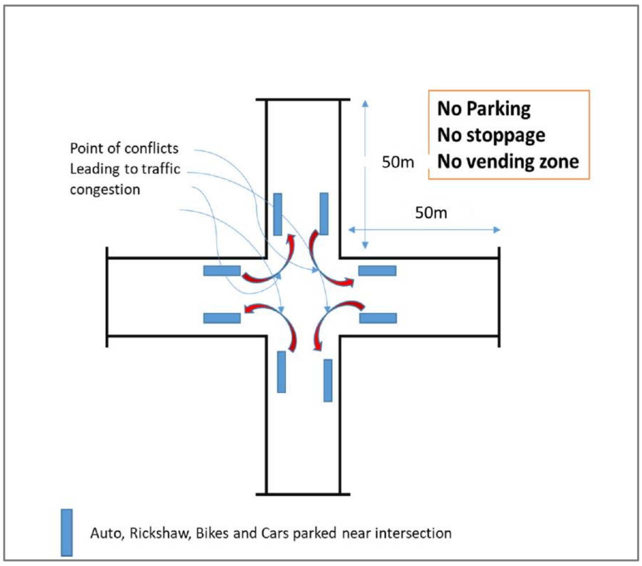


Figure 6.5: Conflicts due to on-street parking near intersections

Parking prices

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

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

Promoting Public Transport Travel

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

6.2.7 Industries

Besides PM pollution (discussed later), ambient air samples collected in the industrial area during the winter months show high levels of PM_{10} and $PM_{2.5}$; these levels are not acceptable. There are almost 3 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. There are 4 stone crusher units that are present in Sunder Nagar contributing to particulate matter emissions.

It is also observed that the majority of industries use coal, LDO 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., Development Authority) 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 Sunder Nagar. It is recommended that no industrial waste should be mixed with MSW rather disposed of at TSDF for hazardous waste disposal.

It is seen that waste is burnt in industrial areas Naulakha (oil, grease, and paint, packaging material) is dumped and burned on the roads in the areas like Service Road and NH-154 where the trucks are being repaired. Industrial waste burning must be stopped under the supervision of HPSPCB. It is also seen that solid waste (all types) is dumped and stored just outside the premises of the industry; this is not acceptable and it looks unpleasant and at times spills over the road. It is recommended that all the hazardous waste should send to an industrial non-hazardous TSDF for industrial waste. They should not be allowed to dispose of the waste on roads or in front of the industry. Strict compliance and surveillance are required that hazardous waste goes to TSDF under the supervision of Municipal Council Sunder Nagar 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 Sunder Nagar, 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 Sunder Nagar (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 Sunder Nagar	1 year
	Link Commercial license to clean fuel	Municipal Council Sunder Nagar, 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 Sunder Nagar	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	Any type of garbage burning should be strictly stopped. Current waste collection and surveillance are poor.	Municipal Council Sunder Nagar	Immediate
	Surveillance is required that hazardous waste goes to TSDF.	Municipal Council Sunder Nagar, HPSPCB, Development Authority	
	Desilting and cleaning of municipal drains	Municipal Council Sunder Nagar	
	Waste burning in Industrial areas should be stopped.	HPSIDC, HPSPCB	
	Daily, Monthly mass balance of MSW generation and disposal	Municipal Council Sunder Nagar	
	Sensitize people and media through workshops and literature distribution so as not to burn the waste.	Municipal Council Sunder Nagar, HPSPCB, and NGO	
Construction and Demolition	Wet suppression	Development Authority, Municipal Council Sunder Nagar, Urban Development Department, PWD	Immediate
	Wind speed reduction (for large construction sites)	Development Authority, Municipal Council Sunder Nagar, Urban Development Department, PWD	
	Enforcement of C&D Waste Management Rules. The	Development Authority, Municipal Council	Immediate

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
	waste should be sent to a construction and demolition processing facility	Sunder Nagar, Urban Development Department, PWD	
	Proper handling and storage of raw material: covered the storage and provide the windbreakers.	Development Authority, Municipal Council Sunder Nagar, Urban Development Department, PWD	
	Vehicle cleaning and specific fixed wheel washing on leaving the site and damping down of haul routes.	Development Authority, Municipal Council Sunder Nagar, Urban Development Department, PWD	
	The actual construction area should be covered by a fine screen.	Development Authority, Municipal Council Sunder Nagar, 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)	Development Authority, Municipal Council Sunder Nagar, Urban Development Department, PWD	
	Builders should leave 25% area for green belt in residential colonies to be made mandatory.	Development Authority, Municipal Council Sunder Nagar, Urban Development Department, PWD	
	Sensitize construction workers and contract agencies through workshops.	Development Authority, Municipal Council Sunder Nagar, Urban Development	

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
		Department, PWD, HPSPCB, and NGO	
Road Dust	The silt load in Sunder Nagar varies from 4 to 5 g/m^2. The silt load on each road should be reduced to under 3 gm/m^2. Regular vacuum sweeping should be done on the road having a silt load above 3 $gm/m^{2.}$	Development Authority, Municipal Council Sunder Nagar, National Highway Authority, PWD, HPSPCB (for silt load compliance)	Immediate
	Convert unpaved roads to paved roads. Maintain pothole-free roads.	Development Authority, Municipal Council Sunder Nagar, 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.	Development Authority, Municipal Council Sunder Nagar, National Highway Authority, PWD	
	Increase green cover and plantation. Undertake the green of open areas, community places, schools, and housing societies.	Development Authority, Municipal Council Sunder Nagar, National Highway Authority, State Forest Department, PWD	
	vacuum-assisted sweeping is carried out four times a month on major roads with road washing.	Development Authority, Municipal Council Sunder Nagar, National Highway Authority, PWD	
Vehicles	Diesel vehicles entering the city should be equipped with DPF which will bring a reduction of 40% in	State Transportation Department	3 years

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
	emissions (This option can be implemented with vehicles of the BS-IV category as well)		
	Industries must be encouraged to use BS-VI or BS-IV (with DPF) vehicles for the transportation of raw and finished products	Industrial Associations and State transport Department	Immediate
	Restriction on plying and phasing out of 10 years old commercial diesel-driven vehicles.	Transport Department	2 years
	Introduction of cleaner fuels (CNG/ LPG) for all vehicles (other than 2-W).	Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian Oil/HP, etc.)	2 years
	Check to overload: Expedited installation of weigh-in-motion bridges and machines at all entry points to Sunder Nagar.	Transport Department, Traffic Police, Sunder Nagar, 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, RTO Sunder Nagar	1 year
	Bus stop and their parking should be rationalized to ensure more efficient utilization. The depots should	Transport Department, RTO Sunder Nagar	1year

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
	include well-equipped maintenance workshops. Adequate charging stations.		
	Enforcement of bus lanes and keeping them free from obstruction and encroachment.	Municipal Council Sunder Nagar, RTO Sunder Nagar	1 year
	Route rationalization: Improvement of availability by rationalizing routes and fleet enhancement with requisite modification.	Development Authority, RTO Sunder Nagar, Traffic Police, Sunder Nagar	1 year
	IT systems in buses, bus stops, control centers, and passenger information systems for the reliability of bus services and monitoring.	Development Authority, RTO Sunder Nagar, Traffic Police, Sunder Nagar	1 year
	Movement of materials (raw and product) within the city should be allowed between 10 PM to 5 AM.	Transport Department, Sunder Nagar, Development Authority, RTO Sunder Nagar, Traffic Police, Sunder Nagar	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, Development Authority, HPSIDC, Industries Department,	2 years

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
		HPSPCB	
	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		Immediate
	Area and road in front of the industry should be the responsibility of the industry		
	Category A Industries (using coal and other dirty fuels)		
	About 3 boilers and hot mix plant in Sunder Nagar are running over wood and LDO 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

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
	Diesel Generator Sets		
	Strengthening of grid power supply, uninterrupted power supply to the industries.	State Energy Department, HPSEBL	2 years
	Renewable energy should be used to cater to the need of office requirements in the absence of power failure to stop the use of DG Set.	Industrial Associations	2 years
Decongestion of Roads in high traffic areas	Strict action on roadside encroachment. Disciplined movement of tempos to stop only at designated spots. Action on driving in the wrong lane.	Development Authority, Municipal Council Sunder Nagar, RTO Sunder Nagar, Traffic Police, Sunder Nagar	6 months
	Disciplined Public transport (designate one lane stop).	RTO Sunder Nagar., Traffic Police, Sunder Nagar	
	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.	Development Authority, Municipal Council Sunder Nagar, RTO Sunder Nagar, Traffic Police, Sunder Nagar	
	Examine the existing framework for removing broken vehicles from roads and create a system for speedy removal and ensure minimal disruption to traffic.	Development Authority, RTO Sunder Nagar, NHAI, Traffic Police, Sunder Nagar	
	Synchronize traffic movements or introduce intelligent traffic systems for lane-driving.	Development Authority, RTO Sunder Nagar, NHAI, Traffic Police, Sunder Nagar	

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
	Mechanized multi-story parking at bus stands, and big commercial areas. Remove at least 50 percent of on-street parking in the city.	Development Authority, RTO Sunder Nagar, Municipal Council Sunder Nagar, NHAI, Traffic Police, Sunder Nagar	
	Identify traffic bottleneck intersections and develop a smooth traffic plan. For example, NH-154, Bhojpur Road, Naresh Chowk, Zero Chowk and Old Market Road. Naresh Chowk are the main bottlenecks for traffic.	Development Authority, RTO Sunder Nagar, Municipal Council Sunder Nagar, Traffic Police, Sunder Nagar	
	Parking policy in congestion areas (high parking cost, at city centers, only parking is limited for physically challenged people, etc).	Development Authority, RTO Sunder Nagar, Municipal Council Sunder Nagar, NHAI, Traffic Police, Sunder Nagar	
	The important point of congestion is Naresh Chowk and Bhojpur road; Parking on Main market should be strictly prohibited.	RTO Sunder Nagar, Traffic Police	2 years
*The above steps should not only be implemented in Sunder Nagar boundary limits rather these should be extended up to at least 10 km beyond the boundary. This will need support from the state government and adjacent city administration.			

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Annexure 1

(a) 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).

(b) Field survey, data collection information, frequency of data collection in various sectors, time period during physical verification

S.No	Sources	Survey Period (2020)	Remark
1	Domestic	September 2 to December 15	Information collected vis physical survey with local household and activity data collected and correlated with available literature and government data.
2	MSW Burning	September 2 to December 15	Physical verification of MSW burning sites, geotagged and activity data collected
3	Hotels, Restaurants, GHs & BHs	October 10 to December 15	Physical verification of hotels, geotagged and activity data collected
4	Construction & Demolition	September 20 to October 15	Physical verification of Construction sites, geotagged and activity data collected and for entire year satellite imagery was used.
5	Industrial DG Sets	November 25 to December 10	Physical visit to sites, geotagged and corelated with PCB data.
6	Hospitals	December 1 to December 3	Physical visit to sites and geotagged.
7	Industries	December 1 to December 15	Physical visit to sites, geotagged and corelated with PCB Data.
8	Vehicle	October 3 to October 20	Video Recorded at 3 locations, parking lane survey and vehicle flow pattern
9	Road Dust	October 21 to October 24	Road dust sampling at 3 locations.
10	Agriculture	December 1-7 and January 1 to January 30, 2021	Landuse pattern and data collected from agriculture department
11	Livestock	December 1-7 and January 1 to January 30, 2021	Data collected from Department.

Annexure 2

Gridded Emissions for Sunder Nagar are represented below.

GRID	PM_{10}	$PM_{2.5}$	SO_2	NO_X	CO
S1	72.59	22.97	1.87	59.45	54.03
S2	0.77	0.51	0.10	0.27	3.48
S3	0.12	0.08	0.02	0.04	0.57
S4	0.00	0.00	0.00	0.00	0.00
S5	0.00	0.00	0.00	0.00	0.00
S6	0.00	0.00	0.00	0.00	0.00
S7	21.82	7.17	1.07	17.31	18.47
S8	128.15	41.00	2.67	109.92	101.10
S9	0.07	0.05	0.01	0.03	0.32
S10	0.00	0.00	0.00	0.00	0.00
S11	0.00	0.00	0.00	0.00	0.01
S12	0.06	0.04	0.01	0.02	0.28
S13	39.55	16.10	0.35	74.86	81.33
S14	180.89	58.21	5.70	143.41	145.43
S15	1.91	1.26	1.50	4.48	7.50
S16	0.00	0.00	0.00	0.00	0.01
S17	25.06	11.79	1.52	52.34	70.73
S18	78.42	32.57	1.44	145.08	167.32
S19	19.98	8.08	0.81	37.94	40.63
S20	235.61	82.06	6.95	273.51	260.89
S21	23.15	11.50	3.15	45.94	66.69
S22	33.00	15.54	1.56	76.45	94.12
S23	142.04	66.13	2.34	317.38	404.50
S24	53.73	31.61	4.57	89.23	319.20
S25	0.01	0.00	0.00	0.00	0.00
S26	112.13	41.63	1.40	152.09	176.18
S27	262.05	93.13	4.67	321.71	355.87
S28	102.18	33.50	1.76	85.25	116.32
S29	148.23	60.78	1.16	213.35	324.44
S30	5.36	2.22	0.77	2.74	10.69

GRID	PM_{10}	$PM_{2.5}$	SO_2	NO_X	CO
S31	0.00	0.00	0.00	0.00	0.00
S32	0.00	0.00	0.00	0.00	0.00
S33	66.15	21.43	0.60	59.59	64.73
S34	208.25	76.84	1.81	256.25	324.60
S35	1.71	1.17	0.23	0.63	8.02
S36	0.00	0.00	0.00	0.00	0.00
S37	0.00	0.00	0.00	0.00	0.00
S38	0.00	0.00	0.00	0.00	0.00
S39	0.00	0.00	0.00	0.00	0.00
S40	10.10	3.27	0.56	9.27	9.70
S41	0.00	0.00	0.00	0.00	0.00
S42	0.00	0.00	0.00	0.00	0.00