

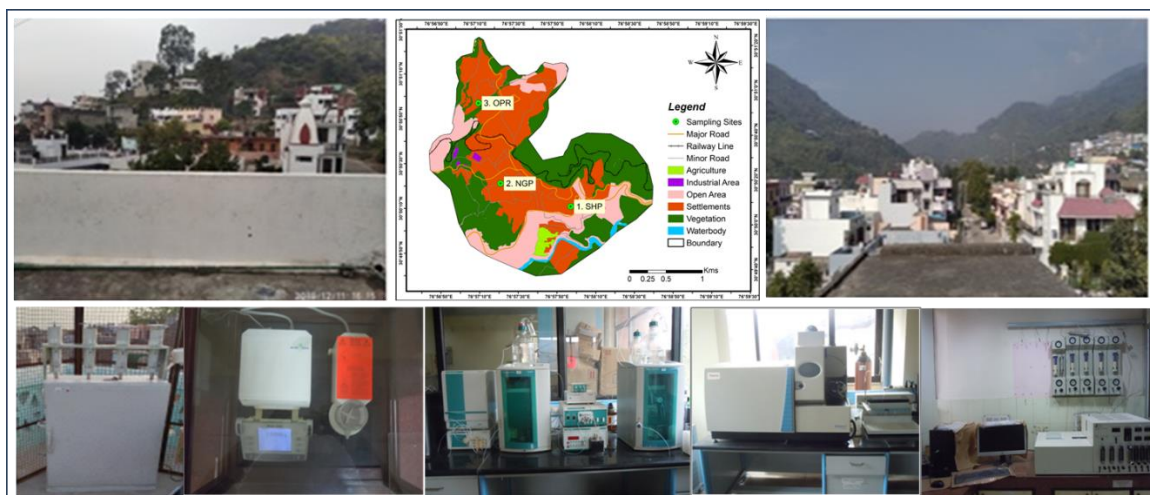
**Source Apportionment-based Action Plans for Restoring Air Quality
in Non- Attainment Cities in the State of Himachal Pradesh in
respect of PM₁₀, PM_{2.5} and other Notified Pollutants**

City: Parwanoo

(Final Report)

Submitted to

Himachal Pradesh State Pollution Control Board, Shimla



Mukesh Sharma; PhD, FNAE

Department of Civil Engineering

Centre for Environmental Science and Engineering

Indian Institute of Technology Kanpur

Kanpur 208016

June 2023

Copyright © IIT Kanpur and Himachal Pradesh State Pollution Control Board, Shimla (2023).

All rights reserved.

Disclaimer

This document is intended as the official report by Indian Institute of Technology (IIT), Kanpur on ‘Source Apportion-based Action Plans for Restoring Air Quality in Non- Attainment Cities in the State of Himachal Pradesh in respect of PM₁₀, PM_{2.5} and other Notified Pollutants (City: Parwanoo)’ submitted to the HP State Pollution Control Board, Shimla. While every effort has been made to ensure the correctness of data/information used in this report, IIT Kanpur does not accept any legal liability for the accuracy or inferences drawn from the material contained therein or for any consequences arising from the use of this material. No part of this report may be reproduced in any form (electronic or mechanical) without prior permission from or intimation to the authors. No part of this report can be used for any scientific publications in any journal, conferences, seminars, workshops, etc., without written permission from the authors.

The full Report should be referenced as follows:

IIT Kanpur and HPSPCB (2023) “Source Apportion-based Action Plans for Restoring Air Quality in Non- Attainment Cities in the State of Himachal Pradesh in respect of PM₁₀, PM_{2.5} and other Notified Pollutants (City: Parwanoo)”

Text from this Report can be quoted provided the source is acknowledged.

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

- Identify and inventorize emission sources (industry, traffic, power plants, local power generation, small-scale industries, etc.) in Parwanoo.
- 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. PM₁₀, PM_{2.5}, SO₂, NO₂, VOCs (volatile organic compounds), OC (organic carbon), EC (elemental carbon), Ions, Elements, PAHs (polyaromatic hydrocarbons), molecular markers, CO and ozone were considered for sampling and measurements. The air quality sampling was conducted during the winter season (December 14 – 23, 2019).

Table 1: Description of sampling sites in Parwanoo

S. No.	Sampling Site	Site Code	Description of the site	Type of sources
1.	Shivalik Polymers Sec 3	SHP	Industrial	Industries, DG sets, vehicles, road dust, garbage/industrial waste burning, coal
2.	Nagar Parishad Sec 1	NGP	Commercial (adjoining industrial area)	DG sets, vehicles, road dust, garbage/waste burning, hotels, restaurants, coal uses
3.	HPPCB Office Sec 4	OPR	Residential	Domestic cooking, vehicles, road dust, garbage/MSW burning, biomass

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

- The mean PM₁₀ levels were 107 – 182 µg/m³ and the mean PM_{2.5} levels were 72 – 100 µg/m³.
- Particulate pollution is the main concern in the city, where PM₁₀ levels are 1.1 – 1.8 times higher than the national air quality standards and PM_{2.5} levels are 1.2 – 1.7 times higher than the national standard in the winter months. It is observed that the air quality in terms of PM₁₀ and PM_{2.5} falls in the poor to very poor category of air quality index (AQI).
- The chemical composition of PM₁₀ and PM_{2.5} carries the signature of sources and their harmful contents. The chemical composition is variable in different size ranges indicating contribution of different types of sources.

PM₁₀

The overall average concentration of PM₁₀ is 135±33 µg/m³ against the acceptable level of 100 µg/m³ (24-hour average). The highest levels were observed at NGP and the lowest at SHP.

The important components are the secondary particles (NO₃⁻ + SO₄²⁻ + NH₄⁺), which account for about 28% of total PM₁₀, and combustion-related total carbon (TC = EC + OC) accounts for about 26%; both fractions of secondary particles and combustion-related carbons account for 56% of PM₁₀ in winter months.

The crustal component (Si + Al + Fe + Ca) accounts for about four percent in PM₁₀. This suggests soil and road dust have less significant contributions. The coefficient of variation (CV) is about 0.03 (of the fraction of crustal component), which suggests the crustal source contributes consistently in the winter months.

The Cl⁻ content in PM₁₀ is consistent and varies between 7 – 10%, which is an indicator of the burning of municipal and plastic solid waste (MSW); recall polyvinyl chloride (PVC) is a major part of MSW. The highest Cl⁻ content is observed at NGP at 17 µg/m³ compared to the overall city level of 12 µg/m³. The high level at NGP signifies some local burning of waste as a means of disposal of solid waste.

PM_{2.5}

The overall average concentration of PM_{2.5} in winter is 88±12 µg/m³ against the acceptable level of 60 µg/m³ (24-hour average). The highest levels are observed at NGP and the lowest at SHP.

The important components are the secondary particles (NO₃⁻ + SO₄²⁻ + NH₄⁺), which account for about 28% of total PM_{2.5} and combustion-related total carbon (TC = EC + OC) accounts for about 29%; both fractions of secondary particles and combustion-related carbons account for 57% of PM_{2.5} in winter months. The highest levels of secondary particles were observed at OPR (32%) and TC at NGP (35%).

The Cl⁻ content in PM_{2.5} is consistent and varies between 7 – 11%, which is an indicator of the burning of MSW and plastic waste.

Gaseous pollutant levels

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

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

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

General inferences

It is to be noted that OC3/TC ratio is about 0.24 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 Parwanoo.

Total PAH levels (17 compounds; particulate phase) had high variability in the range of 4 to 10 and B(a)P at 0.34 ng/m³ (annual standard is one ng/m³); the comparison with the annual standard is not advisable due to different averaging times. The highest PAH levels were observed at NGP.

The concentrations of molecular markers in PM_{2.5} (a total of 6 compounds) vary in the range of 53 to 65 ng/m³, indicating the presence of common sources of emissions from coal, gasoline and domestic fuel.

In a broad sense, the air is toxic in the winter months as it contains a much larger contribution of fine particulates emitted from combustion sources. Combustion sources (vehicles, coal, and MSW burning) are consistent and require a strategy to control these sources.

Trend analysis

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

There is no specific trend in PM₁₀ and NO_x in Parwanoo as few months show a decreasing trend and most of months indicate no trend. The annual levels of PM₁₀ and NO_x show no trend at Station-I and decreasing trend at Station-II.

Emission Inventory

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

The total PM₁₀ emission load in the city is estimated to be 3987 kg/day. The top three contributors to PM₁₀ emissions are Road Dust (78%), Vehicles (14%), and Industries (7%); these are based on annual emissions. Seasonal and daily emissions could be highly variable. The estimated emission suggests that there are many important sources and a composite emission abatement including most of the sources will be required to obtain the desired air quality.

PM_{2.5} emission load in the city is estimated to be 1482 kg/day. The top three contributors to PM_{2.5} emissions are Road Dust (48%), Vehicles (33%), and Industries (16%); these are based on annual emissions. Seasonal and daily emissions could be highly variable.

SO₂ emission load in the city is estimated to be 1335 kg/day. Major sources that contribute to SO₂ emissions are Industries (97%), and Hotels, restaurants, GHs & BHs (2%).

NO_x emissions load in the city is estimated to be 4277 kg/day. The majority of total emissions are attributed to Vehicular (91%), and Industries (9%). Vehicular emissions that occur at ground level, probably making it the most important emission. NO_x apart from being a pollutant itself is an important component in the formation of secondary particles (nitrates)

and ozone. NOx from vehicles and industry are potential sources for controlling NOx emissions.

The estimated CO emission is about 5313 kg/day. The major contributors to CO emissions are Vehicles (77%), Industries (20%), and MSW burning (1%). Vehicles and Industries could be the main target for controlling CO for improving air quality with respect to CO.

The estimated emissions are for benzene: 1673 g/d, Pb: 598 g/d, As: 9 g/d, Ni: 150 g/d and BaP: 10 g/d from all sources.

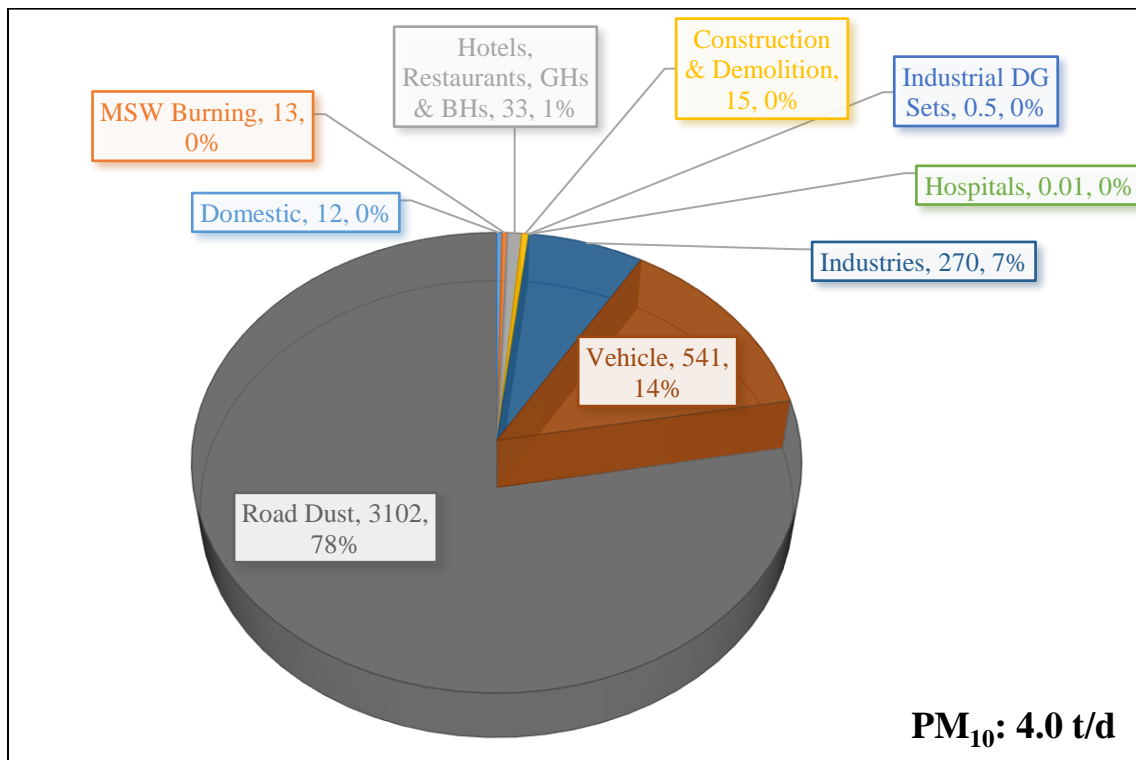


Figure 1: PM₁₀ emission Inventory of different sources in Parwanoo (kg/d)

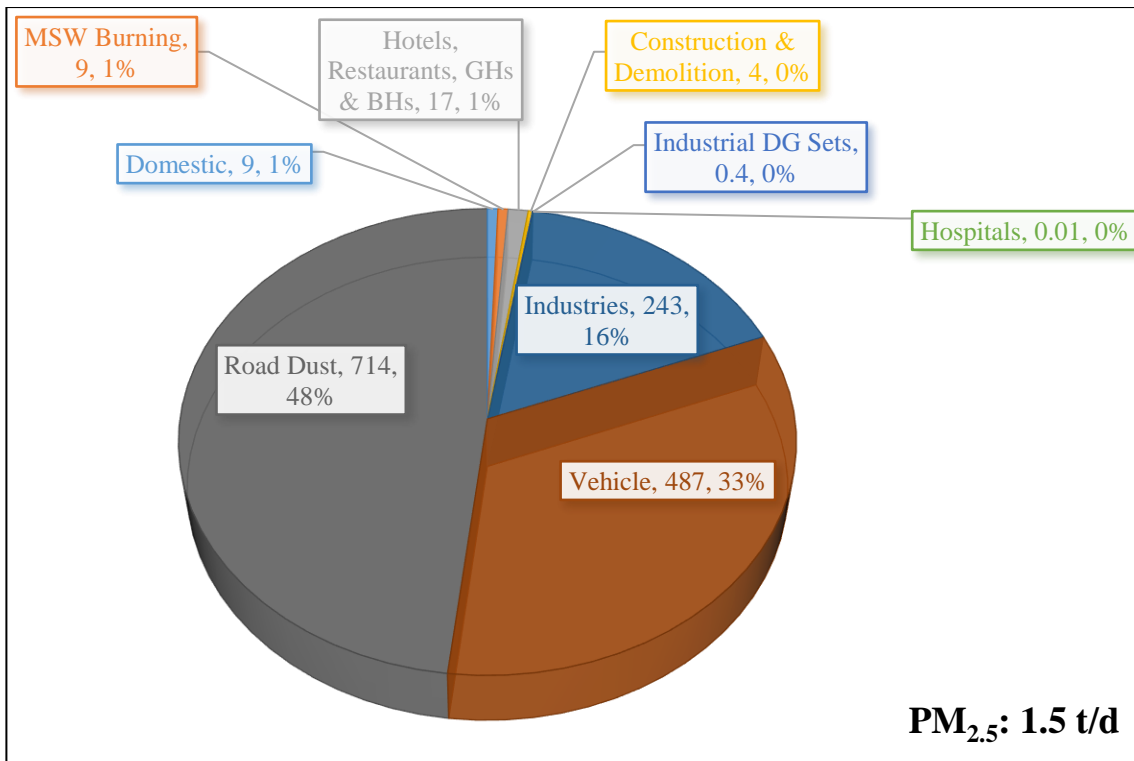


Figure 2: PM_{2.5} emission load of different sources in Parwanoo (kg/d)

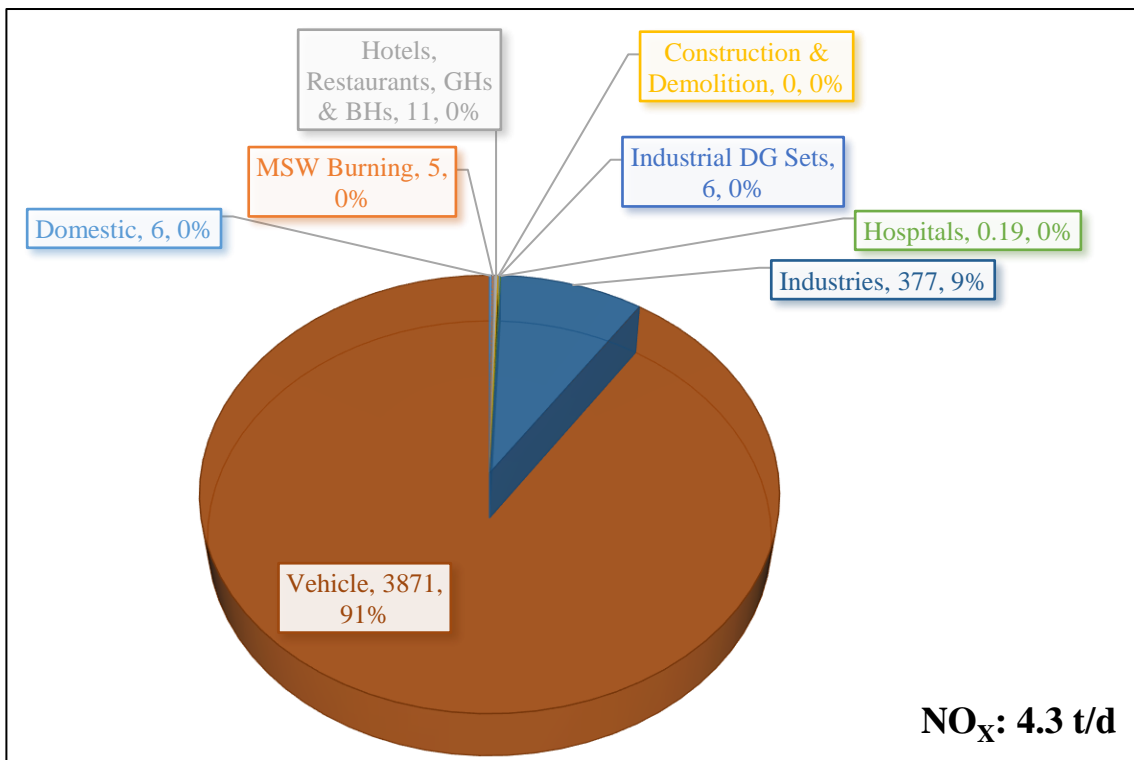


Figure 3: NO_x emission load of different sources in Parwanoo (Kg/d)

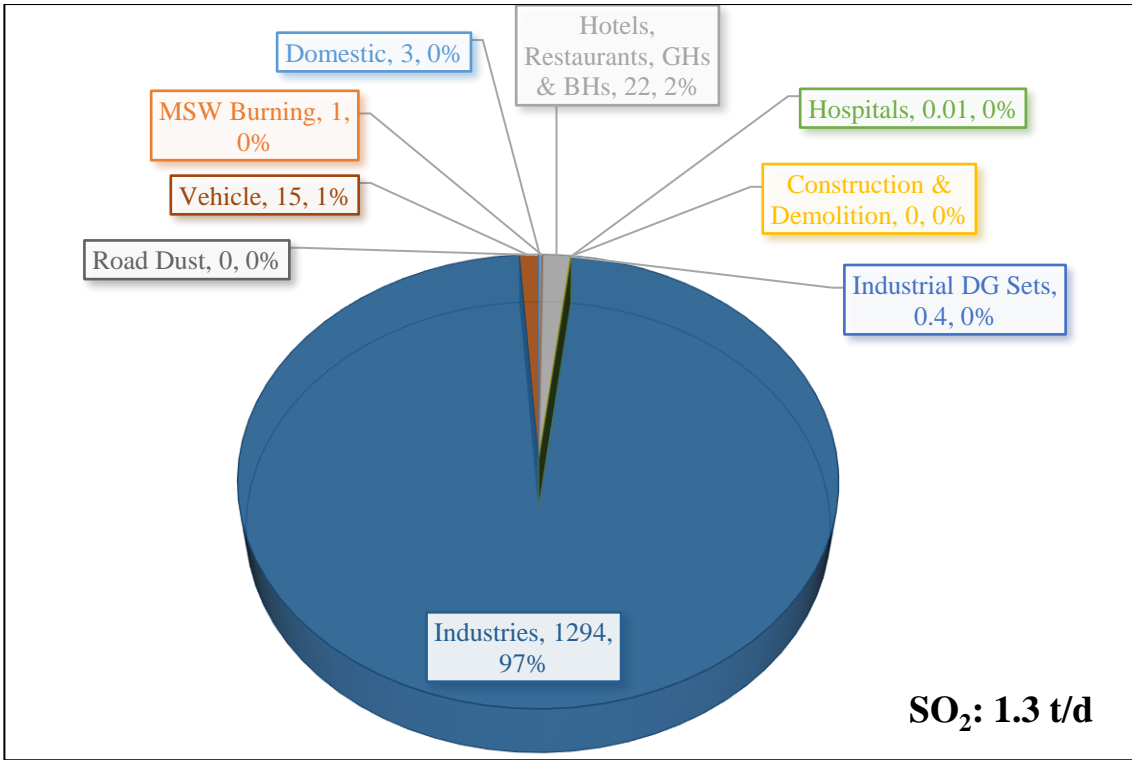


Figure 4: SO₂ emission load of different sources in Parwanoo (kg/d)

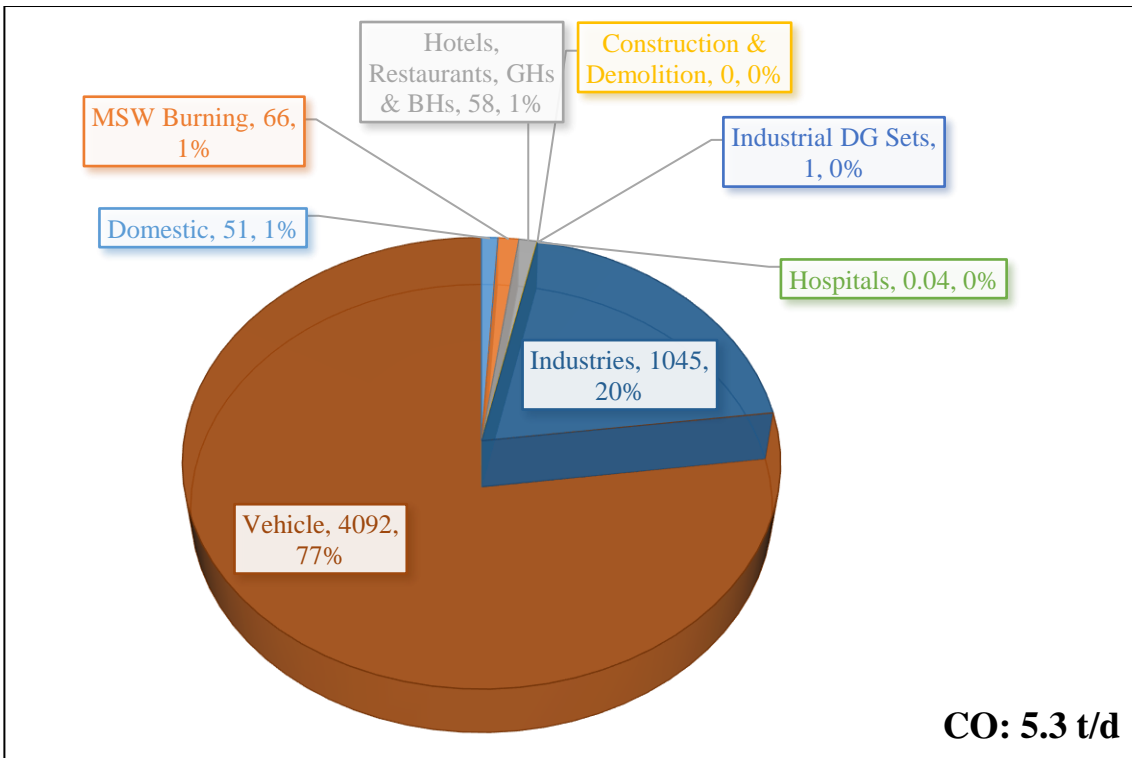
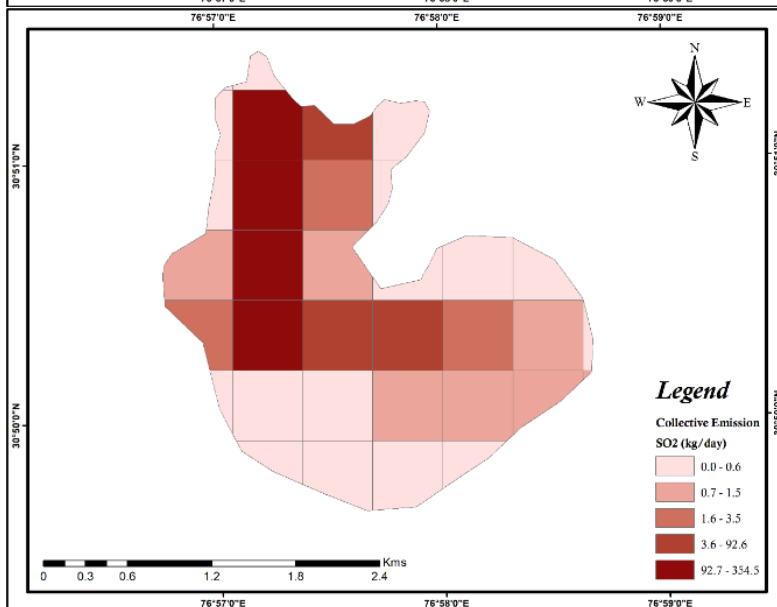
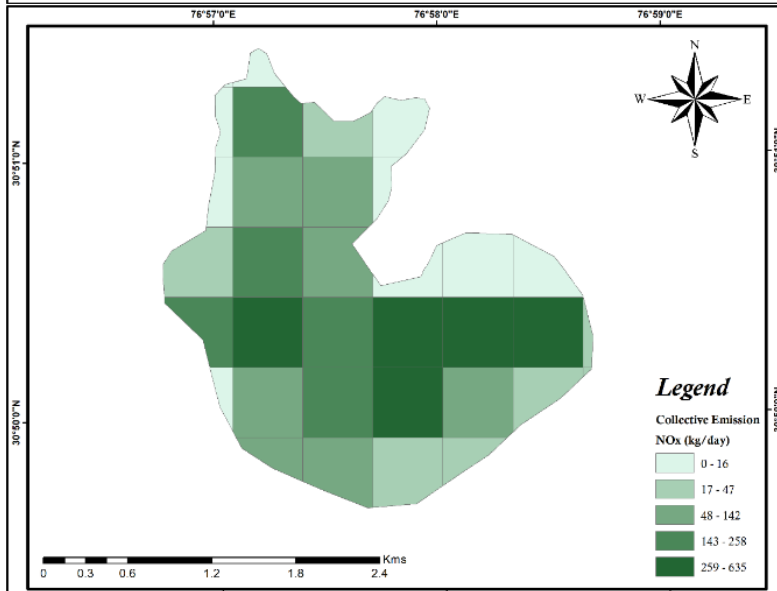
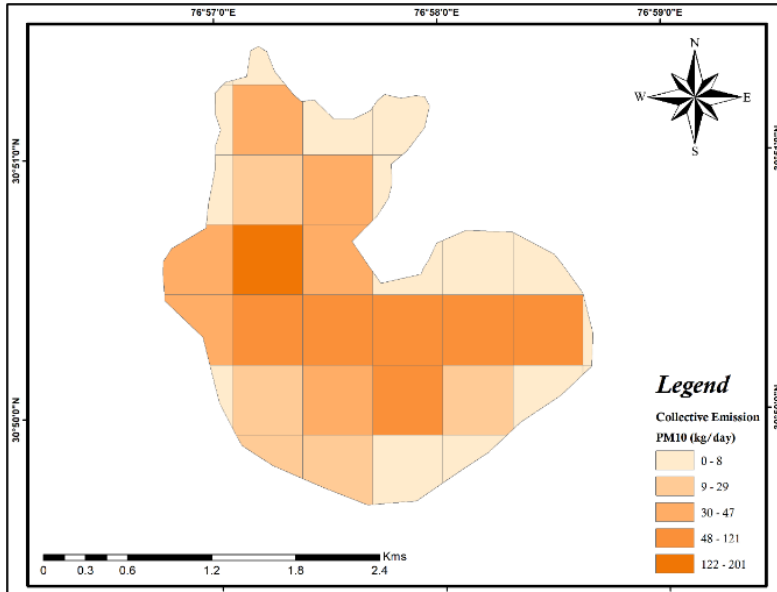


Figure 5: CO emission load of different sources in Parwanoo (kg/d)



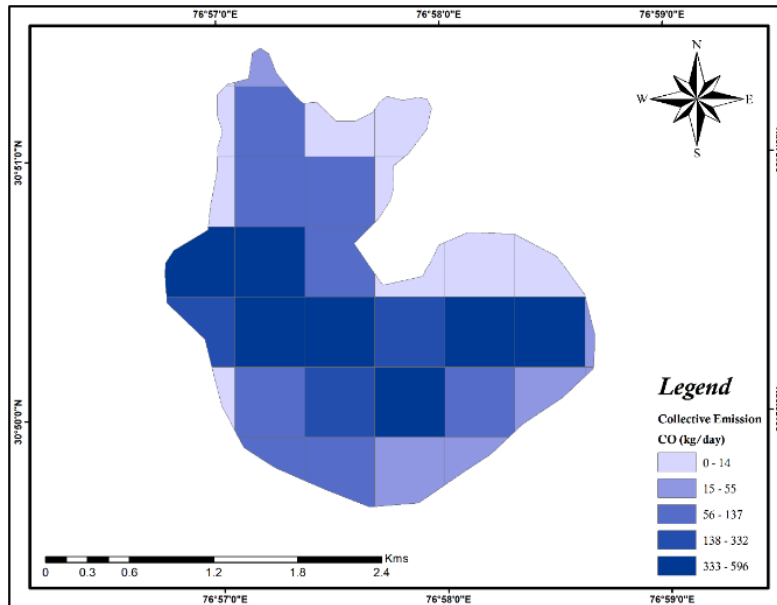


Figure 6: Spatial distribution of PM₁₀, NO_x, SO₂ and CO emissions in the city

Air Quality Modeling

Receptor Modeling

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

- The relative sources contributions of PM₁₀ and PM_{2.5} in ambient air quality are generally the same. The sources (% contribution given in parenthesis for PM₁₀ - PM_{2.5} to the ambient air levels) include secondary inorganic aerosol (SIA) (18 – 19%), industrial and combustion (11 – 6%), soil and road dust (15 – 12%), MSW burning (6 – 5%), vehicles (22 – 27%), coal and flyash (16 – 23%), biomass burning (5 – 6%) and construction activities (8 – 3%).
- The most consistent sources for PM₁₀ and PM_{2.5} are vehicles, SIA and 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 and flyash and industrial emissions.

- Vehicles' contribution is most significant and consistent in PM₁₀ (22%) and PM_{2.5} (27%) in the city.
- Coal and flyash is the second most contributor in PM₁₀ (16%) and PM_{2.5} (23%). It could be due to uses in industries, hotels and restaurants and as a part of cement used for construction activities.
- Secondary inorganic aerosol is significantly high contribution in both PM₁₀ (18%) and PM_{2.5} (19%).
- Soil and road dust contribute 15% in PM₁₀ and 12% in PM_{2.5}, showing high variability, which infers that the road condition in the city is not up to the mark. It indicates that most parts of roads and kerb-sides were poorly maintained.
- From the uncollected solid waste, the major part would be burned. It is seen that MSW burning is a major source that contributes to both PM₁₀ (6%) and PM_{2.5} (5%). 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.
- SHP site was in an industrial area having major polluting industries. Therefore, it has the movement of large trucks ferrying raw material and finished products. The dumping and burning of MSW and plastic waste along the roadsides were a routine practice. The MSW/plastic burning contribution is high both in PM₁₀ (5%) and PM_{2.5} (6%) that indicating improper management of waste generated in market.
- Industrial contribution in the city is moderate for both PM₁₀ (11%) and PM_{2.5} (6%) which are in conformance with the fact that the city has a large number of industries. Most of the industrial emissions are from combustion and process emissions. It may be noted that industrial emissions are 7% of PM₁₀ and 16% of PM_{2.5}, but their contribution is also significant at the breathing level.
- The contribution of biomass burning is reasonable and lowest among all sources at 5% (for PM₁₀) and 6% (for PM_{2.5}). Sizeable biomass is consistent in PM, indicating local sources present in Parwanoo city and nearby areas. Biomass burning is because of arboriculture activities, agricultural residue burning, high energy crop burning for fuel, etc.

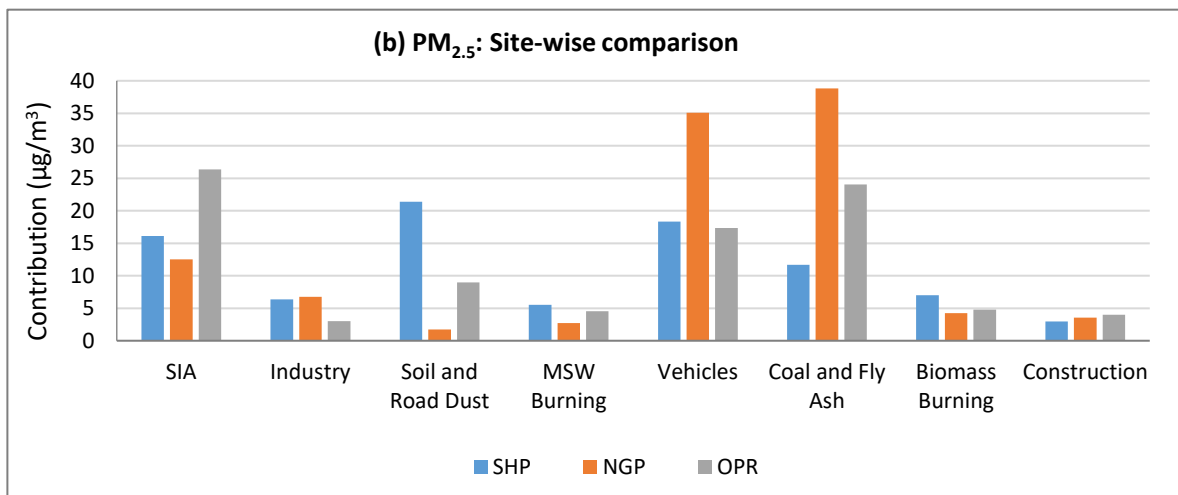
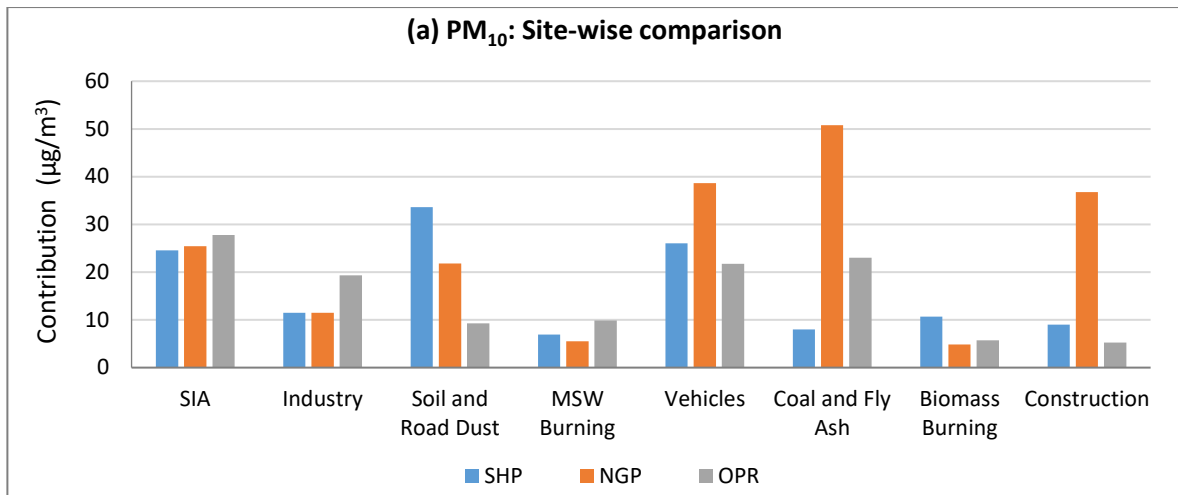
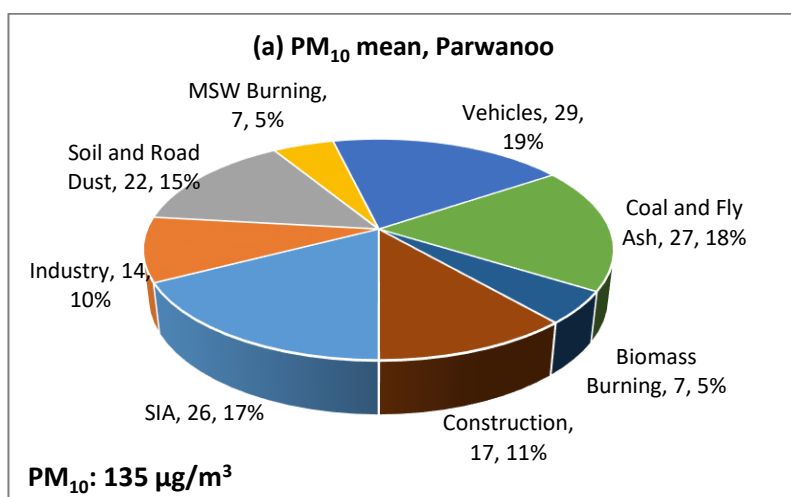


Figure 7: Site-specific source-wise contribution to PM₁₀ and PM_{2.5}: SHP (Industrial), NGP (Commercial), OPR (Residential)



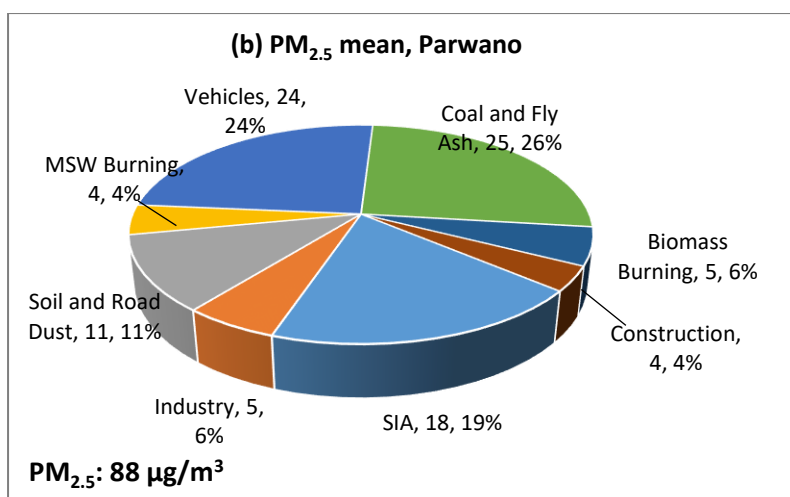


Figure 8: City level source contributions (Source, µg/m³, %) to PM₁₀ and PM_{2.5} levels

Control Options and Actions

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

- **Hotels/Restaurants/Banquet Halls**

The total number of big hotels (sitting capacity of more than 15) and restaurants was approximately 32, mainly situated in the central part of the city and along with the Kalka Shimla and National Highway-5. 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 Committee, Parwanoo may enforce coal-free cooking in hotels, restaurants, BHs and marriage places as far as possible. The ash must be stored in leak-free bags and adequately disposed of. One may consider linking the commercial license to clean fuel, which may be enforced by the Municipal Committee, Parwanoo, Department of Food, Civil Supplies and Consumer Affairs, and oil companies (Indian Oil, HP, etc.).

- **MSW burning and management**

MSW and other residue burning are rampant in Parwanoo. In winter, the overall source contribution from MSW burning is 6% in PM₁₀ and 5% in PM_{2.5} and stopping this burning is the simplest way to reduce PM₁₀ and PM_{2.5} levels. Any form of garbage

burning should be strictly stopped and strictly monitored for its compliance. The Municipal Committee, Parwanoo 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 Rehri Market, Kheri, Gol Market, and Sector 3, 4, 5, 6. Major residential areas (having high density) were sectors 1A, 4 and 6. Desilting and cleaning of municipal drains by Municipal Committee, Parwanoo should be undertaken on a regular interval, as the silt with biological activities can cause emission of air pollutants like H₂S, NH₃, VOCs, etc. In sector 5, the estimated solid waste volume was about 7-8 tonnes per day which is adjoining to Sukhna Nallah and solid waste being haphazardly managed.

In Parwanoo, '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 Committee, Parwanoo should prioritize the MSW collection mechanism starting systematically in each ward with an emphasis on public awareness. Special attention is required for fruits and vegetable markets, commercial areas, mandis and high-rise residential buildings. Industrial waste burning is dealt with separately.

It is recommended to develop an Integrated TSDF along with provision of electricity connection and necessary water connection. The treatment and rightful disposal of fresh waste should not take more than 7 days i.e., as storage becomes a major source of VOCs.

Sensitize people and media through workshops and literature distribution to prevent waste burning and its unauthorized disposal; this activity may be undertaken by Municipal Committee, Parwanoo, 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 Parwanoo authorities, a common practice in large cities. The control measures for emission at a construction site should include:

- Wet suppression
- wind speed reduction (for large construction sites)
- Waste should be properly disposed of and not stored on the premises or the roadside.
- Proper handling and raw material storage: covered the storage and provided the windbreakers.
- Vehicle cleaning and specific fixed wheel washing while leaving the site and damping down haul routes.
- A fine screen covers the actual construction area.
- No storage (no matter how small) of construction material near the roadside (up to 10 m from the edge of the road).

The above control measures should be coordinated and supervised by HP Urban Development Authority (HIMUDA), Himachal Pradesh Housing Board, Municipal Committee, Parwanoo, Urban Development Department, PWD, and HPSPCB.

- **Domestic sector**

The fuel consumption pattern shows LPG (79%) consumption (PPAC, MoPNG, 2016), wood (12%), dung (2%), coal (2%), kerosene (4%) and crop residue (1%). The Department of Food, Civil Supplies and Consumer Affairs and oil companies (Indian Oil, HP, etc.) may formulate a time-bound plan for every household to have LPG. The LPG should be made available to the remaining 21% of households to make the city 100% LPG-fueled. By 2030, planning should be done that as many households as a possible shift to electric cooking. For new societies, buildings should have a good

infrastructure for PNG. A sizable floating population working in industries must also have an LPG supply.

- **Soil and Road Dust**

It has been observed that the soil and road dust emissions and their contribution to ambient air concentration are consistent and it is one of the largest sources of PM₁₀ and PM_{2.5} emissions. The silt load, an important factor in PM emissions from the road varied from 3 to 6 g/m² which is high (typical load in developed countries is less than 1 g/m²). The industrial area, where heavy vehicle movement is seen, also shows the high road dust emission. It is suggested that high traffic density roads should be properly maintained, paved from one end to another, have sidewalks through interlocking blocks for the pedestrians, proper drainage from the road, shrubs should be planted on-road dividers. Out of the total road network, about 70% of surface quality is poor.

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

- Convert all unpaved, partially paved roads to fully paved roads. PWD (Public Works Department) and city administration should act immediately to reduce the pollution load from road dust.
- Municipal Council should carry out vacuum-assisted sweeping.
- If the silt road is greater than 3 gm/m², the vacuum-assisted sweeping should be carried out along with washing by the municipal council and the HPSPCB should have the surveillance of this action.
- NHAI should ensure that the silt load on highways maintained by them should have a silt load of less than 3 gm/m².
- 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 (Kalka Highway, Parwanoo Bus Stop and Dharampur Solan 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 HIMUDA, Himachal Pradesh Housing Board, Municipal Committee, Parwanoo, NHAI, PWD, and State Forest Department (for increasing green cover and plantation) as per their jurisdictions.

- **Vehicle Emission Control and Traffic Management**

The vehicle emission contribution is significant for CO, NO_x, PM₁₀, and PM_{2.5}. There is a relatively large contribution of diesel vehicles (trucks, buses, LCVs, cars, etc.) to PM₁₀, PM_{2.5} and NO_x. Out of about 487 tonnes/d emission of PM_{2.5} from vehicles, about 70% is from diesel vehicles, especially trucks and buses. Therefore, control measures must focus on advanced technological intervention for diesel vehicles like Diesel Particulate Filter (DPF). The general recommendations for vehicular emission control are enumerated below (specific recommendations are discussed later).

- Retro-fitment of DPF: This option must be explored as Bharat stage VI fuel is available and this technology can be adopted.
- Industries should encourage employing trucks and heavy-duty vehicles of Bharat stage-VI or IV with DPF for transportation of the raw and finished products at and from the industry.
- By the end of 2030, a target of 50% of the total registration of vehicles in the city should be electric vehicles (EVs) in the sector of 2Ws, 3Ws and passenger cars. Strong and plug-in hybrid electrified vehicles may also be encouraged. Charging infrastructure should come up quickly at multiple places (As per Ministry of Petroleum guidelines, charging infrastructure for EV- Revised guidelines and standards, Oct 1, 2019, MoPG), including public buildings and parking lots and battery swapping facilities should be planned to avoid long charging periods, especially for two-wheelers.
- Emissions from in-use vehicles also depend on the maintenance and upkeep of vehicles. In this regard, it is suggested that each vehicle manufacturing company should have its authorized service centres in sufficient numbers to cater to the need of their vehicles in the city. Every vehicle at least once a year should undergo a thorough check-up and compliance with pollution control devices and their proper functioning from an authorized centre.

- 4 - 8 PUC Centres are required per 1,00,000 vehicles (5 mins/vehicle and 12 hrs/day). Maintenance and calibration of equipment must be ensured by regular surveillance.
- Restriction on plying and phasing out of 10 years old commercial diesel-driven vehicles may be considered.
- Check the overload vehicles: Expedite installation of weigh-in-motion bridges and machines at all entry points to Parwanoo to ensure that vehicles are not overloaded.
- Himachal Road Transport Corporation (HRTC) should plan and install multiple electric charging facilities in its depots (in Parwanoo and other destinations) to quickly move towards electric buses.
- The local public transport in the city should also move to electric buses. It is suggested that buses should be medium size of 30 seating capacity and provide better frequency for easy maneuvering in the city to avoid difficult turning and congestion.
- Route rationalization: Improve availability by rationalizing routes and fleet enhancement with requisite modifications. Ensure integration of the existing bus stops on the national highway.
- Information Transmission (IT) systems in buses, bus stops, and control centre and passenger information systems should be introduced for the reliability of bus services and monitoring.
- The intersections are poorly designed. There is a need to improve the intersections of roads at many places in Parwanoo city. Wherever installed, the traffic signal does not function properly, leading to slow traffic movement and reduced road safety. Steps shall be taken to install traffic signals on all the major intersections and traffic police shall enforce smooth traffic.
- Other than a few roads, there is a lack of footpath availability and marking of zebra crossing for pedestrian movements and people are forced to walk on the road. Proper footpaths and ease of crossing should be available for the pedestrians.

- **Decongestion of Roads**

To increase the average speed and take full advantage of BS-VI, decongestion, removing road encroachments, and stopping unauthorized and improper parking is

essential. The off-street parking is inadequate in the city causing jams and permanent congestion because of on-street haphazard parking. The specific points that will help in decongestion are elaborated below.

- Strict action on roadside encroachment.
- The operation of unauthorized vehicle service centres should be removed and ensure that service centres have adequate space for workshop activities and that servicing is not done on the roadside.
- Heavy-duty vehicles and buses which are destined for other cities pass through major roads within Parwanoo city and create heavy congestion. The important points of congestions are Kalka Highway, Parwanoo Bus Stop, and Dharampur Solan Road. The city main roads are NH-5, Kalka-Shimla highway, Parwanoo-Kasauli, Taksal and Kamali Road; As a result, these routes within the city will also be congested.
- Areas that are adjacent to the market centers like Rehri Market, Kheri, Gol Market, and Sector 3, 4, 5, 6, and Nagar Nigam experience heavy traffic congestion due to the unregulated parking and encroachment by local shop owners.
- Parking spaces: Off-street parking is inadequate in the city. There must be no parking zone (up to 50 m including auto, electric and hand-pulled rickshaw) near the intersections. It will help the smooth traffic flow.
- Certain parking policies in congestion areas (high parking costs, at city centers), only parking should be limited for physically challenged people.
- The city should strictly follow recommendations from IRC 12-2015 of prohibiting on-street parking.
- Near Intersections: the capacity of an intersection is greatly reduced if vehicles are allowed to park on the approaches.
- Narrow Streets: Narrow streets with heavy traffic require that all possible measures should be taken to remove obstacles to traffic flow. Prohibition of parking can have a salutary effect on traffic flow & congestion.
- Pedestrian Crossings: prohibit parking within about 8.0 m from the pedestrian crossings.

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

- **Industries and Diesel Generator Sets**

More than 17 polluting units are claimed to have control devices installed. The devices are inadequate or poorly operated with very low collection efficiency. It is suggested that these industries must control PM with highly efficient capture devices and suitable disposal of collected particles.

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

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

- The majority of industries use multi-cyclones as air pollution control devices. It is recommended that these cyclones should be replaced by baghouses for effective control of particulate emissions.
- Ensuring compliance with emission standards in industries: All industries causing Air, Water, and Noise pollution shall be made compliant w.r.t environmental regulations.
- Strict action to stop unscientific disposal of industrial waste in the surrounding area.
- Industrial waste burning should be stopped immediately, which is seen in the industrial area especially packing materials and soiled papers and clothes.
- The area and road in front of the industry should be free from any storage or disposal of any waste or raw material at all times.
- The industry should follow best practices to minimize fugitive emissions within the industry premises. All leakages, transfer points, loading and unloading, and material handling within the industry should be controlled and comply with

USEPA regulation LDAR (Leak detection and repairs) for industries dealing with solvents and petroleum uses or manufacturing.

- Adequate and quality electric supply should be available to the industries for an effective industrial operation and avoidance of the DG sets.
- There are industries with induction furnaces, which is a very pollution process, with almost no pollution control devices. The maximum emissions occur when the furnace lids and doors are opened during charging, back charging, alloying, oxygen lancing (if done), poking, slag removal, and tapping operations. These emissions escape from the sides and top of the building.
- To address the pollution caused by fugitive emissions using induction furnaces a fume gas capturing device has been developed and is commercially available (details in Chapter 6).
- It is recommended that a fume gas capturing hood followed by baghouse should be used to control air pollution.
- Strict compliance and surveillance are required that hazardous waste goes to TSDF under the supervision of Municipal Committee, Parwanoo and HPSPCB.

Strengthening of HPSPCB Parwanoo, 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 Parwanoo

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 Committee, Parwanoo	1 year
	Link Commercial license to clean fuel	Municipal Committee, Parwanoo, 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 Committee, Parwanoo	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	Department of Food, Civil Supplies and	10 years

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
	(common in western countries) or PNG at the minimum	Consumer Affairs and Oil Companies (Indian Oil/HP, etc.)	
Municipal Solid Waste (MSW) Burning	Develop an Integrated treatment, storage and disposal facility (TSDF)	Municipal Committee, Parwanoo, HPSPCB, HIMUDA	One year
	Any type of garbage burning should be strictly stopped. Current waste collection and surveillance are poor.	Municipal Committee, Parwanoo	Immediate
	Surveillance is required that hazardous waste goes to TSDF.	Municipal Committee, Parwanoo, HPSPCB, HIMUDA	
	Desilting and cleaning of municipal drains	Municipal Committee, Parwanoo	
	Waste burning in Industrial areas should be stopped.	HPSIDC, HPSPCB	
	Daily, Monthly mass balance of MSW generation and disposal	Municipal Committee, Parwanoo	
Sensitize people and media through workshops and literature distribution so as not to burn the waste.	Municipal Committee, Parwanoo, HPSPCB, and NGO		
Construction and Demolition	Wet suppression	HP Urban Development Authority (HIMUDA), Municipal Committee, Parwanoo, Urban Development Department,	Immediate

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
		PWD	
	Wind speed reduction (for large construction sites)	HIMUDA, Municipal Committee, Parwanoo, Urban Development Department, PWD	
	Enforcement of C&D Waste Management Rules. The waste should be sent to a construction and demolition processing facility	HIMUDA, Municipal Committee, Parwanoo, Urban Development Department, PWD	Immediate
	Proper handling and storage of raw material: covered the storage and provide the windbreakers.	HIMUDA, Municipal Committee, Parwanoo, Urban Development Department, PWD	
	Vehicle cleaning and specific fixed wheel washing on leaving the site and damping down of haul routes.	HIMUDA, Municipal Committee, Parwanoo, Urban Development Department, PWD	
	The actual construction area should be covered by a fine screen.	HIMUDA, Municipal Committee, Parwanoo, 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)	HIMUDA, Municipal Committee, Parwanoo, Urban Development Department, PWD	
	Builders should leave 25% area for green belt in residential colonies to be made mandatory.	HIMUDA, Municipal Committee, Parwanoo, Urban Development Department, PWD	

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
	Sensitize construction workers and contract agencies through workshops.	HIMUDA, Municipal Committee, Parwanoo, Urban Development Department, PWD, HPSPCB, and NGO	
Road Dust	The silt load in Parwanoo varies from 3 to 6 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 .	HIMUDA, Municipal Committee, Parwanoo, National Highway Authority, PWD, HPSPCB (for silt load compliance)	Immediate
	Convert unpaved roads to paved roads. Maintain pothole-free roads.	HIMUDA, Municipal Committee, Parwanoo, 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.	HIMUDA, Municipal Committee, Parwanoo, National Highway Authority, PWD	
	Increase green cover and plantation. Undertake the green of open areas, community places, schools, and housing societies.	HIMUDA, Municipal Committee, Parwanoo, National Highway Authority, State Forest Department, PWD	
	vacuum-assisted sweeping is carried out four times a month on major roads with road washing.	HIMUDA, Municipal Committee, Parwanoo, National Highway Authority, PWD	

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
Vehicles	Diesel vehicles entering the city should be equipped with DPF which will bring a reduction of 40% in emissions (This option can be implemented with vehicles of the BS-IV category as well)	State Transportation Department	3 years
	Industries must be encouraged to use BS-VI or BS-IV (with DPF) vehicles for the transportation of raw and finished products	Industrial Associations and State transport Department	Immediate
	Restriction on plying and phasing out of 10 years old commercial diesel-driven vehicles.	Transport Department	2 years
	Introduction of cleaner fuels (CNG/ LPG) for all vehicles (other than 2-W).	Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian Oil/HP, etc.)	2 years
	Check to overload: Expedited installation of weigh-in-motion bridges and machines at all entry points to Parwanoo.	Transport Department, Traffic Police, Parwanoo, 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 Parwanoo	1 year

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

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
	There should be separate Treatment, Storage, and Disposal Facilities (TSDFs) for hazardous waste.	Industrial Associations, HIMUDA, HPSIDC, Industries Department, HPSPCB	2 years
	Industrial waste burning should be stopped immediately	Industrial Associations, HPSIDC, HPSPCB	Immediate
	Following best practices to minimize fugitive emissions within the industry premises, all leakages within the industry should be controlled	Industrial Associations, HPSIDC, HPSPCB	Immediate
	Area and road in front of the industry should be the responsibility of the industry	Industrial Associations, HPSIDC, HPSPCB	
	Category A Industries (using coal and other dirty fuels)		
	About 17 boilers, Heater and furnaces in Parwanoo are running over coal, wood, and other dirty solid fuels which should be shifted to natural gas and electricity	Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian Oil/HP, etc.), Industrial Associations, HPSPCB	2 years
	Almost all rotary furnaces having significant emissions are running on coal that needs to be shifted to natural gas and electricity.	Industrial Associations, HPSPCB	2 years

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
	Multi-cyclones should be replaced by baghouses. Ensure installation and operation of air pollution control devices in industries.	Industrial Associations, HPSPCB	2 years
	Category B Industries (Induction Furnace)		
	Recommended Fume gas capturing hood followed by Baghouse should be used to control air pollution.	Industrial Associations, HPSPCB	2 years
	Diesel Generator Sets		
	Strengthening of grid power supply, uninterrupted power supply to the industries.	State Energy Department, HPSEBL	2 years
	Renewable energy should be used to cater to the need of office requirements in the absence of power failure to stop the use of DG Set.	Industrial Associations	2 years
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.	HIMUDA, Municipal Committee, Parwanos, RTO Parwanoo, Traffic Police, Parwanoo	6 months
	Disciplined Public transport (designate one lane stop).	RTO Parwanoo., Traffic Police, Parwanoo	
	Removal of the free parking zone. No parking within 50 m of any major crossing and or chaurahs, rotaries.	HIMUDA, Municipal Committee, Parwanoo, RTO Parwanoo, Traffic Police, Parwanoo	

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
	Strictly follow Indian Road Congress guidelines.		
	Examine the existing framework for removing broken vehicles from roads and create a system for speedy removal and ensure minimal disruption to traffic.	HIMUDA, RTO Parwanoo, NHAI, Traffic Police, Parwanoo	
	Synchronize traffic movements or introduce intelligent traffic systems for lane-driving.	HIMUDA, RTO Parwanoo, NHAI, Traffic Police, Parwanoo	
	Mechanized multi-story parking at bus stands, and big commercial areas. Remove at least 50 percent of on-street parking in the city.	HIMUDA, RTO Parwanoo, Municipal Committee, Parwanoo, NHAI, Traffic Police, Parwanoo	
	Identify traffic bottleneck intersections and develop a smooth traffic plan. For example, Kalka Highway, Parwanoo Bus Stop and Dharampur Solan Road are the main bottlenecks for traffic.	HIMUDA, RTO Parwanoo, Municipal Committee, Parwanoo, Traffic Police, Parwanoo	
	Parking policy in congestion areas (high parking cost, at city centers, only parking is limited for physically challenged people, etc).	HIMUDA, RTO Parwanoo, Municipal Committee, Parwanoo, NHAI, Traffic Police, Parwanoo	
	The important point of congestion is Kalka Highway,	RTO Parwanoo, Traffic Police	2 years

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
	Parwanoo Bus Stop, Nagar Nigam Market, and Himuda complex chauraha parking should be strictly prohibited.		
<p>*The above steps should not only be implemented in Parwanoo municipal limits rather these should be extended up to at least 10 km beyond the boundary. This will need support from the central government.</p>			

Table of contents

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

2.1.2	Instruments and Accessories.....	12
2.2	Quality Assurance and Quality Control (QA/QC) Quality Control.....	14
2.3	Ambient Air Quality – Results.....	18
2.3.1	Particulate Matter (PM ₁₀ , PM _{2.5}).....	19
2.3.2	Gaseous pollutants	22
2.3.3	Volatile Organic Compounds (VOCs: BTX).....	25
2.3.4	Elemental and Organic Carbon Content (EC/OC) in PM _{2.5}	26
2.3.5	PAHs in PM _{2.5}	29
2.3.6	Molecular Markers in PM _{2.5}	31
2.3.7	Chemical Composition of PM ₁₀ and PM _{2.5} and their correlation matrix	32
2.3.8	Comparison of PM ₁₀ and PM _{2.5} Composition	40
2.3.9	Carbon monoxide (CO).....	41
2.3.10	Ozone (O ₃)	43
2.4	Interpretations and Inferences	44
3	Time Series Analysis and Trend	48
3.1	Introduction	48
3.2	Methodology	48
3.3	Results and Interpretations	49
3.3.1	Annual pattern in PM ₁₀ and NO ₂	49
3.3.2	Variation in the slope: Trend analyses.....	53
4	Emission Inventory	55
4.1	Introduction	55
4.2	Methodology	55
4.2.1	Categorization of Sources	55
4.2.2	Data Collection	56
4.2.3	Digital Data Generation	56
4.2.4	Emission Factor	62

4.2.5	Domestic Sector	63
4.2.6	Construction and Demolition	69
4.2.7	Industrial Diesel Generator Sets (Industrial DG sets).....	72
4.2.8	Hotels, Restaurants, Guest Houses (GHs), and Banquet Halls (BHs).....	76
4.2.9	Municipal Solid Waste Burning.....	80
4.2.10	Hospitals	84
4.2.11	Industries.....	86
4.2.12	Parking Lot Survey	90
4.2.13	Vehicular-Line Sources	92
4.2.14	Traffic Congestion	98
4.2.15	Paved and Unpaved Road Dust.....	99
4.3	City Level Emission Inventory	104
5	Receptor Modelling and Source Apportionment	111
5.1	Receptor Modeling.....	111
5.2	PMF Modeling: Source Apportionment of PM ₁₀ and PM _{2.5}	112
5.3	PMF Modeling Results and interpretation (Parwanoo).....	113
5.3.1	SHP	115
5.3.2	NGP.....	118
5.3.3	OPR.....	120
5.3.4	Overall.....	122
5.4	Interpretations and Inferences	125
6	Control options, Analyses and Prioritization for Actions.....	128
6.1	Air Pollution Scenario in the City of Parwanoo.....	128
6.2	Controlling of sources within the city	128
6.2.1	Hotels/Restaurants/Banquet Halls	128
6.2.2	Municipal Solid Waste (MSW) Burning	130
6.2.3	Construction and Demolition.....	131

6.2.4	Domestic sector.....	132
6.2.5	Soil and Road Dust	133
6.2.6	Vehicle Emission Control, Congestion and Traffic Management.....	135
6.2.7	Industries.....	142
6.3	Summary of Actions and Control Options.....	145
6.4	Strengthening of HPSPCB Parwanoo, Regional Office.....	145
	References.....	156
	Annexure 1.....	159
	Annexure 2.....	160

List of Figures

Figure 1: PM ₁₀ emission Inventory of different sources in Parwanoo (kg/d).....	viii
Figure 2: PM _{2.5} emission load of different sources in Parwanoo (kg/d)	ix
Figure 3: NO _x emission load of different sources in Parwanoo (Kg/d)	ix
Figure 4: SO ₂ emission load of different sources in Parwanoo (kg/d).....	x
Figure 5: CO emission load of different sources in Parwanoo (kg/d).....	x
Figure 6: Spatial distribution of PM ₁₀ , NO _x , SO ₂ and CO emissions in the city	xii
Figure 7: Site-specific source-wise contribution to PM ₁₀ and PM _{2.5} : SHP (Industrial), NGP (Commercial), OPR (Residential).....	xiv
Figure 8: City level source contributions (Source, µg/m ³ , %) to PM ₁₀ and PM _{2.5} levels	xv
Figure 1.1: Annual average levels of PM ₁₀ from 2013-14 to 2017-18 (HPSPCB, 2018).....	4
Figure 1.2: Approach to the Study and Major Tasks	5
Figure 2.1: Photographs of Sampling Sites.....	10
Figure 2.2: Land-use Pattern and Locations of Sampling Sites (GIS map and Google Map); SHP - Shivalik Polymers Sec 3 (Industrial), NGP - Nagar Parishad Sec 1 (Commercial), OPR - HPPCB Office Sec 4 (Residential).....	11
Figure 2.3: Photographs of the Instruments	14
Figure 2.4: PM Concentrations at SHP	19
Figure 2.5: PM Concentrations at NGP	20
Figure 2.6: PM Concentrations at OPR	20
Figure 2.7: Comparison of PM levels at all sites	21
Figure 2.8: Comparison of PM _{2.5} /PM ₁₀ ratio for all sites	22
Figure 2.9: SO ₂ , NO ₂ and NH ₃ concentrations at SHP	23
Figure 2.10: SO ₂ , NO ₂ and NH ₃ concentrations at NGP.....	23
Figure 2.11: SO ₂ , NO ₂ and NH ₃ concentrations at OPR.....	24
Figure 2.12: Comparison of gaseous pollutants levels at all sites	24
Figure 2.13: VOCs Concentrations at different sites in Parwanoo	25
Figure 2.14: Comparison of gaseous pollutants levels at all sites	26
Figure 2.15: EC and OC Content in PM _{2.5} at SHP	27
Figure 2.16: EC and OC Content in PM _{2.5} at NGP.....	27
Figure 2.17: EC and OC Content in PM _{2.5} at OPR.....	28
Figure 2.18: Comparison of EC and OC in PM _{2.5} for all Sites	29

Figure 2.19: PAHs Concentrations in PM _{2.5}	31
Figure 2.20: Molecular Markers in PM _{2.5}	32
Figure 2.21: Concentrations of species in (a) PM ₁₀ and (b) PM _{2.5}	33
Figure 2.22: Percentage distribution of species in PM ₁₀	34
Figure 2.23: Percentage distribution of species in PM _{2.5}	35
Figure 2.24: Compositional comparison of species in PM _{2.5} vs PM ₁₀	40
Figure 2.25: Hourly average concentration ($\mu\text{g}/\text{m}^3$) of CO at SHP	42
Figure 2.26: Hourly average concentration ($\mu\text{g}/\text{m}^3$) of CO at OPR	42
Figure 2.27: Hourly average concentration ($\mu\text{g}/\text{m}^3$) of O ₃ at SHP	43
Figure 2.28: Hourly average concentration ($\mu\text{g}/\text{m}^3$) of O ₃ at OPR.....	44
Figure 3.1: Stepwise methodology and major tasks (Nagar et al., 2019)	49
Figure 3.2: Variation in PM ₁₀ at (a) Station-I Sector 4 and (b) Station-II Sector 1.....	51
Figure 3.3: Variation in NO _x at (a) Station-I Sector 4 and (b) Station-II Sector 1	51
Figure 3.4: Timeseries of annual mean levels of PM ₁₀	52
Figure 3.5: Timeseries of annual mean levels of NO _x	53
Figure 4.1: Stepwise Methodology adopted for the Study	55
Figure 4.2: Source Category and type of sources	56
Figure 4.3: Parwanoo City Boundary	57
Figure 4.4: Agricultural Area Map	57
Figure 4.5: Green Area Map	58
Figure 4.6: Industrial Area Map.....	58
Figure 4.7: Waterbodies Area Map.....	59
Figure 4.8: Major Road Network Map	59
Figure 4.9: Minor Road Network Map	60
Figure 4.10: Settlement Area Map.....	60
Figure 4.11: Open Area Map	61
Figure 4.12: Land use Map of Parwanoo City	61
Figure 4.13: Grid Map of Parwanoo City showing Grid Identity Numbers	62
Figure 4.14: Emission Load from Domestic Sector.....	64
Figure 4.15: PM ₁₀ Emission load from Domestic Sector (Kg/day, %).....	64
Figure 4.16: PM _{2.5} Emission load from Domestic Sector (Kg/day, %)	65
Figure 4.17: SO ₂ Emission load from Domestic Sector (Kg/day, %).....	65
Figure 4.18: NO _x Emission load from Domestic Sector (Kg/day, %)	66

Figure 4.19: CO Emission load from Domestic Sector (Kg/day, %)	66
Figure 4.20: Spatial Distribution of PM ₁₀ Emissions from Domestic Sector	67
Figure 4.21: Spatial Distribution of PM _{2.5} Emissions from Domestic Sector	67
Figure 4.22: Spatial Distribution of SO ₂ Emissions from Domestic Sector	68
Figure 4.23: Spatial Distribution of NO _x Emissions from Domestic Sector	68
Figure 4.24: Spatial Distribution of CO Emissions from Domestic Sector	69
Figure 4.25: Construction and Demolition debris near construction sites	70
Figure 4.26: Location of Construction and Demolition sites in Parwanoo city	70
Figure 4.27: Emission Load from Construction and Demolition activities	71
Figure 4.28: Spatial Distribution of PM ₁₀ Emissions from Construction/Demolition	71
Figure 4.29: Spatial Distribution of PM _{2.5} Emissions from Construction/Demolition	72
Figure 4.30: Location of Industrial DG Sets	73
Figure 4.31: Emission Load from Industrial DG sets	73
Figure 4.32: Spatial Distribution of PM ₁₀ Emissions from Industrial DG Sets	74
Figure 4.33: Spatial Distribution of PM _{2.5} Emissions from Industrial DG Sets	74
Figure 4.34: Spatial Distribution of SO ₂ Emissions from Industrial DG Sets	75
Figure 4.35: Spatial Distribution of NO _x Emissions from Industrial DG Sets	75
Figure 4.36: Spatial Distribution of CO Emissions from Industrial DG Sets	76
Figure 4.37: Location of Hotels, Restaurants & GHs	77
Figure 4.38: Emission Load from Hotels, Restaurants & GHs	77
Figure 4.39: Spatial Distribution of PM ₁₀ Emissions from Hotels, Restaurants & GHs	78
Figure 4.40: Spatial Distribution of PM _{2.5} Emissions from Hotels, Restaurants & GHs	78
Figure 4.41: Spatial Distribution of SO ₂ Emissions from Hotels, Restaurants & GHs	79
Figure 4.42: Spatial Distribution of NO _x Emissions from Hotels, Restaurants & GHs	79
Figure 4.43: Spatial Distribution of CO Emissions from Hotels, Restaurants & GHs	80
Figure 4.44: MSW Burning in parts of Parwanoo city	81
Figure 4.45: Emission Load from MSW Burning	81
Figure 4.46: Spatial Distribution of PM ₁₀ Emissions from MSW Burning	82
Figure 4.47: Spatial Distribution of PM _{2.5} Emissions from MSW Burning	82
Figure 4.48: Spatial Distribution of SO ₂ Emissions from MSW Burning	83
Figure 4.49: Spatial Distribution of NO _x Emissions from MSW Burning	83
Figure 4.50: Spatial Distribution of CO Emissions from MSW Burning	84
Figure 4.51: Locations of Hospitals in Parwanoo City	85

Figure 4.52: Emission Load from Hospitals	85
Figure 4.53: Location of Industries in Parwanoo city.....	86
Figure 4.54: Emission Load from Industries	87
Figure 4.55: Spatial Distribution of PM ₁₀ Emissions from Industries.....	88
Figure 4.56: Spatial Distribution of PM _{2.5} Emissions from Industries	88
Figure 4.57: Spatial Distribution of SO ₂ Emissions from Industries.....	89
Figure 4.58: Spatial Distribution of NO _x Emissions from Industries	89
Figure 4.59: Spatial Distribution of CO Emissions from Industries.....	90
Figure 4.60: Distribution of 2-Ws in the study area (parking lot survey).....	91
Figure 4.61: Distribution of 4-Ws in the study area (parking lot survey).....	91
Figure 4.62: Traffic location considered for vehicle emission in Parwanoo city	92
Figure 4.63: Emission Load from Vehicles	93
Figure 4.64: PM ₁₀ Emission Load contribution of each vehicle type (kg/day)	93
Figure 4.65: PM _{2.5} Emission Load contribution of each vehicle type (kg/day).....	94
Figure 4.66: SO ₂ Emission Load contribution of each vehicle type (kg/day)	94
Figure 4.67: NO _x Emission Load contribution of each vehicle type (kg/day).....	95
Figure 4.68: CO Emission Load contribution of each vehicle type (kg/day)	95
Figure 4.69: Spatial Distribution of PM ₁₀ Emissions from Vehicles.....	96
Figure 4.70: Spatial Distribution of PM _{2.5} Emissions from Vehicles.....	96
Figure 4.71: Spatial Distribution of SO ₂ Emissions from Vehicles.....	97
Figure 4.72: Spatial Distribution of NO _x Emissions from Vehicles	97
Figure 4.73: Spatial Distribution of CO Emissions from Vehicles	98
Figure 4.74: Typical Traffic conditions at different locations in Parwanoo.....	99
Figure 4.75: Road Dust Sampling Location	101
Figure 4.76: Road Dust Sampling in the City of Parwanoo	101
Figure 4.77: Road dust deposition on the paved road.....	102
Figure 4.78: Emissions from Road Dust in Parwanoo city.....	102
Figure 4.79: Spatial Distribution of PM ₁₀ Emissions from Road Dust Re-suspension	103
Figure 4.80: Spatial Distribution of PM _{2.5} Emissions from Road Dust Re-suspension	103
Figure 4.81: PM ₁₀ Emission Load Contribution of Different Sources	106
Figure 4.82: PM _{2.5} Emission Load Contribution of Different Sources.....	106
Figure 4.83: SO ₂ Emission Load Contribution of Different Sources	107
Figure 4.84: NO _x Emission Load Contribution of Different Sources	107

Figure 4.85: CO Emission Load Contribution of Different Sources	108
Figure 4.86: Spatial Distribution of PM ₁₀ Emissions in the City of Parwanoo	108
Figure 4.87: Spatial Distribution of PM _{2.5} Emissions in the City of Parwanoo	109
Figure 4.88: Spatial Distribution of SO ₂ Emissions in the City of Parwanoo	109
Figure 4.89: Spatial Distribution of NO _x Emissions in the City of Parwanoo.....	110
Figure 4.90: Spatial Distribution of CO Emissions in the City of Parwanoo	110
Figure 5.1: PMF-based Source profiles for PM ₁₀ and PM _{2.5}	114
Figure 5.2: PMF modeling Results for PM ₁₀ at all sites	114
Figure 5.3: PMF modeling Results for PM _{2.5} at all sites	115
Figure 5.4: PMF modeling for (a) PM ₁₀ and (b) PM _{2.5} at SHP.....	117
Figure 5.5: Backward trajectories at SHP	117
Figure 5.6: PMF modeling for (a) PM ₁₀ and (b) PM _{2.5} at NGP.....	119
Figure 5.7: Backward trajectories at NGP	119
Figure 5.8: PMF modeling for (a) PM ₁₀ and (b) PM _{2.5} at OPR.....	121
Figure 5.9: Backward trajectories at OPR	121
Figure 5.10: source concentration comparison at sites for (a) PM ₁₀ and (b) PM _{2.5} at all sites.....	123
Figure 5.11: Overall contribution (Source, µg/m ³ , %) for (a) PM ₁₀ and (b) PM _{2.5}	123
Figure 6.1: Location of Hotels, Restaurants, GHs and BHs in Parwanoo City	129
Figure 6.2: MSW Burning in several parts in Parwanoo City	130
Figure 6.3: Construction material and debris near construction sites.....	132
Figure 6.4: Road Dust is prominent on various roads	134
Figure 6.5: Quality of dust-free Roads, footpaths and dividers with dust control (Courtesy Greater Hyderabad Municipal Corporation)	135
Figure 6.6: Location of traffic bottlenecks	139
Figure 6.7: Conflicts due to on-street parking near intersections	140
Figure 6.8: Multi-level car parking (example).....	141
Figure 6.9: Proposed Suction Hood (Pic courtesy: Electrotherm).....	143
Figure 6.10: Side-based Suction Hood (Pic courtesy: Electrotherm)	143
Figure 6.11: Working on side-based Suction Hood (Sharma, 2020).....	144

List of Tables

Table 1: Description of sampling sites in Parwanoo	iv
Table 2: Control Options and Action Plan for Parwanoo	xxiv
Table 2.1: Description of sampling sites in Parwanoo	9
Table 2.2: Details of Samplers/Analyzers and Methods.....	12
Table 2.3: Chemical Components for PM Characterization	12
Table 2.4: Sampling Days of Various Pollutants at SHP.....	17
Table 2.5: Sampling Days of Various Pollutants at NGP	17
Table 2.6: Sampling Days of Various Pollutants at OPR	17
Table 2.7: National Ambient Air Quality Standards	18
Table 2.8: Statistical Results of PM _{2.5} and PM ₁₀ in (µg/m ³) at Parwanoo.....	22
Table 2.9: Statistical results of gaseous pollutants (µg/m ³) at Parwanoo	24
Table 2.10: Statistical Results of VOCs Contents (µg/m ³) at Parwanoo.....	26
Table 2.11: Statistical Results of Carbon Contents (µg/m ³) in PM _{2.5} at SHP	27
Table 2.12: Statistical Results of Carbon Contents (µg/m ³) in PM _{2.5} at NGP.....	27
Table 2.13: Statistical Results of Carbon Contents (µg/m ³) in PM _{2.5} at OPR.....	28
Table 2.14: Overall summary of Carbon Contents (µg/m ³) in PM _{2.5}	29
Table 2.15: Overall summary of average concentration (ng/m ³) of PAHs in PM _{2.5} all sites.....	36
Table 2.16: Overall summary of average concentration (ng/m ³) of molecular markers in PM _{2.5} all sites	36
Table 2.17: Statistical results of chemical characterization (µg/m ³) of PM ₁₀ at sites.....	37
Table 2.18: Overall statistical results of chemical characterization (µg/m ³) of PM ₁₀ at city level.....	37
Table 2.19: Statistical results of chemical characterization (µg/m ³) of PM _{2.5} at all sites	38
Table 2.20: Overall statistical results of chemical characterization (µg/m ³) of PM _{2.5} at city level.....	38
Table 2.21: Correlation matrix for PM and its composition	39
Table 2.22: Mean of major components: PM ₁₀ , winter (µg/m ³).....	41
Table 2.23: Statistical summary of major components: PM _{2.5} , winter (µg/m ³).....	41
Table 2.24: 8 Hourly Statistical Results of CO (µg/m ³) at Parwanoo	42
Table 2.25: 8 Hourly Statistical Results of O ₃ (µg/m ³) at Parwanoo	44

Table 3.1: Comparison of mean PM ₁₀ slopes (in µg/m ³ /year) and trends in monthly slots during 2008-2019	53
Table 3.2: Comparison of mean NO _x slopes (in µg/m ³ /year) and trends in monthly slots during 2008-2019	54
Table 4.1: Hospitals Details in Parwanoo city (emissions in kg/day and g/day).....	85
Table 4.2: Furnace/Boiler Details in Parwanoo city (emissions in kg/day and g/day).....	87
Table 4.3: Major Traffic Bottleneck at Parwanoo	98
Table 4.4: Parwanoo City Level Inventory (emissions in kg/day and g/day).....	105
Table 5.1: Summary of source concentration of PM ₁₀ : Parwanoo	124
Table 5.2: Summary of source concentration of PM _{2.5} : Parwanoo.....	124
Table 6.1: Major Traffic Bottleneck at Parwanoo City	138
Table 6.2: A Glance of Control Options and Action Plan for City of Parwanoo (for details read section 6.2).....	146

Acknowledgments

This project “Source Apportion-based Action Plans for Restoring Air Quality in Non-Attainment Cities in the State of Himachal Pradesh in respect of PM₁₀, PM_{2.5} and other Notified Pollutants (City: Parwanoo)” was sponsored by Himachal Pradesh State Pollution Control Board (HPSPCB), Shimla to the Indian Institute of Technology (IIT) Kanpur. The project was quite vast in terms of activities, including field sampling, data collection, laboratory analyses, computational work and interpretation of results. Support of different institutions and individuals at all levels is gratefully acknowledged. Although it will be an endeavor to remember and acknowledge all those who assisted in the project, we seek pardon in anticipation, if we err.

We gratefully acknowledge the assistance and guidance received from Shri Prabodh Saxena, Chairman, Shri Sh. Apoorv Devgan, Member Secretary and Dr. R.K. Pruthi, Former Member Secretary, HPSPCB, Shimla. We are thankful to Dr. Sharawan Kumar, Retired Chief Environmental Engineer, HPSPCB, Praveen Gupta, Chief Environmental Engineer, HPSPCB, R.K. Nadda, Senior Environmental Engineer, HPSPCB, Chandan Singh, Assistant Environmental Engineer, HPSPCB for coordinating the study and providing support at the ground level. We thank Mr. Chandan Singh for his assistance in data collection and constant progress follow-ups.

The analytical facilities of Centre for Environmental Science and Engineering, IIT Kanpur (created under MPLADS, Govt of India) were of great help in carrying out trace level analyses.

Dr. Pavan Kr Nagar, Post-Doctoral Fellow and Brajesh Singh, Sr. Project Engineer, IIT Kanpur worked tirelessly from field sampling to analysis and preparation of report; thanks to Pavan for their inestimable support. I also thank Mr. Dharendra Singh of Airshed Professionals for assisting in the preparation of emission inventory for the city. Sincere thanks are also due to the entire IITK team engaged in the project, Reeta Maurya, Ashutosh Pathak, Sahir Azmi, Arunima, Ritika, Krishna, Shashank, Ram Saroj, Sanny, Rohit, Girish, Vakeel, Kuldeep, Shivansh, Ajit, Anju, Nitya and Virendra.

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 (HSPSCB), Shimla has sponsored the study “Source Apportionment-based Action Plans for Restoring Air Quality in Non- Attainment Cities in the State of Himachal Pradesh in respect of PM₁₀ (particulate matter of size 10 µm or less), PM_{2.5} (particulate matter of size 2.5 µm or less) and other Notified Pollutants” to the Indian Institute of Technology Kanpur (IITK). The study has commenced in June 06, 2019 but has been delayed considerably due to lockdown. The main objectives of the study are preparation of emission inventory, air quality monitoring, chemical composition of PM₁₀ and PM_{2.5}, apportionment of sources to ambient air quality, preparation of action plan for cities and trend analysis in historical air quality data.

This report presents the source apportionment and action plan for Parwanoo, a city in Himachal Pradesh having a large number of industries in different sectors, i.e., textile, fast-moving consumer goods, pharmaceuticals, pesticides, food processing, electroplating, metal finishing, metal refining and engineering industries.

1.2 General Description of Parwanoo

1.2.1 Geography and Demography

Parwanoo is an industrial cum commercial town and municipal council in Solan district of Himachal Pradesh situated at 30°50'14" N and 76°57'41" E with the elevation of 762 m. The city lies in the lap of Shiwalik foothills of the Solan District near the border of Himachal Pradesh and Haryana states. It is situated at junction of National Highway - 22 and Parwanoo-Kasauli road that is about 22 Kms away from Chandigarh. It has immense potential for future growth for establishing an export market for fruit; vegetable timber other producers.

In Parwanoo, the key business activities are trade, commerce, industries and agriculture. The industry sectors are categorized as textile, fast-moving consumer goods, pharmaceuticals, pesticides, food processing, electroplating, metal finishing, metal refining and engineering industries. Parwanoo houses more than 500 industries in different sectors. The major red category industries are comprising Bulk Drug, Metal Finishing, electroplating, Phosphating and Pesticides Formulations.

As per the 2011 census, the population of Parwanoo city is 8,758; of which males and females are 5,144 and 3,614 respectively (Census-India, 2012) with the population density of 980 persons per km². The projected population of Parwanoo in 2023 is approximately 11,900 (www.census2011.co.in). The city is governed by Municipal Council, which has 9 wards.

1.2.2 Climate

The climate of Parwanoo features humid subtropical (warm and temperate) nature and the temperature varies from 12°C to 38°C with an annual average of 21.6°C. The city features mild winters, hot and dry summers and a monsoon season. The total average rainfall in Parwanoo area is about 1445 mm with occasionally foggy weather. The relative humidity in the city varies between 10% to 85%.

1.2.3 Emission Source Activities

The source activities for air pollution in the city can be broadly classified as: the transport sector (motor vehicles), commercial activities, industrial activities, domestic activities, institutional and office activities and fugitive non-point sources. For transport of men, mostly public transport, tempos and buses fulfill the transport requirement for the city. The

combustion of fuels like coal, liquefied petroleum gas (LPG) and wood come under the source of domestic activities. As far as industrial activities are concerned, mostly small and medium scale industries are responsible for industrial air pollution. In most institutions and offices, diesel generators are used at the time of power failure. The industries generating air pollution are mainly due to the use of induction furnaces/boilers/ thermic fluid heaters etc. (having Particulate Matter - PM, Oxides of Sulphur and Oxides of Nitrogen as a pollutant).

1.3 Need for the Study

1.3.1 Air Pollution Levels: Earlier Studies

The annual average levels of SO₂ and NO_x were observed well below the permissible limit at stations of the national air quality monitoring programme (NAMP) (CPCB, 2019). PM₁₀ concentrations varied seasonally with atmospheric processes and anthropogenic activities. The annual average of PM₁₀ at two NAMP stations were observed slightly above the permissible limit for the period of 2013-14 to 2017-18.

A report (HPSPCB, 2018) submitted to the Hon'ble National Green Tribunal (NGT) by HPSPCB, showed the annual average levels of PM₁₀ for the years 2013-14 to 2017-18 (Figure 1.1). The average PM₁₀ levels in 2017-18 was 65 µg/m³. Sharma and Dikshit (2014) have reported levels of PM₁₀ (88 – 166 µg/m³), PM_{2.5} (28 – 52 µg/m³), SO₂ (2 – 13 µg/m³) and NO_x (10 – 14 µg/m³) for Parwanoo.

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

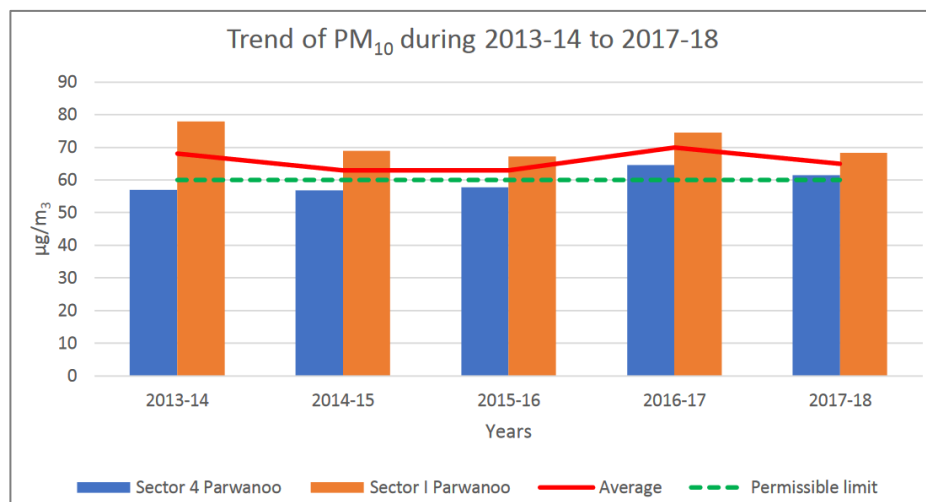


Figure 1.1: Annual average levels of PM₁₀ from 2013-14 to 2017-18 (HPSPCB, 2018)

1.4 Objectives and Scope of Work

Objectively the project aims to achieve the following:

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

- Selection of most effective control options for implementation and development of time-bound action plan.

1.5 Approach to the Study

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

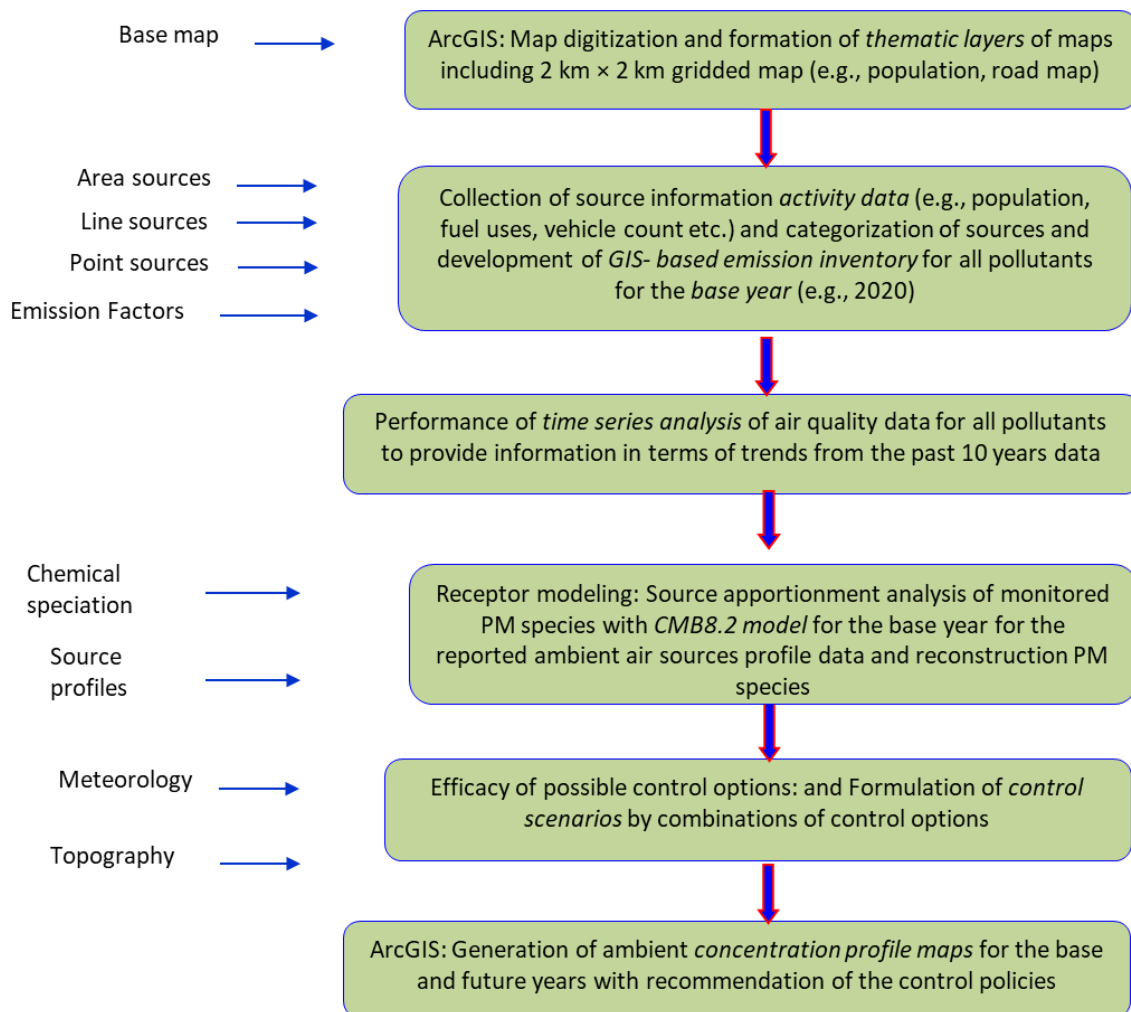


Figure 1.2: Approach to the Study and Major Tasks

1.5.1 Selection of sampling sites

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

1.5.2 Identification and Grouping of Sources for Emission Inventory

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

1.5.3 Emission Source Profiles

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

Since for PM_{2.5}, Indian or Himachal Pradesh specific source profiles are not available except for vehicular sources (ARAI, 2009), the source profiles for this study were taken from ‘SPECIATE version 3.2’ of USEPA (2006) and later versions. 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 Parwanoo city. For the sake of uniformity, source profiles for non-vehicular sources for PM₁₀ and PM_{2.5} were adopted from USEPA (2006).

1.5.4 Application of Receptor modeling

There are several methods and available commercial software that can be used for apportioning the sources if the emission profiles and measurements are available in the

ambient air particulate in terms of elemental composition. The most common software is USEPA PMF 5.0 (USEPA, 2014). This model should be able to provide the contribution of each source in the particulate in ambient air. The modeling results should help identify major sources for pollution control. It was important to note that along with source contribution, the model could also provide the associated uncertainties in estimated source contributions.

1.5.5 Time Series Analysis

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

1.6 Report Structure

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

Chapter 1

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

Chapter 2

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

Chapter 3

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

Chapter 4

This chapter describes the methodology of developing an emission inventory of pollutants at different grids of the city. The chapter also presents and compares the grid-wise results of emission inventory outputs for various pollutants. The contributions of various sources towards air pollution loads (pollutant-wise) are presented. The QA/QC approaches for emission inventory are also explained in this chapter.

Chapter 5

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

Chapter 6

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

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

2 Air Quality: Measurements, Data Analyses and Inferences

Air pollution continues to remain a public health concern despite various actions taken to control air pollution. There is a need to take stock of benefits that have accrued and ponder on 'Way Forward'. Further analysis of actions and future needs become even more important in view of the revised air quality standards that have been notified (http://www.cpcb.nic.in/National_Ambient_Air_Quality_Standards.php) (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 Parwanoo city in Himachal Pradesh for the winter season from the sampling and chemical analysis results carried out in the present study.

2.1 Methodology

2.1.1 Site Selection and details

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

Table 2.1: Description of sampling sites in Parwanoo

S. No.	Sampling Site	Site Code	Description of the site	Type of sources
1.	Shivalik Polymers Sec 3	SHP	Industrial	Industries, DG sets, vehicles, road dust, garbage/industrial waste burning, coal
2.	Nagar Parishad Sec 1	NGP	Commercial (adjoining industrial area)	DG sets, vehicles, road dust, garbage/waste burning, hotels, restaurants, coal uses
3.	HPPCB Office Sec 4	OPR	Residential	Domestic cooking, vehicles, road dust, garbage/MSW burning, biomass

Figure 2.1 shows the physical features (photographs) of the sampling sites. Figure 2.2 shows the locations of the sampling sites on the map and overall land-use pattern of the city.

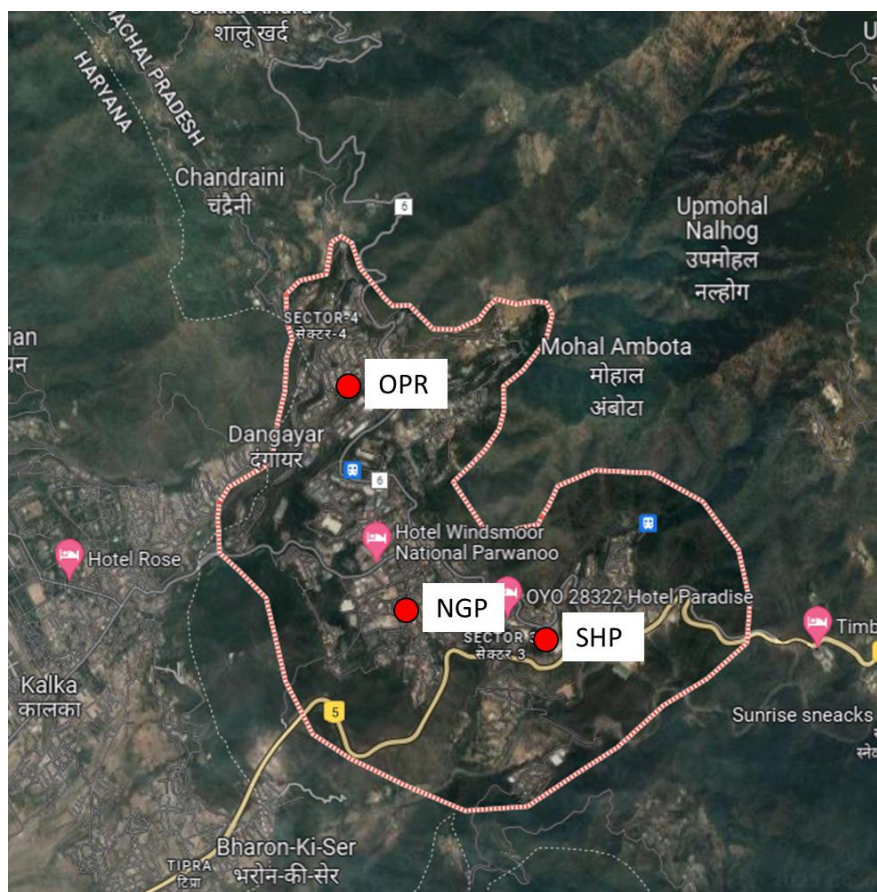


Figure 2.2: Land-use Pattern and Locations of Sampling Sites (GIS map and Google Map); SHP - Shivalik Polymers Sec 3 (Industrial), NGP - Nagar Parishad Sec 1 (Commercial), OPR - HPPCB Office Sec 4 (Residential)

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

Table 2.2: Details of Samplers/Analyzers and Methods

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

*Instruments are factory calibrated and were compared with NDIR-based CO analyzer and UV-fluorescence based ozone analyzer. The detection range for CO was 0.01 - 50 PPM and ozone was 0.01 ppb – 500 ppb

Table 2.3: Chemical Components for PM Characterization

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

2.1.2 Instruments and Accessories

As indicated in Table 2.2, the 4-channel speciation samplers (Umwelttechnik MCZ GmbH, Germany) were used for the sampling studies for monitoring particulate matter (Figure 2.3 (a)). The flow rate was 16.7 LPM. Three channels of the sampler are utilized: The first channel for PM₁₀, second channel for PM_{2.5} (Teflon filters - Whatman grade PTFE filters of 47 mm diameter) and third for collection of PM_{2.5} on quartz fiber filter (Whatman grade QM-

A quartz filters of 47 mm Diameter). PTFE filters are used for the analysis of ions and elements and quartz filters are used for OC-EC and PAHs. Gaseous sampler (AAS 118, Ecotech, India, flow rate of 1.0 LPM; Figure 2.3(h)) is used for gaseous pollutants (SO_2 , NO_2 and NH_3), Continuous online gaseous analyzers (Model: Easy-CAMS, make: Airshed planning professional Pvt Ltd, India, Figure 2.3(i)) are used for CO and O_3 . 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 $\text{PM}_{2.5}$ 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 $1\mu\text{g}$; Figure 2.3(b)) in controlled room having temperature $22\pm 2^\circ\text{C}$ and relative humidity less than 45%. OC and EC are analyzed by thermal optical transmittance (DRI Model 2001A Thermal/Optical Carbon Analyzer; Figure 2.3(c)).

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

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

PAHs were extracted in hexane and dichloromethane (DCM) solvent (1:1v/v) followed by passing it through silica cartridge (Rajput et al., 2011, USEPA, 1999d). The extracted samples were concentrated using rotary evaporator (up to 10 mL) and Turbo Vap (Work Station-II, Caliper Life Sciences, Hopkinton, USA) for final volume of 1 mL. Extracted samples were analyzed for PAHs using the Gas chromatography-Mass spectrophotometer (Model Clarus 600 S, Perkin Elmer, USA; Figure 2.3(d)).

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



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



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



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

Figure 2.3: Photographs of the Instruments

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

Quality assurance and quality control (QA/QC) in entire project planning and its implementation at all levels were designed and the hands-on training was imparted to the

project team before the beginning of any sampling and analysis. During sampling and analysis, a coding system has been adopted to eliminate any confusion. Separate codes for parameters, and time slots are adopted.

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

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

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

Sampling periods: The ambient air sampling has been completed for 7 days at each site during winter (December 14 – 23, 2019). The analysis of SO₂, NO₂ and NH₃ was carried out daily at the laboratory in Parwanoo 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 SHP

SHP - Parwanoo, Winter										
	14-Dec-19	15-Dec-19	16-Dec-19	17-Dec-19	18-Dec-19	19-Dec-19	20-Dec-19	21-Dec-19	22-Dec-19	23-Dec-19
PM10										
PM2.5										
OC										
EC										
VOC										
NO2										
NH3										
SO2										
CO										
O3										

Table 2.5: Sampling Days of Various Pollutants at NGP

NGP - Parwanoo, Winter										
	14-Dec-19	15-Dec-19	16-Dec-19	17-Dec-19	18-Dec-19	19-Dec-19	20-Dec-19	21-Dec-19	22-Dec-19	23-Dec-19
PM10										
PM2.5										
OC										
EC										
VOC										
NO2										
NH3										
SO2										

Table 2.6: Sampling Days of Various Pollutants at OPR

OPR - Parwanoo, Winter								
	15-Dec-19	16-Dec-19	17-Dec-19	18-Dec-19	19-Dec-19	20-Dec-19	21-Dec-19	22-Dec-19
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 *	50	20
	24 Hours **	80	80
Nitrogen Dioxide (NO ₂), µg/m ³	Annual *	40	30
	24 Hours **	80	80
Particulate Matter (Size less than 10µm) or PM ₁₀ , µg/m ³	Annual *	60	60
	24 Hours **	100	100
Particulate Matter (Size less than 2.5µm) or PM _{2.5} , µg/m ³	Annual *	40	40
	24 Hours **	60	60
Ozone (O ₃) µg/m ³	8 Hours *	100	100
	1 Hour **	180	180
Lead (Pb) µg/m ³	Annual *	0.50	0.50
	24 Hours **	1.0	1.0
Carbon Monoxide (CO), mg/m ³	8 Hours **	02	02
	1 Hour **	04	04
Ammonia (NH ₃), µg/m ³	Annual *	100	100
	24 Hours **	400	400
Benzene (C ₆ H ₆), µg/m ³	Annual *	5	5
Benzo(a)Pyrene (BaP) Particulate phase only, ng/m ³	Annual *	1	1
Arsenic (As), ng/m ³	Annual *	6	6
Nickel (Ni), ng/m ³	Annual *	20	20

*Annual Arithmetic mean of minimum 104 measurements in a year at a particular site taken twice a week 24 hourly at uniform intervals.
 ** 24 hourly or 8 hourly or 1 hourly monitored values, as applicable, shall be complied with 98% of the time in a year. 2% of the time, they may exceed the limits but not on two consecutive days of monitoring.
 NOTE: Whenever and wherever monitoring results on two consecutive days of monitoring exceed the limits specified above for the respective category, it shall be considered an adequate reason to institute regular or continuous monitoring and further investigations.
Conversion (µg/m³ to ppbv): CO = 0.87, O₃ = 0.51, SO₂ = 0.38, NO₂ = 0.53, NH₃ = 1.43

2.3.1 Particulate Matter (PM₁₀, PM_{2.5})

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

Shivalik Polymers Sec 3 (SHP)

The time-series of 24-hr average concentrations of PM₁₀ and PM_{2.5} are shown in Figure 2.4. Average levels were $72 \pm 28 \mu\text{g}/\text{m}^3$ (for PM_{2.5}) and $107 \pm 47 \mu\text{g}/\text{m}^3$ (for PM₁₀). The levels of PM₁₀ and PM_{2.5} are non-complying with the NAAQS. The corresponding CPCB air quality Index (AQI) was less than 303 and 173 in the category *very poor*. The ratio of PM_{2.5} to PM₁₀ was 0.68 at SHP.

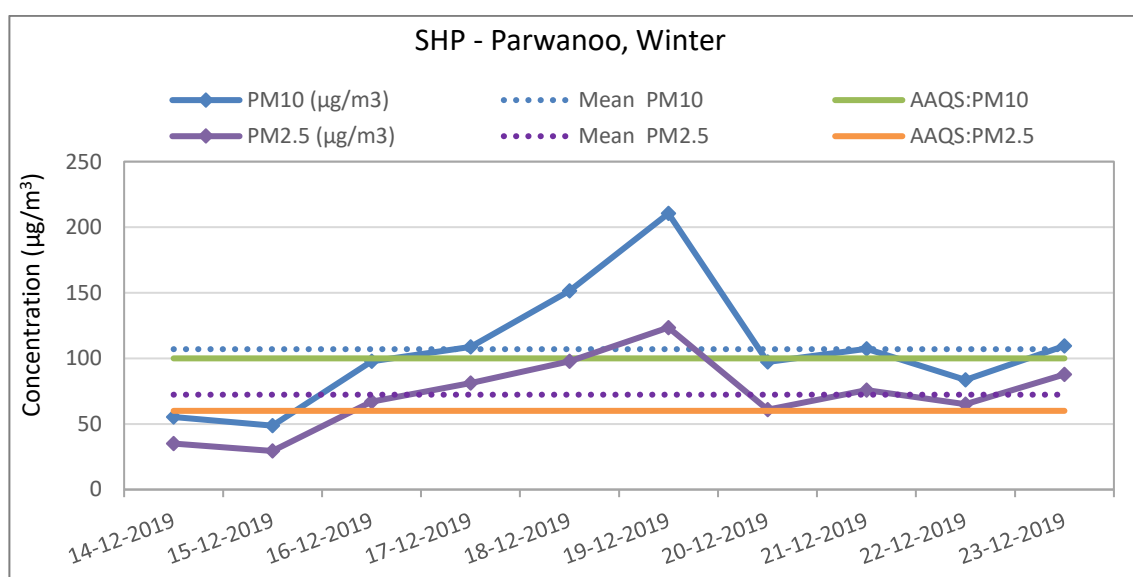


Figure 2.4: PM Concentrations at SHP

Nagar Parishad Sec 1 (NGP)

Time-series of 24-hr average concentrations of PM₁₀ and PM_{2.5} is shown in Figure 2.5. Average levels were $100 \pm 26 \mu\text{g}/\text{m}^3$ (for PM_{2.5}) and $182 \pm 59 \mu\text{g}/\text{m}^3$ (for PM₁₀). The levels of PM₁₀ and PM_{2.5} are non-complying with the NAQS. The corresponding CPCB air quality Index (AQI) was less than 312 and 210 in the category *very poor*. The ratio of PM_{2.5} to PM₁₀ was 0.57 at NGP.

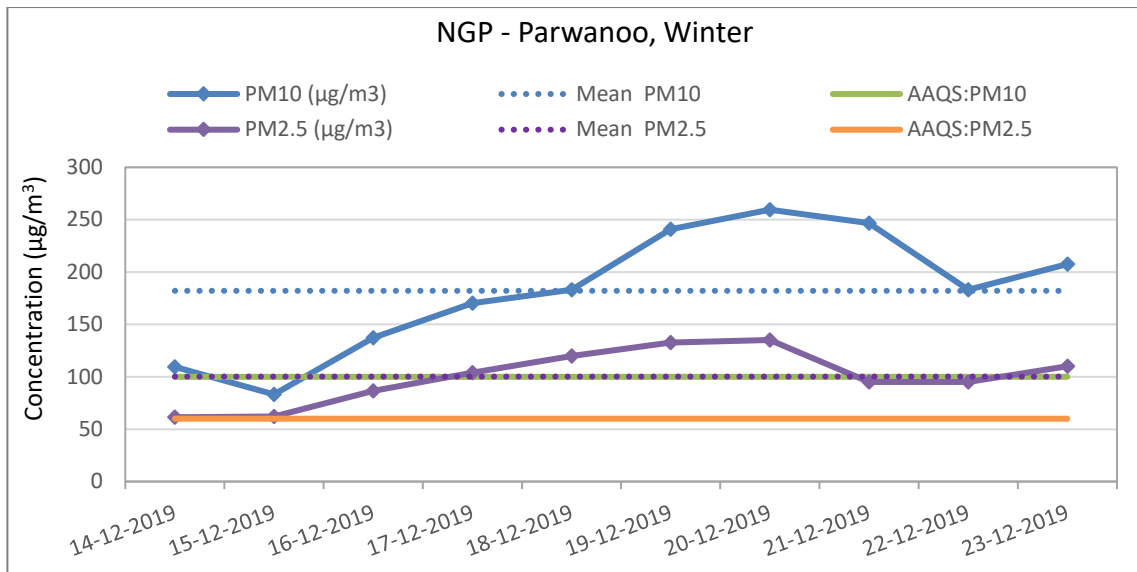


Figure 2.5: PM Concentrations at NGP

HPPCB Office Sec 4 (OPR)

The time-series of 24-hr average concentrations of PM₁₀ and PM_{2.5} is shown in Figure 2.6. Average levels were 91±38 µg/m³ (for PM_{2.5}) and 116±50 µg/m³ (for PM₁₀). The levels of PM₁₀ and PM_{2.5} are non-complying with the NAQS. The corresponding CPCB air quality Index (AQI) was less than 322 and 170 in the category *very poor*. The ratio of PM_{2.5} to PM₁₀ was 0.78 at OPR.

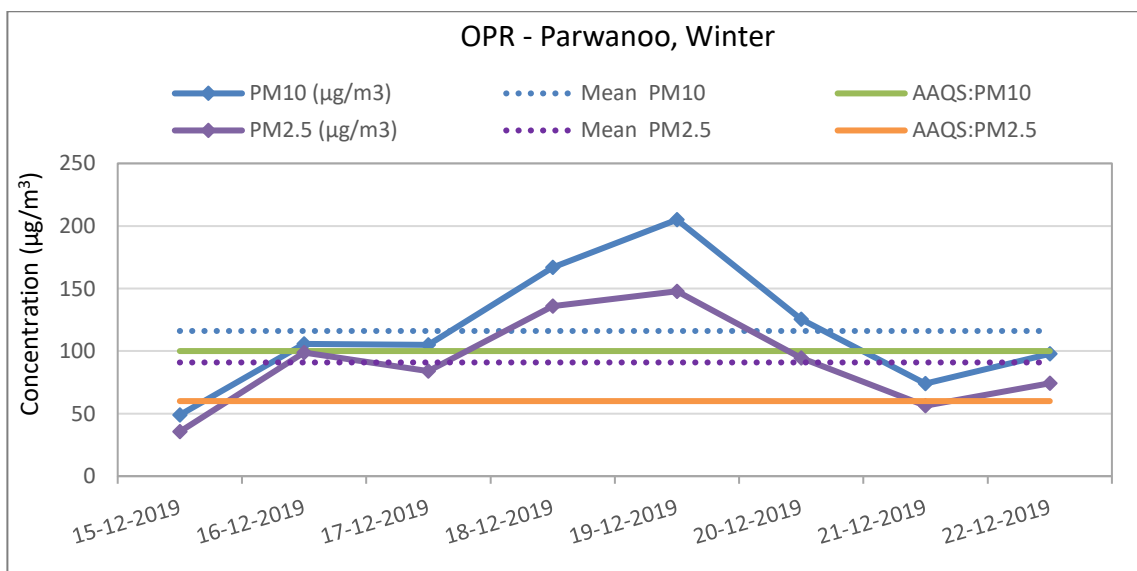


Figure 2.6: PM Concentrations at OPR

Overall PM levels

The site-wise comparison is shown for PM₁₀ and PM_{2.5} (Figure 2.7) and the ratio of PM_{2.5} to PM₁₀ (Figure 2.8) for all sites. The overall summary of experimental results for PM is shown for Parwanoo (Table 2.8).

The overall city mean levels in winter were $88 \pm 12 \mu\text{g}/\text{m}^3$ (for PM_{2.5}) and $135 \pm 33 \mu\text{g}/\text{m}^3$ (for PM₁₀) and the ratio (PM_{2.5}/PM₁₀) was 0.68 ± 0.09 . The PM_{2.5} levels are about 1.5 times higher than the NAAQS ($60 \mu\text{g}/\text{m}^3$) and PM₁₀ also about 1.4 times higher than the standard ($100 \mu\text{g}/\text{m}^3$). The PM₁₀ and PM_{2.5} levels were highest at NGP (182 and $100 \mu\text{g}/\text{m}^3$) and lowest at SHP (107 and $72 \mu\text{g}/\text{m}^3$).

The ratio of PM_{2.5} to PM₁₀ is a useful parameter to indicate the relative abundance of fine particles (i.e., PM_{2.5}) and toxicity of particulate matter. The overall city ratio is 0.68 and it was highest at OPR (0.78) followed by SHP (0.68). The relatively high PM_{2.5} at these sites could be attributed to high traffic and emissions from industrial units.

The lowest levels of PM₁₀ and PM_{2.5} at SHP, an industrial site, could be because most of industries are non-polluting engineering units and it was observed during field survey there was insignificant commercial activities in the industrial area. However, the site NGP, a commercial site was buzzing with activities, traffic movement and dust emissions. The concentration levels at two sites are justified in respect to emissions and prevailing land-use.

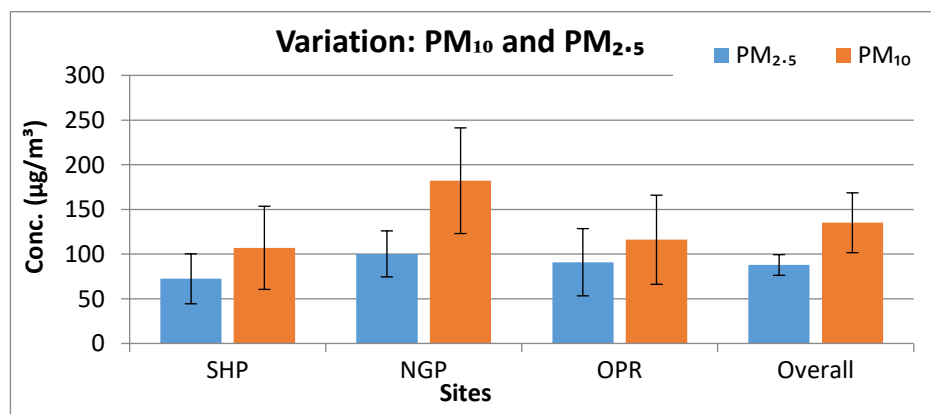


Figure 2.7: Comparison of PM levels at all sites

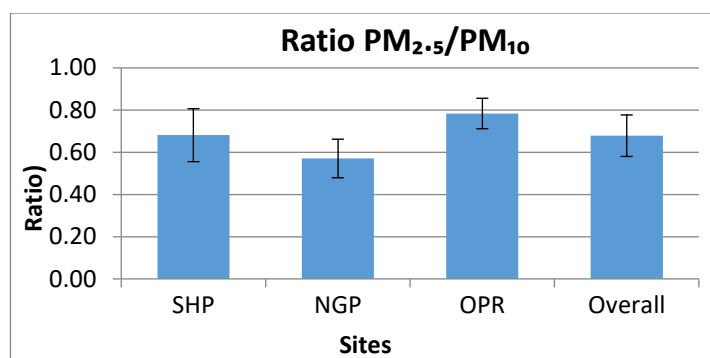


Figure 2.8: Comparison of PM_{2.5}/PM₁₀ ratio for all sites

Table 2.8: Statistical Results of PM_{2.5} and PM₁₀ in (µg/m³) at Parwanoo

Site		PM _{2.5}	PM ₁₀	PM _{2.5} /PM ₁₀
SHP	Mean±SD	72±28	107±47	0.68±0.07
	Range	29-124	49-210	0.59-0.80
NGP	Mean±SD	100±26	182±59	0.57±0.10
	Range	61-135	83-260	0.39-0.75
OPR	Mean±SD	91±38	116±50	0.78±0.07
	Range	36-148	49-205	0.72-0.94
Overall	Mean±SD	88±12	135±33	0.68±0.09

2.3.2 Gaseous pollutants

The statistical summary for gaseous pollutant (SO₂, NO₂ and NH₃) results are given in Table 2.9.

SHP

The time-series of 24-hr average concentrations of SO₂, NO₂ and NH₃ are shown in Figure 2.9. It was observed that SO₂, NO₂ and NH₃ concentrations were low and meets the air quality standards.

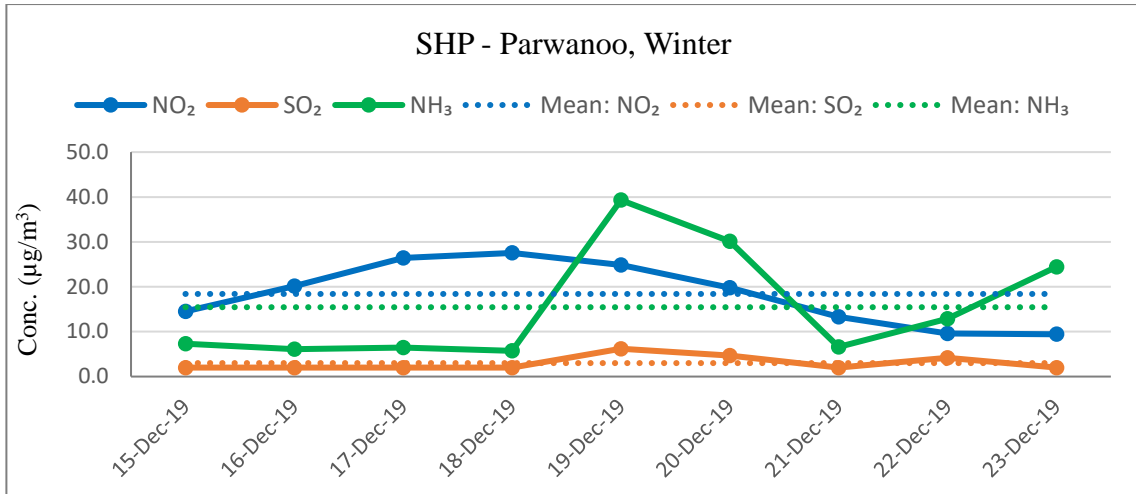


Figure 2.9: SO₂, NO₂ and NH₃ concentrations at SHP

NGP

Time-series of 24-hr average concentrations of SO₂, NO₂ and NH₃ are shown in Figure 2.10. It was observed that SO₂, NO₂ and NH₃ concentrations were low and met the air quality standard. SO₂ concentrations are lesser than NO₂ concentrations.

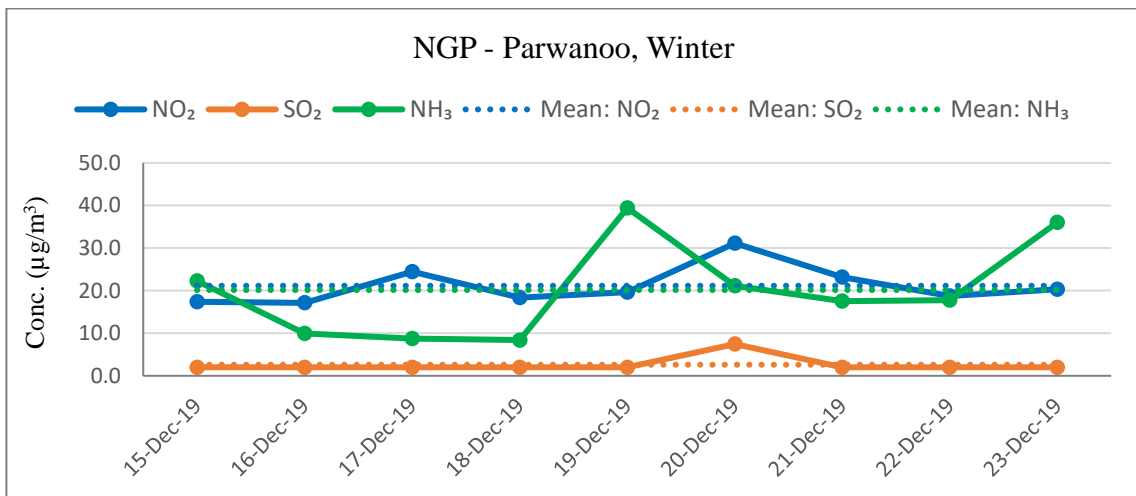


Figure 2.10: SO₂, NO₂ and NH₃ concentrations at NGP

OPR

Time-series of 24-hr average concentrations of SO₂, NO₂ and NH₃ are shown in Figure 2.11. It was observed that SO₂, NO₂ and NH₃ concentrations were low and met the air quality standard.

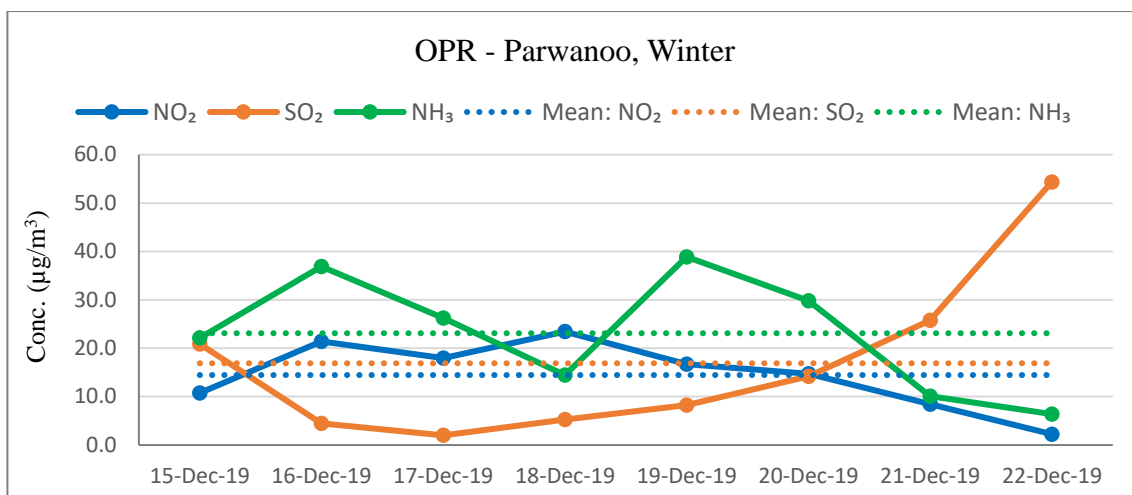


Figure 2.11: SO₂, NO₂ and NH₃ concentrations at OPR

Overall gaseous levels

The site-wise comparison is shown for NO₂, SO₂ and NH₃ (Figure 2.12) for all sites. The overall summary of experimental results for gaseous pollutants are shown for Parwanoo (Table 2.9). It was observed that SO₂, NO₂ and NH₃ concentrations were met the air quality standard at all sites.

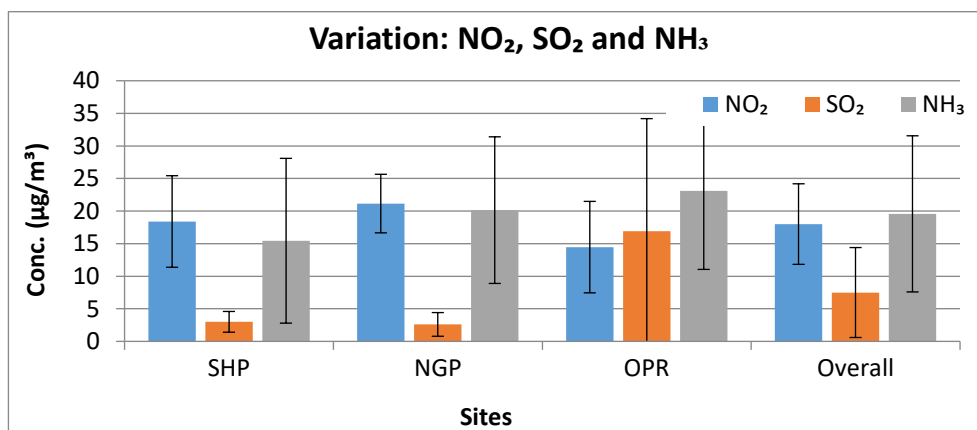


Figure 2.12: Comparison of gaseous pollutants levels at all sites

Table 2.9: Statistical results of gaseous pollutants (µg/m³) at Parwanoo

Site		NO ₂	SO ₂	NH ₃
SHP	Mean±SD	18.4±7.0	3.0±1.6	15.4±12.6
	Range	9.4-27.5	2.0-6.2	5.7-39.3
NGP	Mean±SD	21.2±4.5	2.6±1.8	20.1±11.2
	Range	17.1-31.1	2.0-7.4	8.4-39.4

OPR	Mean±SD	14.5±7.0	16.9±17.3	23.1±12.1
	Range	2.2-23.4	2.0-54.4	6.4-38.9
Overall	Mean±SD	18.0±6.2	7.5±6.9	19.6±12.0

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 Parwanoo are presented in Table 2.10.

The overall city-level average of total BTX levels is $1.19 \pm 0.44 \mu\text{g}/\text{m}^3$ in winter. It is observed that the BTX concentrations are highest at NGP ($1.52 \mu\text{g}/\text{m}^3$) could be due to the more industrial and traffic activities and the lowest at the OPR ($1.02 \mu\text{g}/\text{m}^3$) could be due to the less organic solvent uses and less traffic movement in residential area. The possible reason for higher concentrations in NGP could be more vehicle movement in this area due to petrol pumps, main market, alongside the main road and which may cause large evaporative losses from fuel tanks of vehicles and petrol pumps.

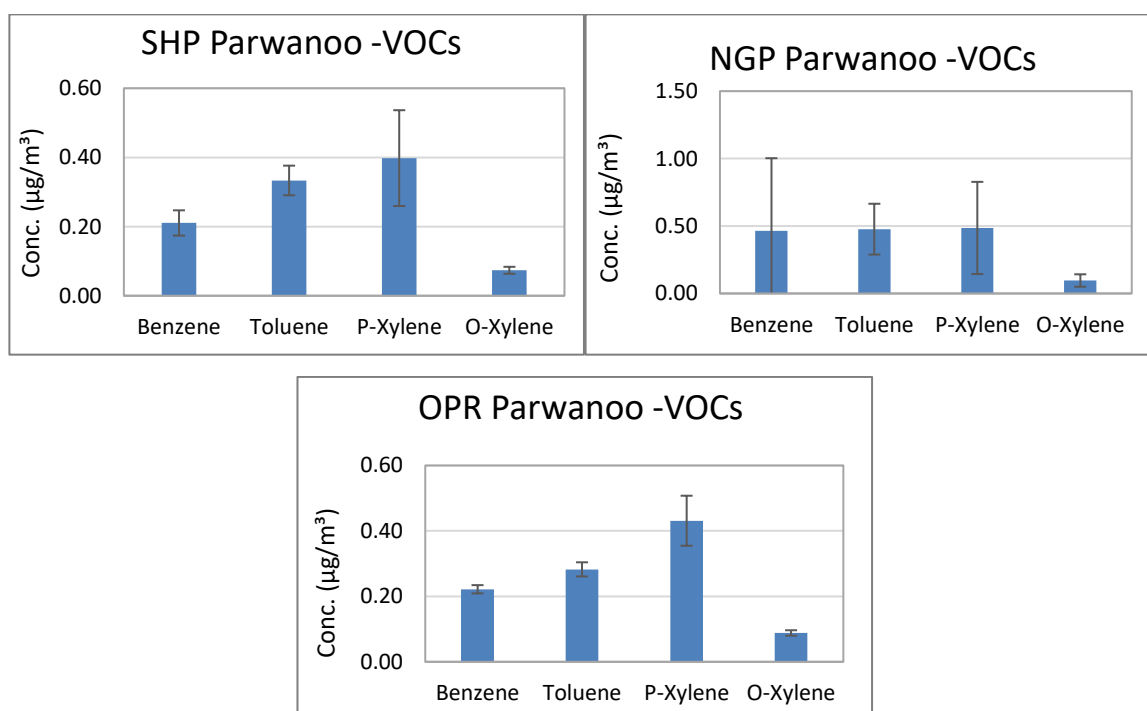


Figure 2.13: VOCs Concentrations at different sites in Parwanoo

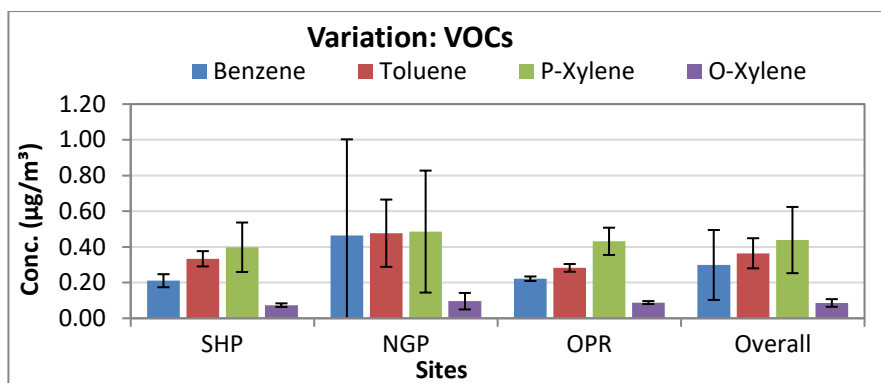


Figure 2.14: Comparison of gaseous pollutants levels at all sites

Table 2.10: Statistical Results of VOCs Contents ($\mu\text{g}/\text{m}^3$) at Parwanoo

Site		Benzene	Toluene	P-Xylene	O-Xylene	Total (BTX)
SHP	Mean \pm SD	0.21 \pm 0.04	0.33 \pm 0.04	0.40 \pm 0.14	0.07 \pm 0.01	1.02 \pm 0.16
	Range	0.16-0.24	0.30-0.40	0.24-0.59	0.06-0.09	0.85-1.23
NGP	Mean \pm SD	0.46 \pm 0.54	0.48 \pm 0.19	0.49 \pm 0.34	0.10 \pm 0.05	1.52 \pm 1.08
	Range	0.21-1.43	0.36-0.81	0.18-1.01	0.06-0.18	0.82-3.42
OPR	Mean \pm SD	0.22 \pm 0.01	0.28 \pm 0.02	0.43 \pm 0.08	0.09 \pm 0.01	1.02 \pm 0.07
	Range	0.21-0.24	0.26-0.32	0.35-0.52	0.08-0.10	0.91-1.09
Overall	Mean \pm SD	0.30 \pm 0.20	0.36 \pm 0.08	0.44 \pm 0.19	0.09 \pm 0.02	1.19 \pm 0.44

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

SHP

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 SHP. Statistical results of carbon contents ($\mu\text{g}/\text{m}^3$) in $\text{PM}_{2.5}$ at SHP are presented in Table 2.11.

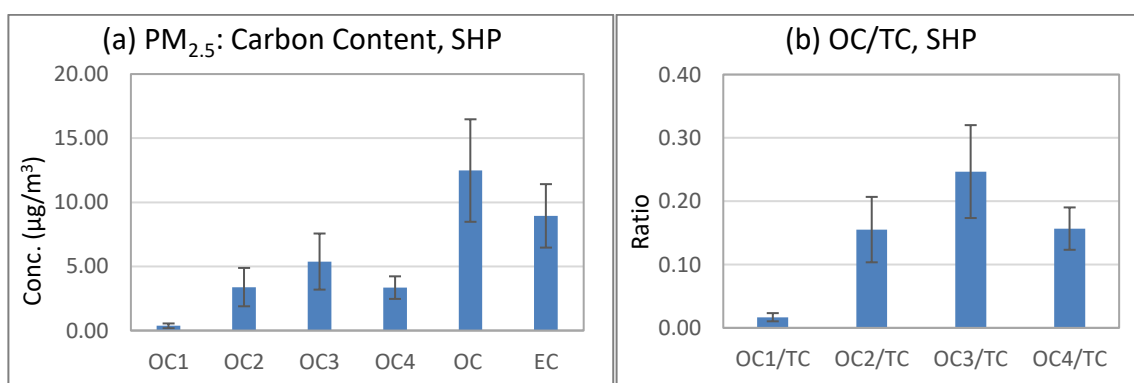


Figure 2.15: EC and OC Content in PM_{2.5} at SHP

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

	OC1	OC2	OC3	OC4	OC	EC	TC	OC1/TC	OC2/TC	OC3/TC	OC4/TC
Mean	0.37	3.39	5.38	3.35	12.48	8.94	21.42	0.02	0.16	0.25	0.16
SD	0.19	1.50	2.19	0.88	4.00	2.47	3.90	0.01	0.05	0.07	0.03
CV	0.51	0.44	0.41	0.26	0.32	0.28	0.18	0.38	0.33	0.30	0.21
Max	0.79	6.22	10.12	4.70	18.49	13.89	28.00	0.03	0.24	0.41	0.20
Min	0.16	1.34	2.40	1.52	5.42	6.33	16.75	0.01	0.07	0.12	0.08

NGP

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 NGP. Statistical results of carbon contents ($\mu\text{g}/\text{m}^3$) in PM_{2.5} at NGP are presented in Table 2.12.

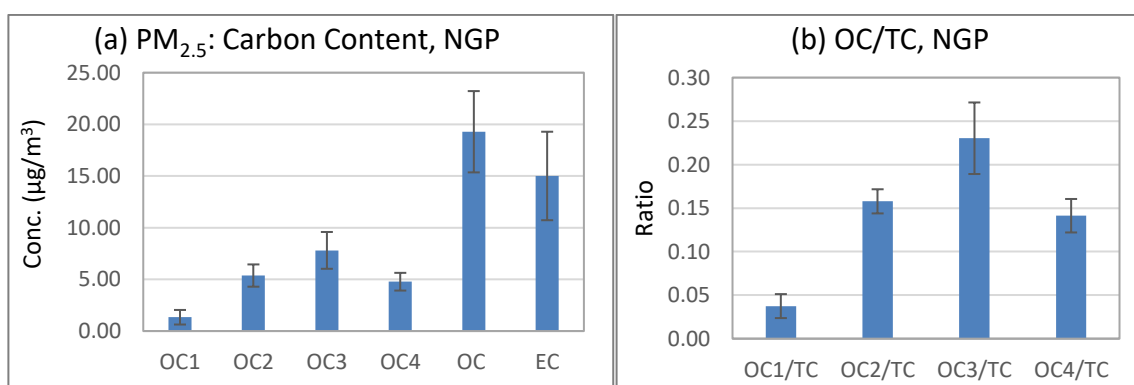


Figure 2.16: EC and OC Content in PM_{2.5} at NGP

Table 2.12: Statistical Results of Carbon Contents ($\mu\text{g}/\text{m}^3$) in PM_{2.5} at NGP

	OC1	OC2	OC3	OC4	OC	EC	TC	OC1/TC	OC2/TC	OC3/TC	OC4/TC
Mean	1.34	5.37	7.80	4.78	19.29	15.01	34.29	0.04	0.16	0.23	0.14
SD	0.70	1.08	1.78	0.86	3.93	4.28	7.34	0.01	0.01	0.04	0.02
CV	0.53	0.20	0.23	0.18	0.20	0.29	0.21	0.37	0.09	0.18	0.14
Max	2.35	7.02	10.48	5.96	25.12	21.73	45.28	0.06	0.19	0.31	0.17
Min	0.59	3.84	4.93	3.18	13.56	8.87	22.83	0.02	0.13	0.16	0.12

OPR

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 than indicating the formation of secondary organic carbon in the atmosphere at OPR. Statistical results of carbon contents ($\mu\text{g}/\text{m}^3$) in $\text{PM}_{2.5}$ at OPR are presented in Table 2.13.

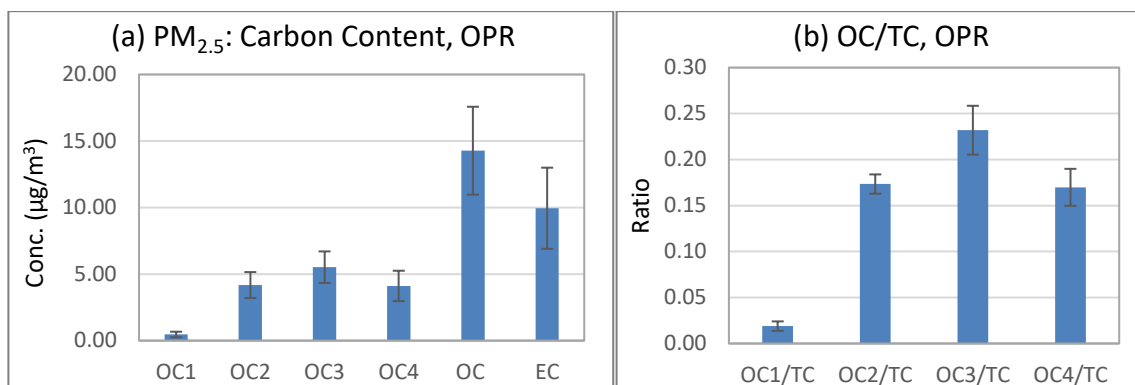


Figure 2.17: EC and OC Content in $\text{PM}_{2.5}$ at OPR

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

	OC1	OC2	OC3	OC4	OC	EC	TC	OC1/TC	OC2/TC	OC3/TC	OC4/TC
Mean	0.46	4.18	5.52	4.11	14.27	9.95	24.22	0.02	0.17	0.23	0.17
SD	0.21	0.97	1.19	1.14	3.30	3.05	6.15	0.01	0.01	0.03	0.02
CV	0.45	0.23	0.21	0.28	0.23	0.31	0.25	0.28	0.06	0.11	0.12
Max	0.86	5.23	7.52	5.54	18.33	13.76	31.42	0.03	0.20	0.27	0.21
Min	0.28	2.35	3.84	2.30	8.77	5.28	14.05	0.01	0.16	0.20	0.15

Overall

The comparison for OC and EC is presented in Figure 2.18 for $\text{PM}_{2.5}$. The overall summary of carbon content (TC, EC, OC; OC1, OC2, OC3 and OC4 with fractions OC1/TC, OC2/TC, OC3/TC and OC4/TC) is presented in Table 2.14.

The $\text{PM}_{2.5}$ contained a high fraction of TC (OC+EC) at 28% in winter. The OC is observed higher than the EC at each site; this is generally true that in the atmosphere volatile and semi-volatile organic compounds continuously undergo nucleation, oxidation, condensation and conversion into organic particles, whereas EC remains unchanged, as a result, the ratio of OC to EC further increases. However, the ratio of OC3/TC is observed higher than other OC

fractions; this indicates the formation of secondary organic carbon particles in the atmosphere is an important process. It is also observed that the OC and EC are high probably because of poor dispersion in winter and more combustion sources, including coal, biomass and municipal solid waste (MSW) burning. It is observed that the average TC to PM_{2.5} ratio was maximum at NGP (33%) and minimum at OPR (23%) in winter (Table 2.14).

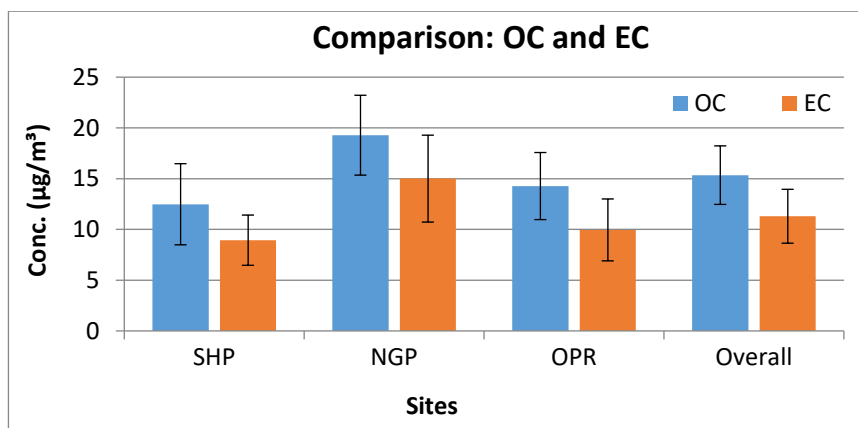


Figure 2.18: Comparison of EC and OC in PM_{2.5} for all Sites

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

Sites	PM _{2.5}	OC1	OC2	OC3	OC4	OC	EC	TC	OC1/TC	OC2/TC	OC3/TC	OC4/TC
SHP	79	0.37	3.39	5.38	3.35	12.48	8.94	21.42	0.02	0.16	0.25	0.16
NGP	105	1.34	5.37	7.80	4.78	19.29	15.01	34.29	0.04	0.16	0.23	0.14
OPR	104	0.46	4.18	5.52	4.11	14.27	9.95	24.22	0.02	0.17	0.23	0.17
Overall	96	0.72	4.31	6.23	4.08	15.34	11.30	26.64	0.02	0.16	0.24	0.16
SD	12	0.44	0.82	1.11	0.58	2.88	2.65	5.53	0.01	0.01	0.01	0.01

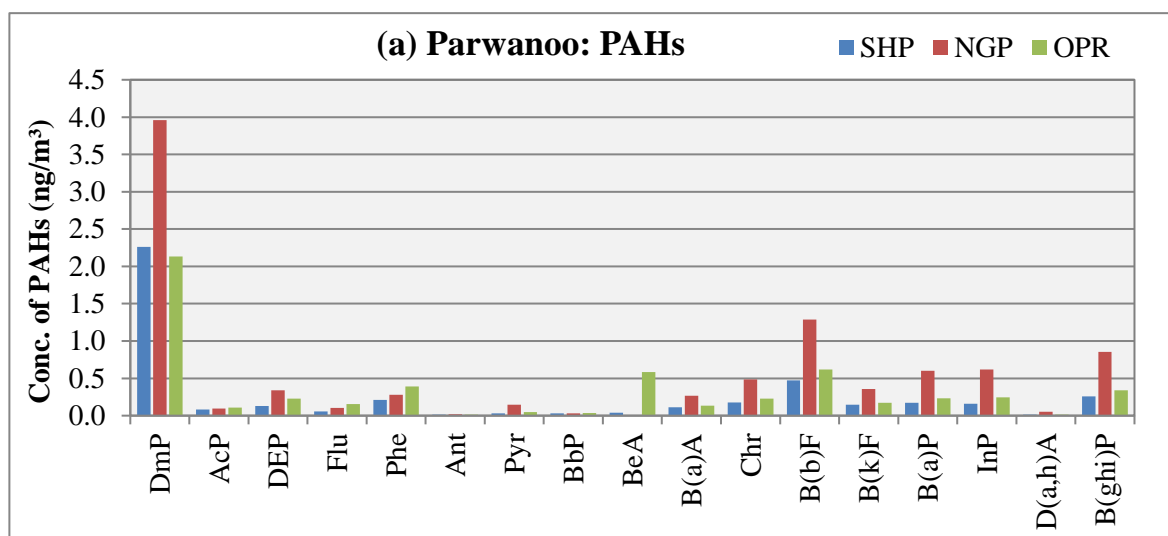
2.3.5 PAHs in PM_{2.5}

The concentrations of PAHs (from solid phase only) with some specific markers were analyzed. Figure 2.19 shows the average measured concentration of PAHs in Parwanoo for winter season. A statistical summary of PAHs is presented in Table 2.15 for winter season at all sites. The PAHs compounds analyzed were: (i) Di methyl Phthalate (DmP), (ii) Acenaphthylene (AcP), (iii) Di ethyl Phthalate (DEP), (iv) Fluorene (Flu), (v) Phenanthrene (Phe), (vi) Anthracene (Ant), (vii) Pyrene (Pyr), (viii) Butyl benzyl phthalate (BbP), (ix)

Bis(2-ethylhexyl) adipate (BeA), (x) Benzo(a)anthracene (B(a)A), (xi) Chrysene (Chr), (xii) Benzo(b)fluoranthene (B(b)F), (xiii) Benzo(k)fluoranthene (B(k)F), (xiv) Benzo(a)pyrene (B(a)P), (xv) Indeno(1,2,3-cd)pyrene (InP), (xviii) Dibenzo(a,h)anthracene (D(a,h)A) and (xix) Benzo(ghi)perylene (B(ghi)P). Major PAHs (mostly higher molecular weight compounds) are DmP (2.8 ng/m³), B(b)F (0.8 ng/m³), B(ghi)P (0.5 ng/m³), B(a)P (0.34 ng/m³), InP (0.34 ng/m³), Chr (0.30 ng/m³) and B(k)F (0.23 ng/m³) in winter.

The overall average total PAHs were 6.5±2.5 ng/m³. B(a)P, although has the annual standard of 1 ng/m³ and we cannot compare it with levels of 7 days sampling at each site, however levels of B(a)P (mean: 0.34 ng/m³) were low and annual standard may likely meets 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 (0.41) 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.



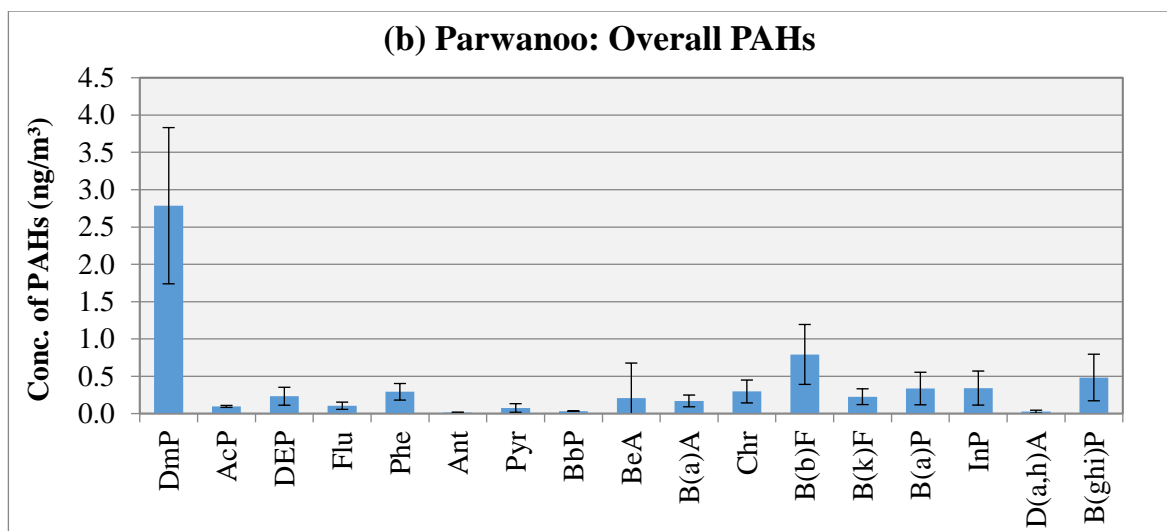
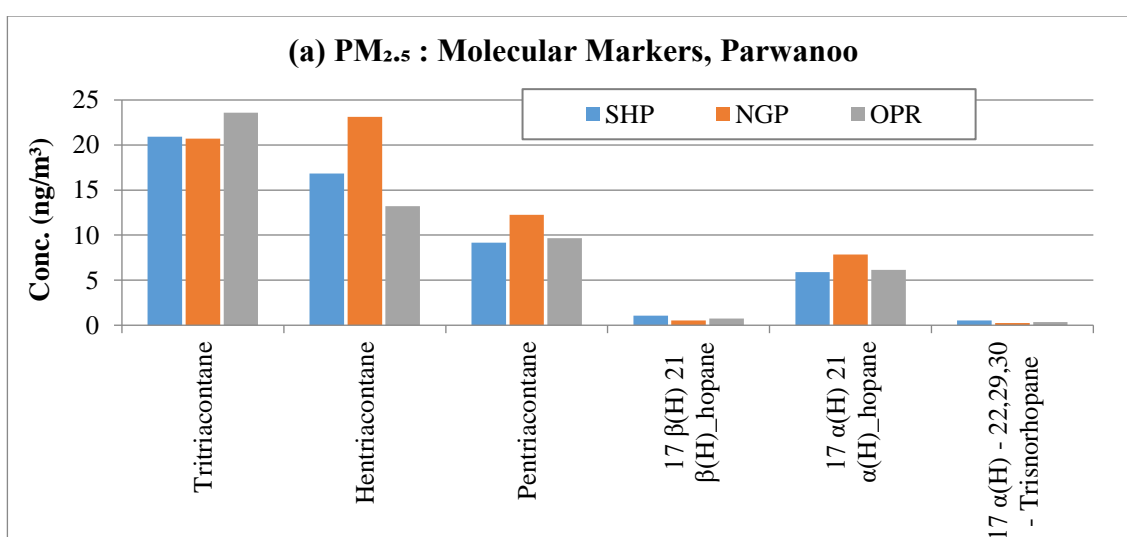


Figure 2.19: PAHs Concentrations in PM_{2.5}

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 57.6±6.4 ng/m³ in winter. The presence of significant quantities of molecular markers, especially hopanes conclusively establishes contribution of CGD.



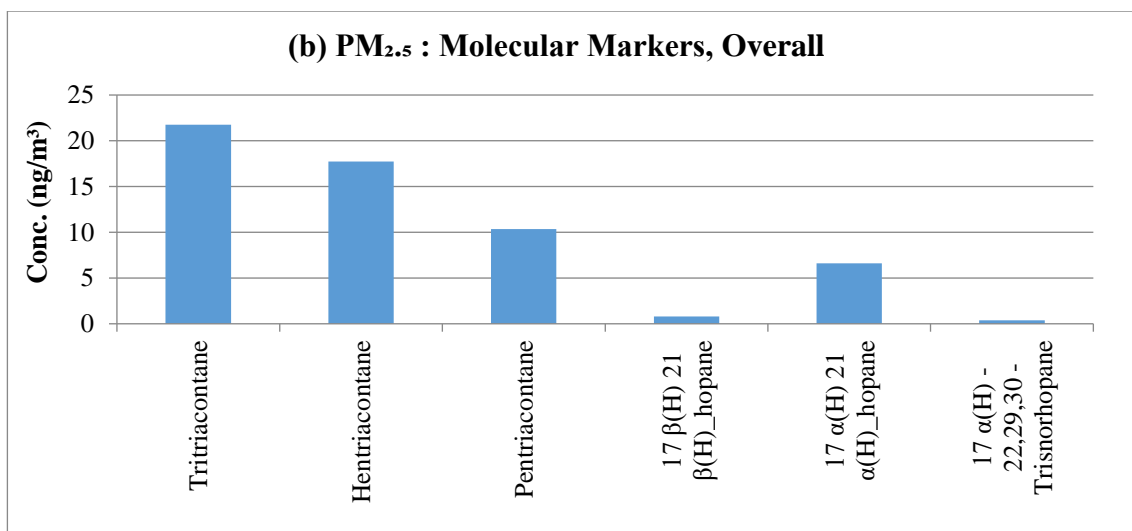
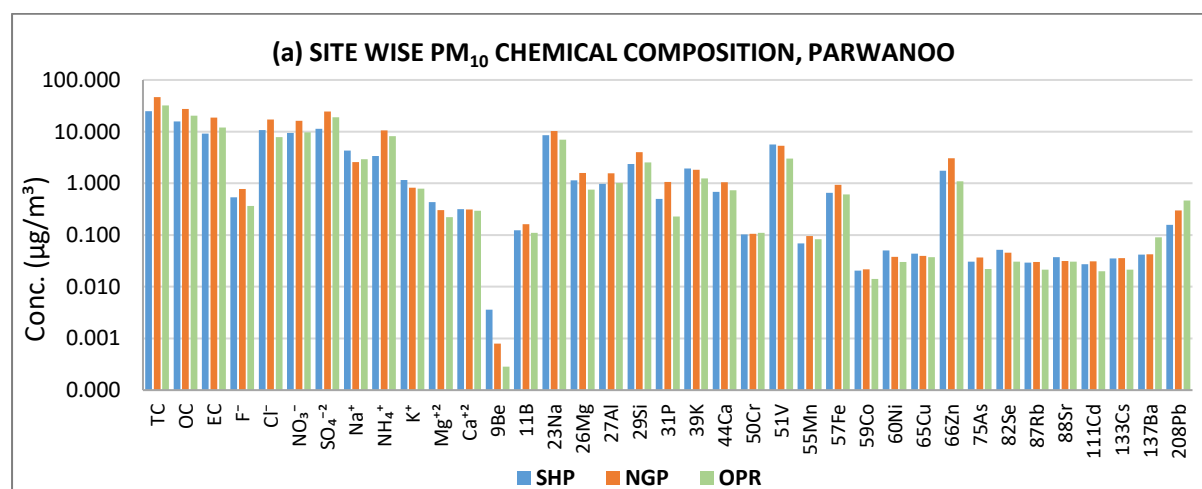


Figure 2.20: Molecular Markers in PM_{2.5}

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

Graphical presentations of chemical species for PM₁₀ and PM_{2.5} for all the sites of Parwanoo are shown in Figure 2.21. Statistical summary for particulate matter (PM₁₀ and PM_{2.5}), its chemical composition [carbon content, ionic species and elements] along with mass percentage (% R) recovered from PM are presented in Tables 2.17 – 2.20.

The correlation between different parameters (i.e., PM, OC, EC, F⁻, Cl⁻, NO₃⁻, SO₄⁻², Na⁺, NH₄⁺, K⁺, Ca⁺², Mg⁺² and metals (elements) with major species (PM, OC, EC, NO₃⁻, SO₄⁻², NH₄⁺, Metals) for PM₁₀ and PM_{2.5} composition is presented in Table 2.21. It is seen that most of the parameters showed a good correlation (>0.30) with PM₁₀ and PM_{2.5}. The percentage constituent of the PM₁₀ and PM_{2.5} are presented in Figures 2.22 and 2.23 respectively.



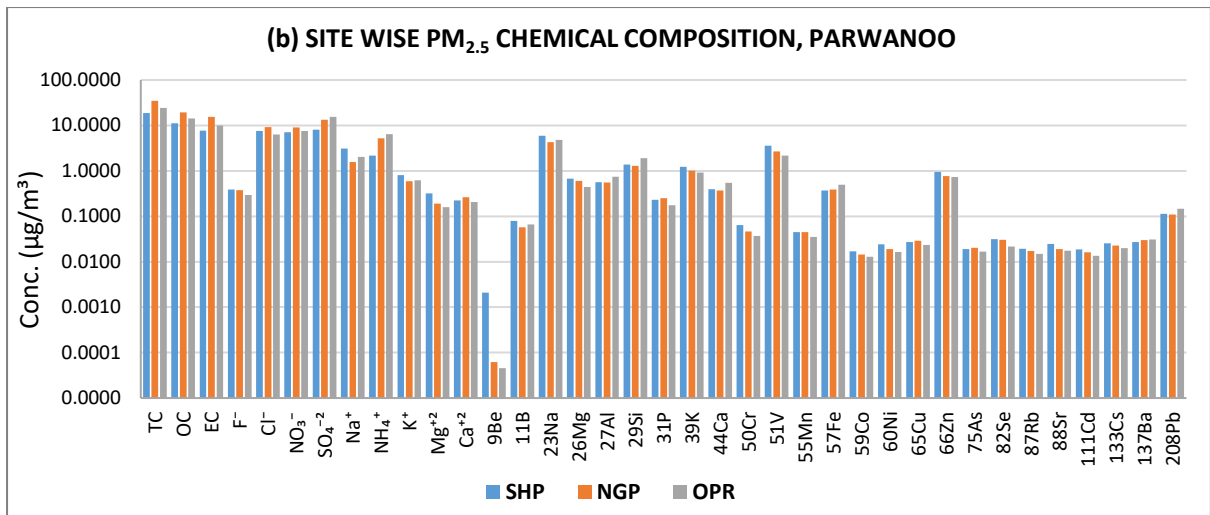
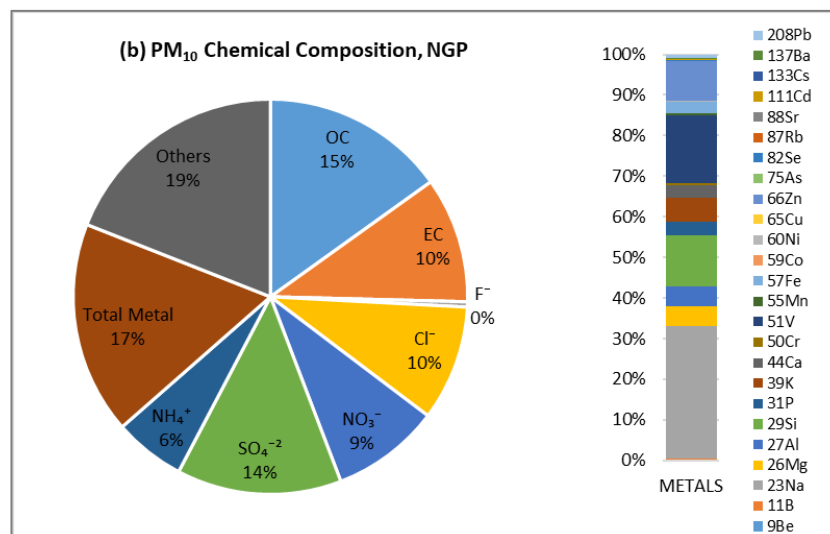
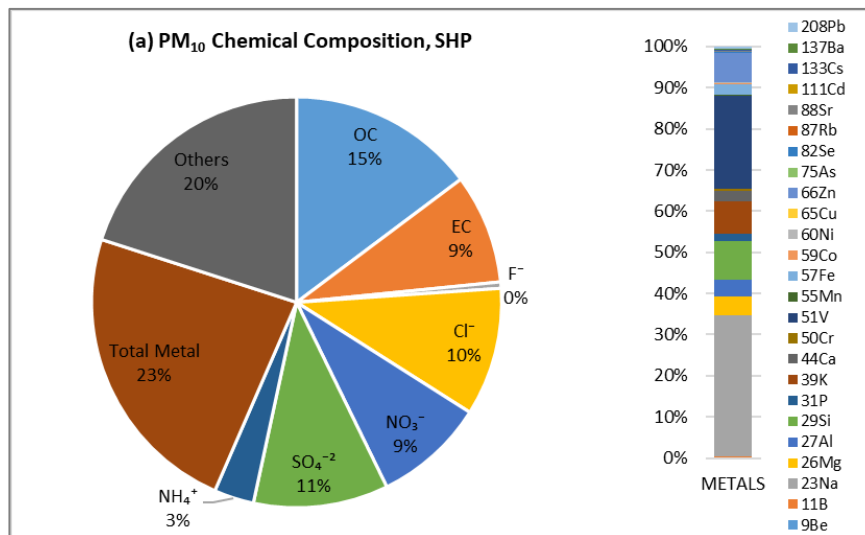


Figure 2.21: Concentrations of species in (a) PM₁₀ and (b) PM_{2.5}



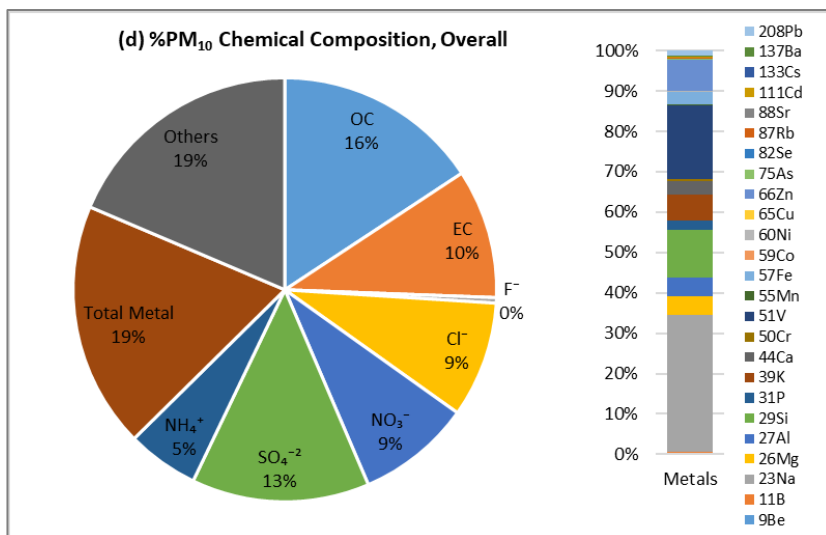
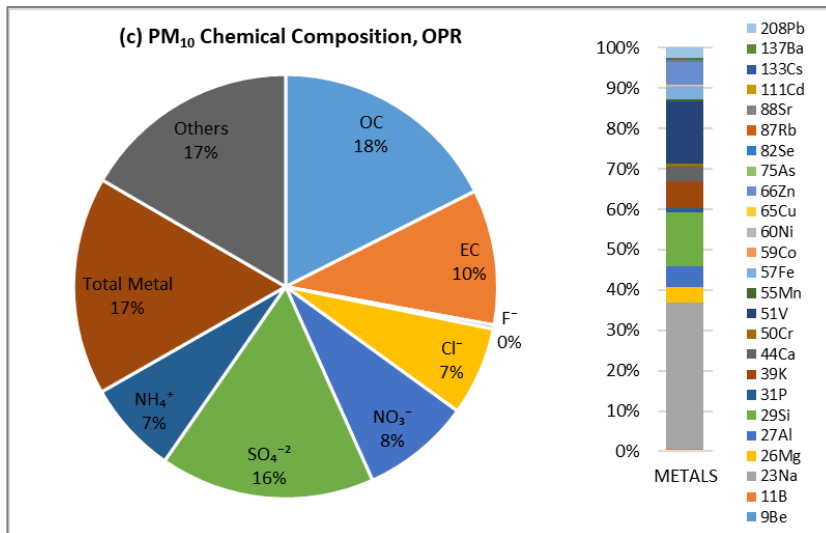
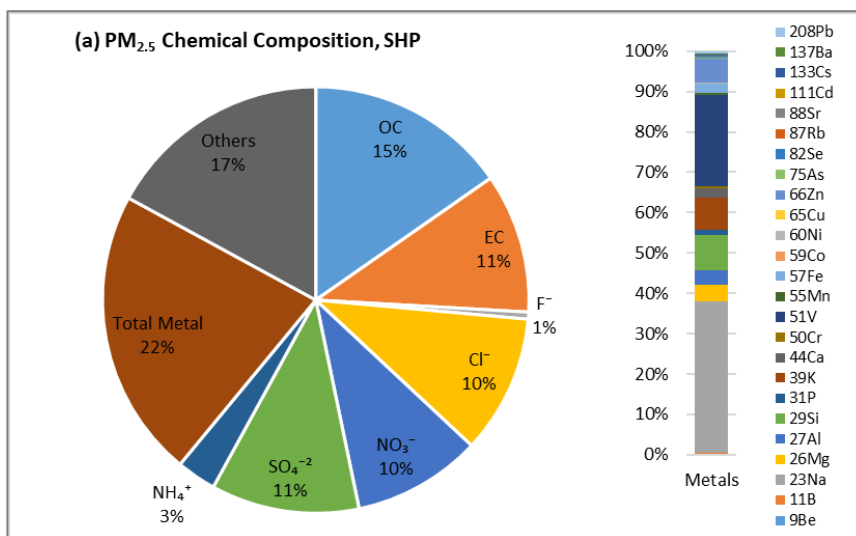


Figure 2.22: Percentage distribution of species in PM₁₀



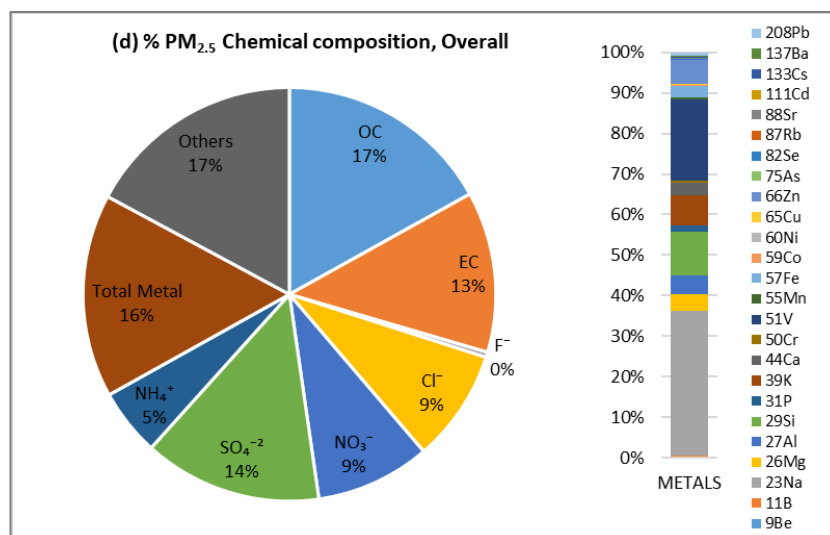
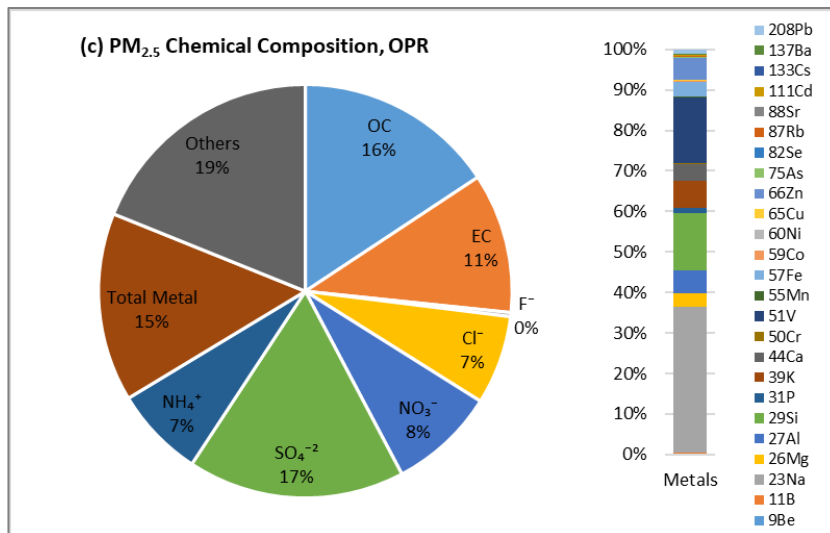
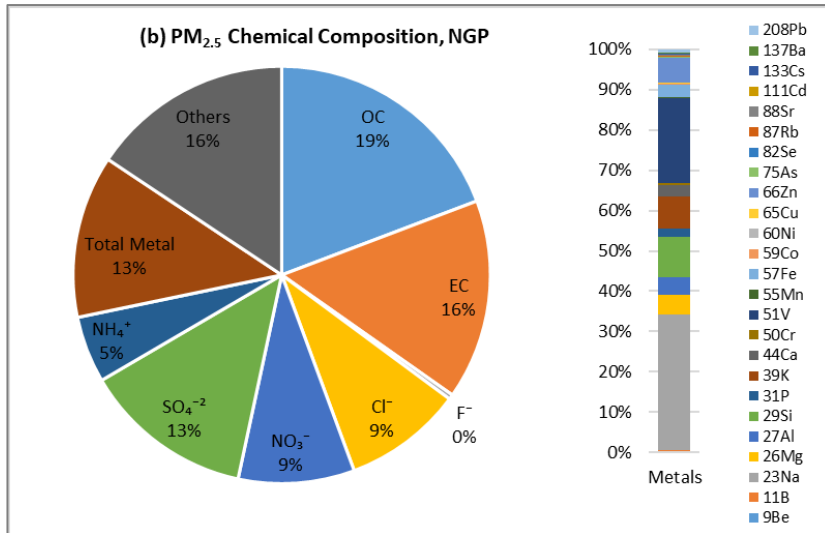


Figure 2.23: Percentage distribution of species in PM_{2.5}

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
SHP	2.26	0.08	0.13	0.06	0.21	0.01	0.03	0.03	0.04	0.11	0.18	0.47	0.15	0.17	0.16	0.02	0.26	4.37
NGP	3.96	0.10	0.34	0.10	0.28	0.02	0.14	0.03	0.00	0.27	0.48	1.29	0.36	0.60	0.62	0.05	0.85	9.50
OPR	2.13	0.11	0.23	0.15	0.39	0.01	0.05	0.03	0.58	0.13	0.23	0.62	0.17	0.23	0.25	0.01	0.34	5.68
Mean	2.79	0.10	0.23	0.11	0.29	0.02	0.08	0.03	0.21	0.17	0.30	0.79	0.23	0.34	0.34	0.03	0.48	6.51
SD	1.05	0.01	0.12	0.05	0.11	0.00	0.06	0.00	0.47	0.08	0.15	0.40	0.11	0.22	0.23	0.02	0.31	2.52
Max	4.32	0.11	0.34	0.17	0.49	0.02	0.17	0.03	1.17	0.31	0.54	1.42	0.39	0.69	0.72	0.05	1.04	9.81
Min	1.41	0.08	0.08	0.03	0.14	0.01	0.03	0.03	0.00	0.10	0.18	0.39	0.12	0.13	0.13	0.01	0.23	3.99
CV	0.38	0.14	0.52	0.46	0.38	0.29	0.76	0.07	2.28	0.47	0.52	0.51	0.47	0.65	0.67	0.73	0.65	0.39

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
SHP	20.92	16.84	9.17	1.07	5.88	0.54	54.43
NGP	20.71	23.11	12.24	0.54	7.84	0.26	64.70
OPR	23.59	13.20	9.65	0.76	6.15	0.37	53.72
Mean	21.74	17.72	10.35	0.79	6.62	0.39	57.61
SD	1.61	5.01	1.65	0.27	1.06	0.14	6.14
CV	0.07	0.28	0.16	0.34	0.16	0.37	0.11

Table 2.17: Statistical results of chemical characterization ($\mu\text{g}/\text{m}^3$) of PM₁₀ at sites

		PM ₁₀	OC	EC	F ⁻	Cl ⁻	NO ₃ ⁻	SO ₄ ⁻²	Na ⁺	NH ₄ ⁺	K ⁺	Mg ⁺²	Ca ⁺²	Be	B	Na	Mg	Al	Si	P
SHP	MEAN	107.03	15.82	9.23	0.54	10.78	9.38	11.38	4.30	3.36	1.16	0.44	0.32	0.00	0.12	8.59	1.14	0.98	2.35	0.50
	SD	46.52	6.97	3.10	0.17	5.32	3.65	5.19	3.55	4.86	0.94	0.28	0.13	0.00	0.14	4.02	0.46	0.72	1.81	0.53
NGP	MEAN	182.11	27.53	18.74	0.78	17.21	16.22	24.62	2.58	10.64	0.82	0.30	0.31	0.00	0.16	10.28	1.59	1.56	3.99	1.06
	SD	59.11	4.59	5.15	0.48	9.17	8.04	10.58	1.30	6.27	0.48	0.24	0.11	0.00	0.10	3.67	0.79	0.98	2.78	0.90
OPR	MEAN	116.05	20.39	11.99	0.36	7.84	9.65	19.02	2.91	8.21	0.79	0.22	0.29	0.00	0.11	6.99	0.76	1.02	2.55	0.23
	SD	49.87	4.72	3.67	0.10	4.43	6.13	14.16	1.00	5.86	0.48	0.14	0.10	0.00	0.05	2.93	0.28	0.36	0.98	0.13
		K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	%R
SHP	MEAN	1.93	0.68	0.10	5.67	0.07	0.66	0.02	0.05	0.04	1.74	0.03	0.05	0.03	0.04	0.03	0.04	0.04	0.16	80.86
	SD	0.97	0.53	0.05	2.30	0.02	0.57	0.01	0.03	0.01	1.53	0.01	0.03	0.01	0.02	0.01	0.01	0.02	0.11	3.67
NGP	MEAN	1.83	1.05	0.11	5.35	0.10	0.93	0.02	0.04	0.04	3.05	0.04	0.05	0.03	0.03	0.03	0.04	0.04	0.30	78.23
	SD	0.53	0.72	0.07	1.15	0.06	0.62	0.00	0.01	0.02	1.80	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.29	4.19
OPR	MEAN	1.24	0.74	0.11	2.99	0.08	0.61	0.01	0.03	0.04	1.09	0.02	0.03	0.02	0.03	0.02	0.02	0.09	0.46	83.99
	SD	0.66	0.28	0.07	1.93	0.05	0.21	0.00	0.01	0.01	0.76	0.00	0.01	0.00	0.01	0.00	0.00	0.06	0.20	3.30

Table 2.18: Overall statistical results of chemical characterization ($\mu\text{g}/\text{m}^3$) of PM₁₀ 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	135.06	20.83	13.00	0.56	11.86	11.57	17.80	3.35	7.09	0.95	0.33	0.31	0.00	0.13	8.62	1.16	1.17	2.92	0.59
SD	33.47	7.36	5.58	0.32	7.35	6.59	11.36	2.43	6.25	0.69	0.24	0.11	0.00	0.11	3.71	0.62	0.75	2.04	0.67
MAX	259.53	35.07	26.18	1.80	31.03	25.00	51.04	9.70	19.69	3.58	0.91	0.63	0.01	0.50	16.45	2.57	3.12	9.17	2.77
MIN	48.72	3.87	3.00	0.25	2.85	1.49	3.16	0.25	0.93	0.13	0.01	0.10	0.00	0.02	2.28	0.36	0.46	1.17	0.01
CV	0.46	0.35	0.43	0.58	0.62	0.57	0.64	0.73	0.88	0.73	0.73	0.37	1.05	0.80	0.43	0.53	0.64	0.70	1.13
	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	%R
MEAN	1.69	0.81	0.11	4.75	0.08	0.73	0.02	0.04	0.04	1.94	0.03	0.04	0.03	0.03	0.03	0.03	0.06	0.30	81.01
SD	0.79	0.54	0.06	2.18	0.04	0.51	0.01	0.02	0.01	1.60	0.01	0.02	0.01	0.01	0.01	0.01	0.04	0.23	4.26
MAX	4.26	2.49	0.26	10.46	0.23	2.14	0.03	0.10	0.07	6.13	0.06	0.12	0.06	0.07	0.06	0.06	0.20	0.93	89.64
MIN	0.54	0.36	0.04	0.31	0.03	0.27	0.01	0.02	0.02	0.14	0.02	0.01	0.01	0.02	0.01	0.02	0.02	0.05	70.76
CV	0.47	0.67	0.55	0.46	0.54	0.70	0.30	0.57	0.30	0.82	0.39	0.48	0.41	0.38	0.40	0.35	0.71	0.79	0.05

Table 2.19: Statistical results of chemical characterization ($\mu\text{g}/\text{m}^3$) of PM_{2.5} at all sites

		PM _{2.5}	OC	EC	F ⁻	Cl ⁻	NO ₃ ⁻	SO ₄ ⁻²	Na ⁺	NH ₄ ⁺	K ⁺	Mg ⁺²	Ca ⁺²	Be	B	Na	Mg	Al	Si	P
SHP	MEAN	72.33	11.07	7.66	0.39	7.61	7.08	8.13	3.09	2.18	0.81	0.32	0.23	0.00	0.08	5.94	0.68	0.56	1.37	0.23
	SD	27.94	4.88	2.57	0.13	3.16	2.22	4.06	2.34	2.46	0.48	0.22	0.07	0.00	0.07	3.61	0.24	0.26	0.67	0.11
NGP	MEAN	100.19	19.27	15.55	0.38	9.24	9.03	13.24	1.57	5.17	0.59	0.19	0.27	0.00	0.06	4.26	0.60	0.55	1.28	0.25
	SD	25.75	3.22	4.27	0.16	4.99	4.48	5.74	1.06	3.13	0.36	0.14	0.11	0.00	0.03	2.81	0.18	0.15	0.37	0.08
OPR	MEAN	90.89	14.27	9.95	0.29	6.32	7.58	15.44	2.04	6.45	0.63	0.16	0.21	0.00	0.07	4.83	0.45	0.74	1.90	0.18
	SD	37.64	3.30	3.05	0.07	4.65	5.48	9.61	0.90	4.16	0.39	0.11	0.08	0.00	0.05	2.16	0.29	0.26	0.73	0.09
		K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	%R
SHP	MEAN	1.24	0.40	0.06	3.61	0.04	0.37	0.02	0.02	0.03	0.95	0.02	0.03	0.02	0.02	0.02	0.03	0.03	0.11	84.40
	SD	0.54	0.16	0.04	1.04	0.02	0.17	0.00	0.01	0.01	0.68	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.08	7.02
NGP	MEAN	1.01	0.37	0.05	2.68	0.04	0.39	0.01	0.02	0.03	0.76	0.02	0.03	0.02	0.02	0.02	0.02	0.03	0.11	81.05
	SD	0.49	0.11	0.02	1.06	0.02	0.13	0.00	0.00	0.01	0.46	0.01	0.01	0.00	0.00	0.00	0.01	0.01	0.05	4.90
OPR	MEAN	0.91	0.55	0.04	2.17	0.04	0.50	0.01	0.02	0.02	0.73	0.02	0.02	0.01	0.02	0.01	0.02	0.03	0.15	81.89
	SD	0.44	0.19	0.02	1.48	0.01	0.20	0.00	0.00	0.01	0.53	0.00	0.01	0.00	0.00	0.00	0.00	0.02	0.14	4.32

Table 2.20: Overall statistical results of chemical characterization ($\mu\text{g}/\text{m}^3$) 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	87.72	14.58	10.79	0.35	7.71	7.83	11.95	2.30	4.41	0.69	0.23	0.23	0.00	0.07	5.08	0.58	0.61	1.51	0.22
SD	32.08	5.15	4.64	0.13	4.24	4.06	7.16	1.72	3.64	0.41	0.18	0.09	0.00	0.05	2.96	0.25	0.24	0.65	0.10
MAX	147.80	24.55	21.73	0.63	17.15	18.14	34.33	7.23	14.19	2.03	0.66	0.45	0.00	0.27	10.80	1.31	1.05	3.07	0.48
MIN	29.41	2.71	2.49	0.17	1.98	1.24	2.26	0.18	0.68	0.09	0.01	0.09	0.00	0.01	0.29	0.15	0.25	0.67	0.01
CV	0.37	0.35	0.43	0.36	0.55	0.52	0.60	0.75	0.83	0.60	0.77	0.38	1.32	0.80	0.58	0.43	0.39	0.43	0.44
	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	%R
MEAN	1.07	0.43	0.05	2.88	0.04	0.41	0.01	0.02	0.03	0.82	0.02	0.03	0.02	0.02	0.02	0.02	0.03	0.12	82.60
SD	0.50	0.17	0.03	1.31	0.02	0.17	0.00	0.01	0.01	0.56	0.00	0.01	0.00	0.01	0.00	0.01	0.01	0.09	5.65
MAX	2.50	0.82	0.17	5.91	0.08	0.82	0.03	0.06	0.05	2.05	0.03	0.06	0.03	0.05	0.03	0.04	0.07	0.46	93.38
MIN	0.21	0.22	0.01	0.23	0.01	0.20	0.01	0.01	0.02	0.06	0.01	0.00	0.01	0.01	0.01	0.02	0.02	0.02	72.42
CV	0.47	0.39	0.63	0.45	0.37	0.42	0.27	0.42	0.31	0.68	0.26	0.39	0.28	0.38	0.26	0.27	0.40	0.77	0.07

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	0.87	0.78	0.79	0.38	0.66	0.84	0.75	0.09	0.85	0.34	-0.03	0.18	0.50	0.62
PM ₁₀	0.87	1.00	0.81	0.87	0.50	0.63	0.78	0.58	-0.07	0.70	0.17	0.07	0.35	0.25	0.83
OC	0.78	0.81	1.00	0.77	0.32	0.49	0.56	0.48	-0.10	0.55	-0.06	-0.18	0.19	0.13	0.61
EC	0.79	0.77	0.77	1.00	0.29	0.53	0.64	0.52	-0.21	0.61	0.10	-0.08	0.30	0.13	0.61
NO ₃ ⁻	0.84	0.78	0.56	0.64	0.33	0.74	1.00	0.59	0.05	0.72	0.45	0.11	0.29	0.38	0.59
SO ₄ ⁻²	0.75	0.58	0.48	0.52	0.01	0.24	0.59	1.00	0.20	0.79	0.31	-0.01	0.10	0.35	0.28
NH ₄ ⁺	0.85	0.70	0.55	0.61	0.22	0.43	0.72	0.79	-0.07	1.00	0.18	-0.10	0.13	0.32	0.37
Metals_PM _{2.5}	0.50	0.25	0.13	0.13	0.40	0.25	0.38	0.35	0.76	0.32	0.63	0.24	-0.06	1.00	0.32
Metals_PM ₁₀	0.62	0.83	0.61	0.61	0.68	0.50	0.59	0.28	0.14	0.37	0.17	0.26	0.36	0.32	1.00

2.3.8 Comparison of PM₁₀ and PM_{2.5} Composition

The graphical compositional comparison of PM_{2.5} Vs PM₁₀ for all species is shown (Figure 2.24). The chemical species considered for the comparisons are carbon content (TC, OC and EC), ionic species (F⁻, Cl⁻, NO₃⁻, SO₄⁻², Na⁺, NH₄⁺, K⁺, Ca⁺², Mg⁺²) and elements (Be, B, Na, Mg, Al, Si, P, K, Ca, Cr, V, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Rb, Sr, Cd, Cs, Ba, Pb).

It is observed that a significant portion of PM is having more fine-mode particles during winter (62%). The major species contributing to fine mode are TC, OC, EC, Cl⁻, NO₃⁻, SO₄⁻², Na⁺, K⁺, Mg²⁺, Ca²⁺, K, V, Co, Cu, As, Se, Rb, Sr, Cd and Cs; whereas major species contributing to coarse mode are Be, P, Cr, Mn, Si and Pb.

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

The statistical summary of the major components (i.e., crustal elements – Si, Al, Fe, Ca; Secondary ions - NO₃⁻, SO₄⁻², NH₄⁺; TC) in PM₁₀ and PM_{2.5} are presented in Tables 2.22 – 2.23.

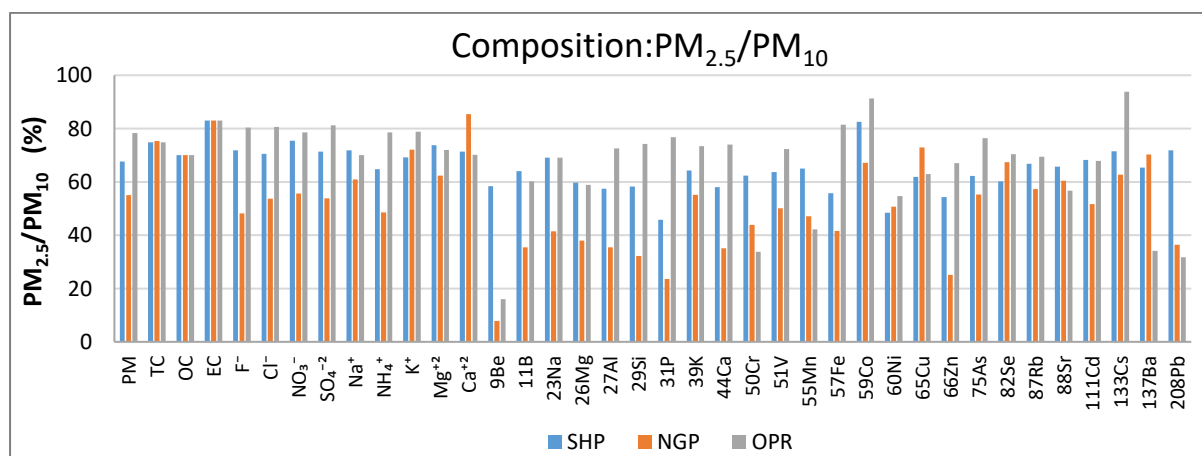


Figure 2.24: Compositional comparison of species in PM_{2.5} vs PM₁₀

Table 2.22: Mean of major components: PM₁₀, winter (µg/m³)

Sites	PM ₁₀	Crustal (Si + Al + Fe + Ca)	Ratio Crustal/PM ₁₀	Sec Ions (NO ₃ ⁻ + SO ₄ ⁻² + NH ₄ ⁺)	Ratio Sec Ions/PM ₁₀	TC	Ratio TC/PM ₁₀
SHP	107	4.7	0.044	24.1	0.225	25.1	0.234
NGP	182	7.5	0.041	51.5	0.283	46.3	0.254
OPR	116	4.9	0.042	36.9	0.318	32.4	0.279
Overall	135	5.7	0.042	37.5	0.275	34.6	0.256
SD	41	1.6	0.001	13.7	0.047	10.8	0.022
CV	0.304	0.277	0.028	0.365	0.169	0.312	0.088

Table 2.23: Statistical summary of major components: PM_{2.5}, winter (µg/m³)

Sites	PM _{2.5}	Crustal (Si + Al + Fe + Ca)	Ratio Crustal/PM _{2.5}	Sec Ions (NO ₃ ⁻ + SO ₄ ⁻² + NH ₄ ⁺)	Ratio Sec Ions/PM _{2.5}	TC	Ratio TC/PM _{2.5}
SHP	72	2.7	0.037	17.4	0.240	18.7	0.259
NGP	100	2.6	0.026	27.4	0.274	34.8	0.348
OPR	91	3.7	0.040	29.5	0.324	24.2	0.266
Overall	88	3.0	0.035	24.8	0.279	25.9	0.291
SD	14	0.6	0.008	6.5	0.042	8.2	0.049
CV	0.162	0.200	0.222	0.261	0.151	0.315	0.169

2.3.9 Carbon monoxide (CO)

CO levels were measured at two sites. 8 Hourly Statistical Results of CO (µg/m³) at all two sites are presented in Table 2.24.

SHP

The hourly average concentration of CO was observed at SHP. 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 higher in evening hours than in morning hours.

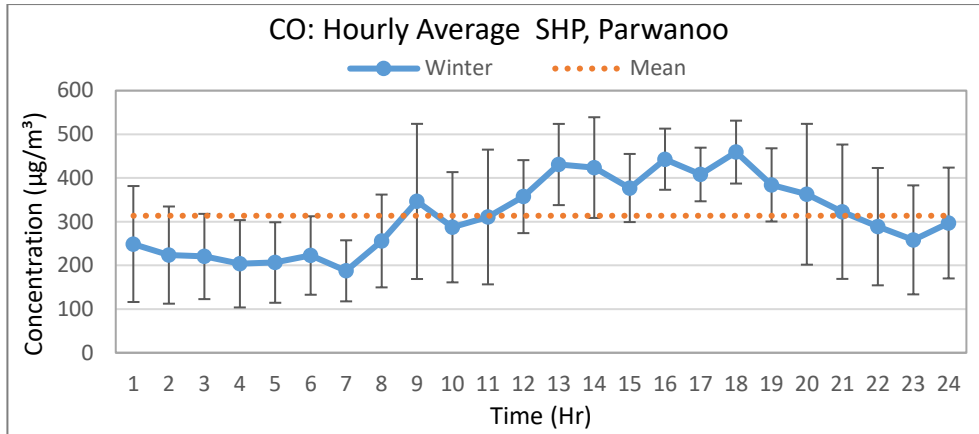


Figure 2.25: Hourly average concentration (µg/m³) of CO at SHP

OPR

The hourly average concentration of CO was observed at OPR. 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 higher in evening hours than in morning hours.

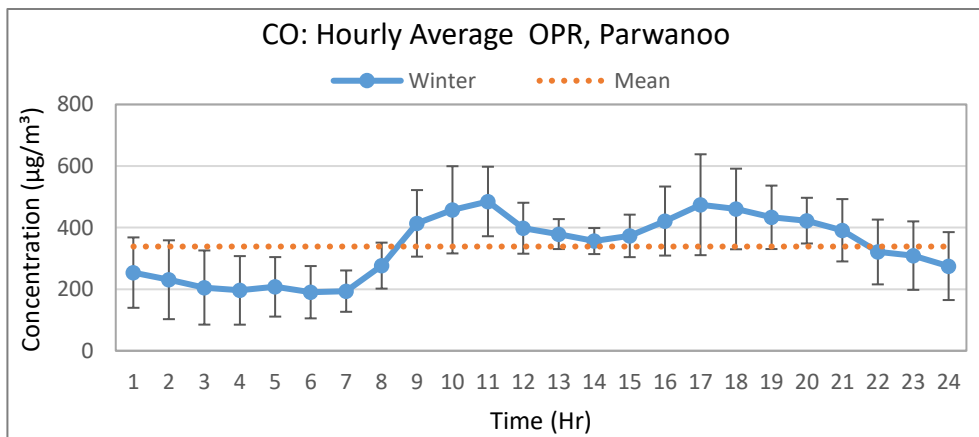


Figure 2.26: Hourly average concentration (µg/m³) of CO at OPR

Table 2.24: 8 Hourly Statistical Results of CO (µg/m³) at Parwanoo

SITE	CO at SHP			CO at OPR		
	0-8 Hr	8-16 Hr	16-24 Hr	0-8 Hr	8-16 Hr	16-24 Hr
Mean	221.15	372.1	347.66	219.28	410.55	385.92
SD	22.79	57.35	67.94	31.55	43.71	75.08
CV	0.10	0.15	0.20	0.14	0.11	0.19
Max	255.89	443.07	459.3	276.54	484.84	474.34
Min	187.53	287.32	258.42	190.21	356.36	275.06

2.3.10 Ozone (O₃)

O₃ levels were measured at two sites. 8 Hourly Statistical Results of O₃ levels ($\mu\text{g}/\text{m}^3$) at two sites are presented in Table 2.25.

SHP

The hourly average concentration of O₃ was observed at SHP. 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 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).

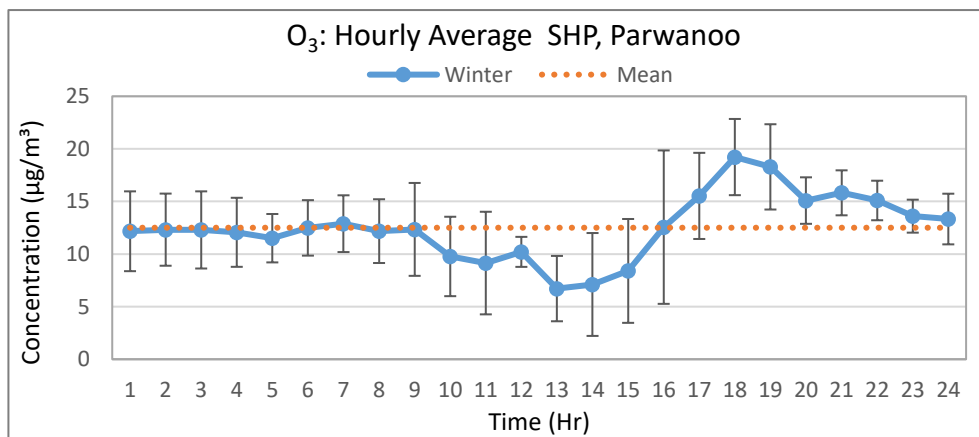


Figure 2.27: Hourly average concentration ($\mu\text{g}/\text{m}^3$) of O₃ at SHP

OPR

Hourly average concentration of O₃ was observed at OPR. 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 higher in evening hours than in morning hours.

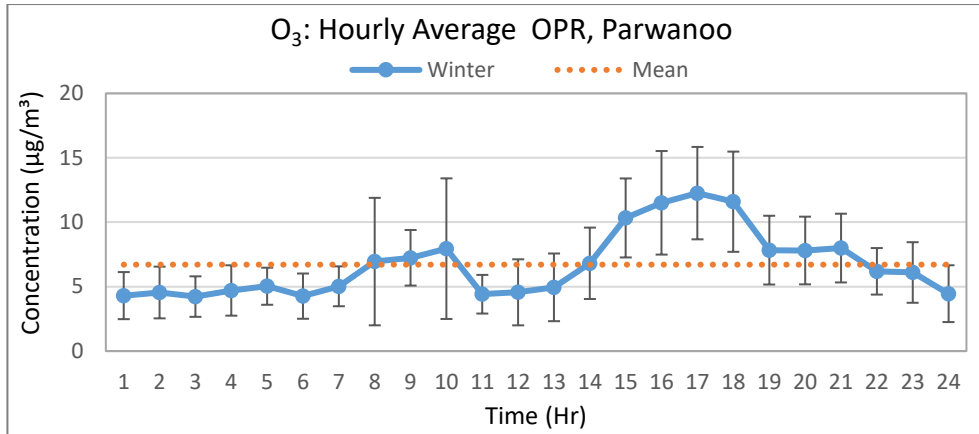


Figure 2.28: Hourly average concentration ($\mu\text{g}/\text{m}^3$) of O_3 at OPR

Table 2.25: 8 Hourly Statistical Results of O_3 ($\mu\text{g}/\text{m}^3$) at Parwanoo

SITE	O_3 at SHP			O_3 at OPR		
	0-8 Hr	8-16 Hr	16-24 Hr	0-8 Hr	8-16 Hr	16-24 Hr
Mean	12.24	9.53	15.75	4.88	7.22	8.03
SD	0.39	2.17	2.07	0.89	2.64	2.69
CV	0.03	0.23	0.13	0.18	0.37	0.33
Max	12.89	12.56	19.22	6.95	11.51	12.26
Min	11.51	6.72	13.33	4.23	4.41	4.46

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} , $\text{PM}_{2.5}$ 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 $107 - 182 \mu\text{g}/\text{m}^3$ and the mean $\text{PM}_{2.5}$ levels were $72 - 100 \mu\text{g}/\text{m}^3$.
- Particulate pollution is the main concern in the city, where PM_{10} levels are 1.1 – 1.8 times higher than the national air quality standards and $\text{PM}_{2.5}$ levels are 1.2 – 1.7 times higher than the national standard in the winter months. It is observed that the air quality in terms of PM_{10} and $\text{PM}_{2.5}$ falls in the poor to very poor category of air quality index (AQI).

- The chemical composition of PM₁₀ and PM_{2.5} carries the signature of sources and their harmful contents. The chemical composition is variable in different size ranges indicating contribution of different types of sources.

PM₁₀

The overall average concentration of PM₁₀ is 135±33 µg/m³ against the acceptable level of 100 µg/m³ (24-hour average). The highest levels were observed at NGP and the lowest at SHP.

The important components are the secondary particles (NO₃⁻ + SO₄²⁻ + NH₄⁺), which account for about 28% of total PM₁₀, and combustion-related total carbon (TC = EC + OC) accounts for about 26%; both fractions of secondary particles and combustion-related carbons account for 56% of PM₁₀ in winter months.

The crustal component (Si + Al + Fe + Ca) accounts for about four percent in PM₁₀. This suggests soil and road dust have less significant contributions. The coefficient of variation (CV) is about 0.03 (of the fraction of crustal component), which suggests the crustal source contributes consistently in the winter months.

The Cl⁻ content in PM₁₀ is consistent and varies between 7 – 10%, which is an indicator of the burning of municipal and plastic solid waste (MSW); recall polyvinyl chloride (PVC) is a major part of MSW. The highest Cl⁻ content is observed at NGP at 17 µg/m³ compared to the overall city level of 12 µg/m³. The high level at NGP signifies some local burning of waste as a means of disposal of solid waste.

PM_{2.5}

The overall average concentration of PM_{2.5} in winter is 88±12 µg/m³ against the acceptable level of 60 µg/m³ (24-hour average). The highest levels are observed at NGP and the lowest at SHP.

The important components are the secondary particles (NO₃⁻ + SO₄²⁻ + NH₄⁺), which account for about 28% of total PM_{2.5} and combustion-related total carbon (TC = EC + OC) accounts for about 29%; both fractions of secondary particles and combustion-related carbons account for 57% of PM_{2.5} in winter months. The highest levels of secondary particles were observed at OPR (32%) and TC at NGP (35%).

The Cl⁻ content in PM_{2.5} is consistent and varies between 7 – 11%, which is an indicator of the burning of MSW and plastic waste.

Gaseous pollutant levels

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

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

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

General inferences

It is to be noted that OC3/TC ratio is about 0.24 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 Parwanoo.

Total PAH levels (17 compounds; particulate phase) had high variability in the range of 4 to 10 and B(a)P at 0.34 ng/m³ (annual standard is one ng/m³); the comparison with the annual standard is not advisable due to different averaging times. The highest PAH levels were observed at NGP.

The concentrations of molecular markers in PM_{2.5} (a total of 6 compounds) vary in the range of 53 to 65 ng/m³, indicating the presence of common sources of emissions from coal, gasoline and domestic fuel.

In a broad sense, the air is toxic in the winter months as it contains a much larger contribution of fine particulates emitted from combustion sources. Combustion sources (vehicles, coal,

and MSW burning) are consistent and require a strategy to control these sources. A possible effective mixture of control options is discussed in Chapter 6.

3 Time Series Analysis and Trend

3.1 Introduction

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

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

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

3.2 Methodology

The long-term (2008–2019) air quality data for two sites were considered for Parwanoo city. The sites were Station-I Sector 4 (Residential) and Station-II Sector 1 (Industrial). 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 PM₁₀ and NO_x concentrations over the years were calculated and plotted against the corresponding monthly slot for each site. A fifth-degree polynomial was fitted by regression analysis to each plot to obtain a minimum R² value of 0.50 (lower degree polynomial did not fill well). These plots help in understanding the pattern of concentrations with the changing time and seasons.

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

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

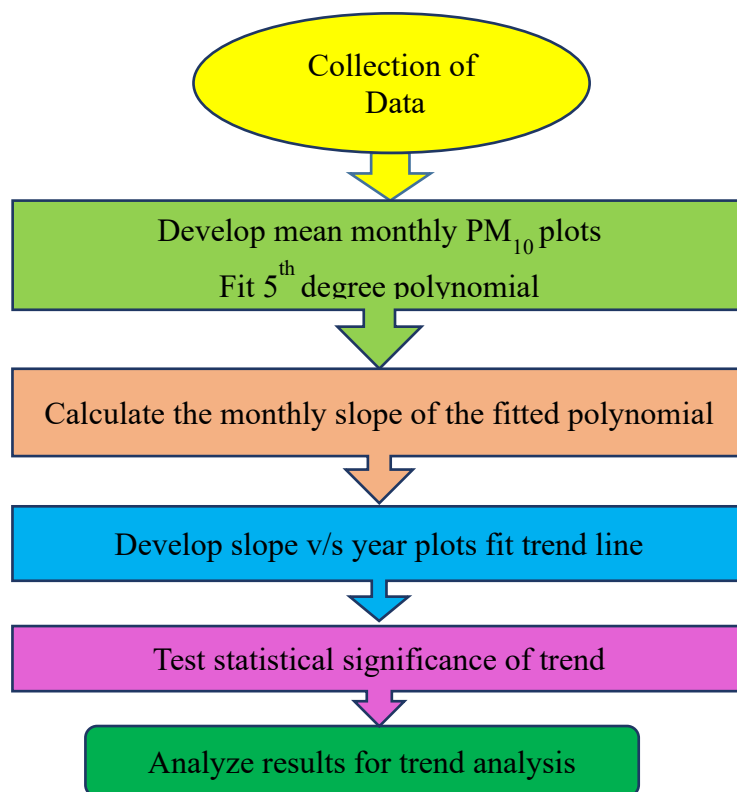


Figure 3.1: Stepwise methodology and major tasks (Nagar et al., 2019)

3.3 Results and Interpretations

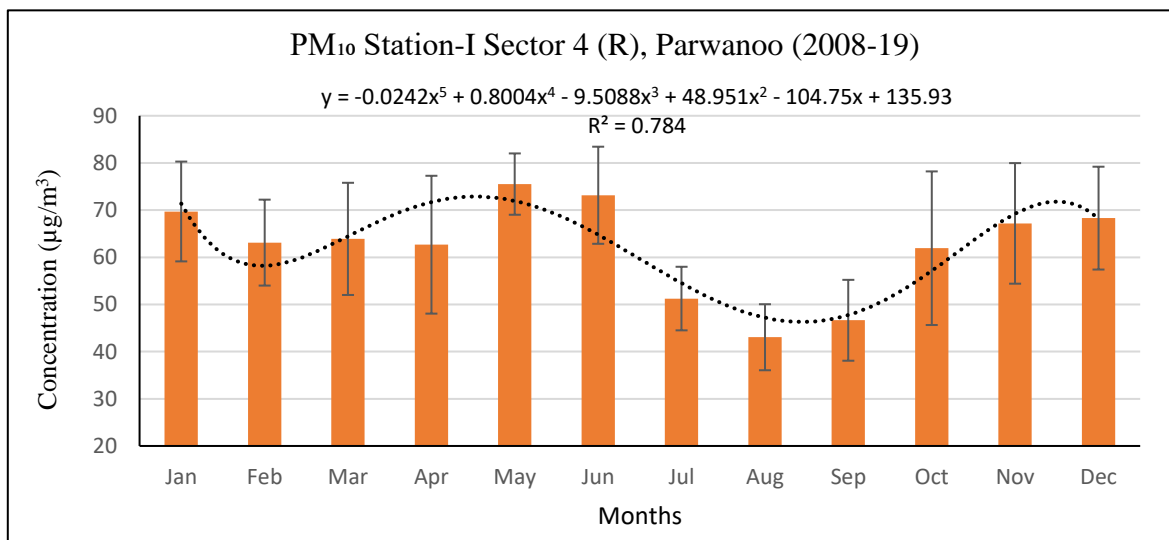
3.3.1 Annual pattern in PM₁₀ and NO₂

The total number of monthly means of 24-hr PM₁₀ and NO_x measurements in Parwanoo was about 130 (at each site). The monthly mean levels of PM₁₀ and NO_x averaged over 2008 – 2019 for two sites in Figures 3.2 – 3.3.

Two peaks were observed (Figure 3.2) in PM₁₀, one during pre-monsoon season and the other during post-monsoon to winter. A sharp increase in the levels during post-monsoon is observed. The PM₁₀ levels continue to gradually increase in winter or tend to stabilize. It is interesting to note that in the month of May, levels increase and show significant variability. Parwanoo may have been dust storms in the months of May and June. The PM₁₀ levels generally meet the 24-hr national air quality standards at Station-I (residential) while 24-hr national air quality standards exceed in in most of the months except monsoon months (July to October) at Station-II, an industrial site.

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

The annual time-series variations of PM₁₀ and NO_x mean concentrations over 2008-2019 for one site is presented in Figures 3.4 – 3.5.



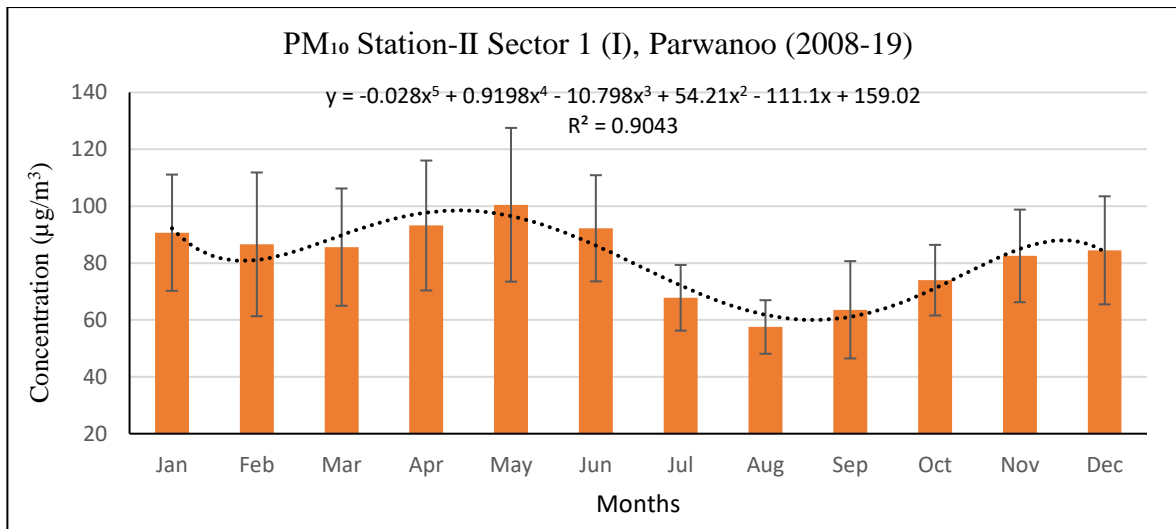


Figure 3.2: Variation in PM₁₀ at (a) Station-I Sector 4 and (b) Station-II Sector 1

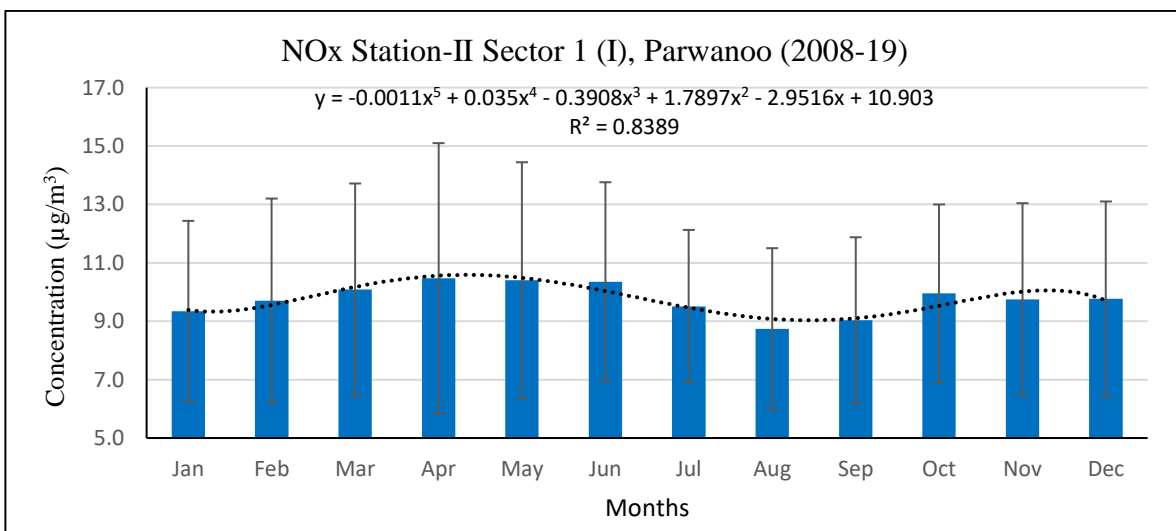
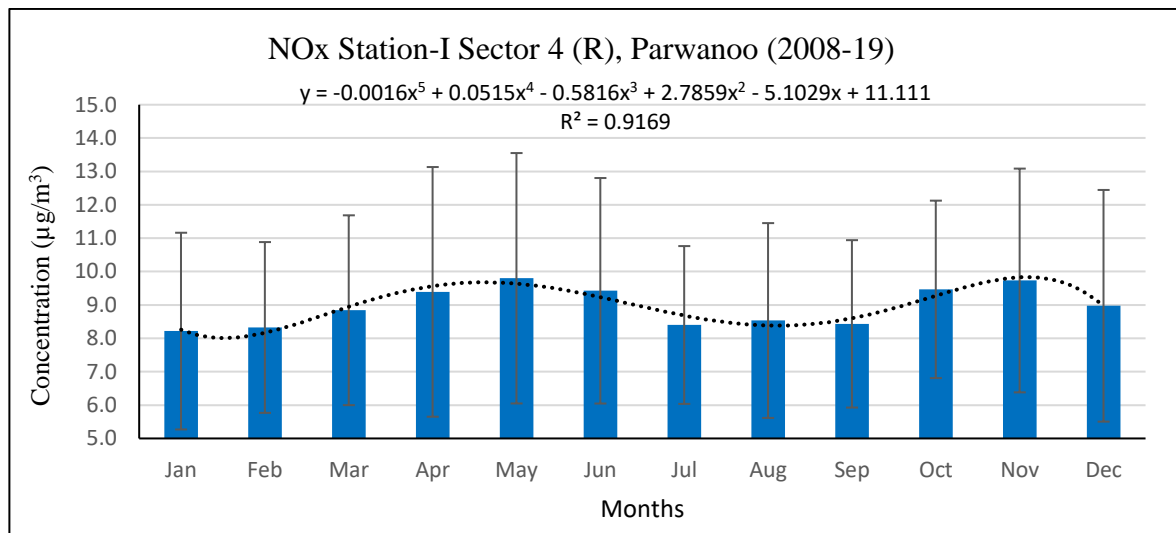


Figure 3.3: Variation in NO_x at (a) Station-I Sector 4 and (b) Station-II Sector 1

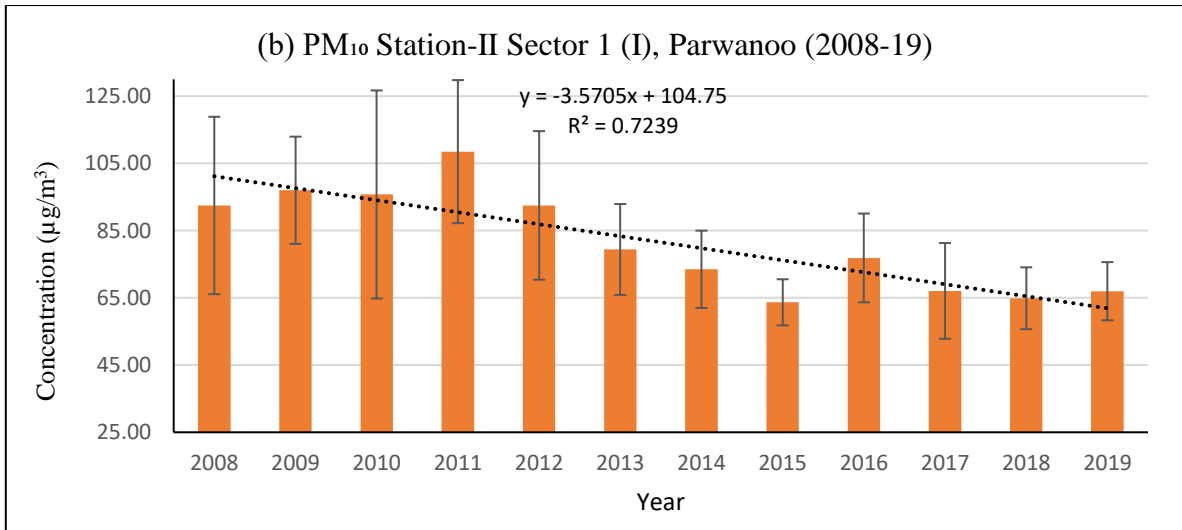
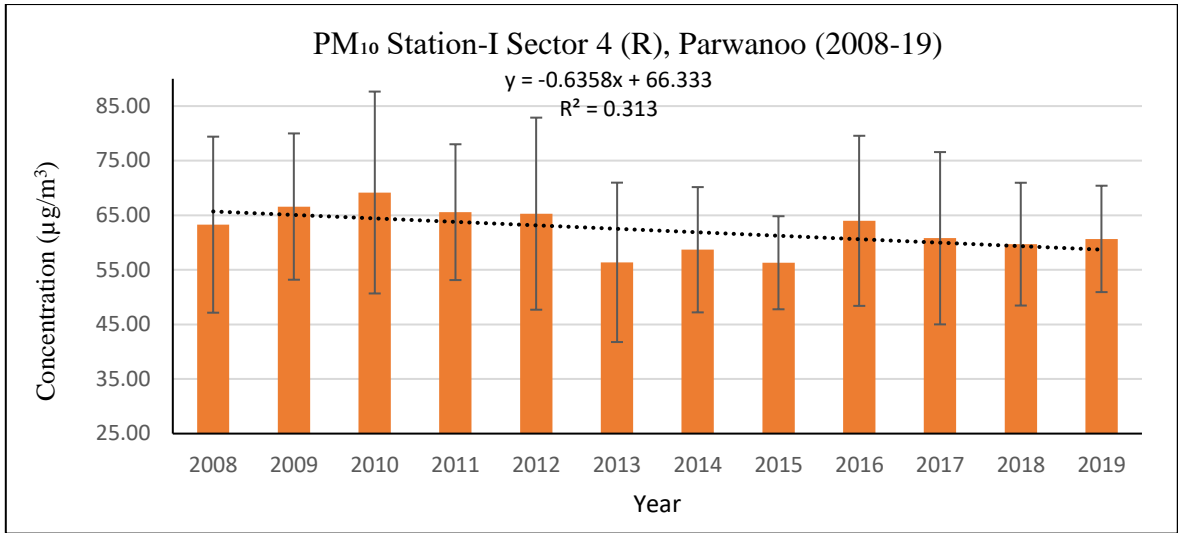
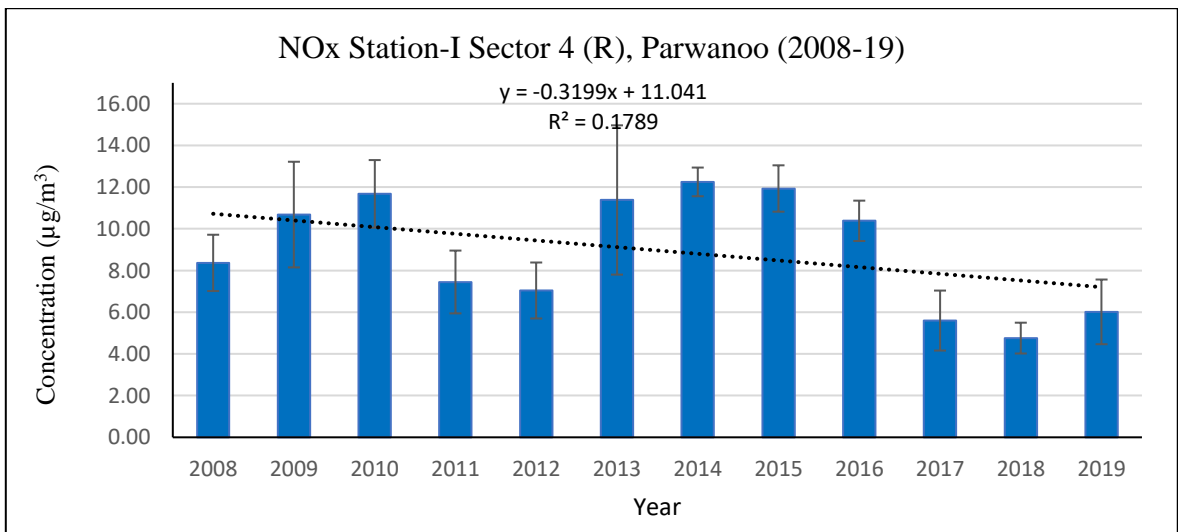


Figure 3.4: Timeseries of annual mean levels of PM₁₀



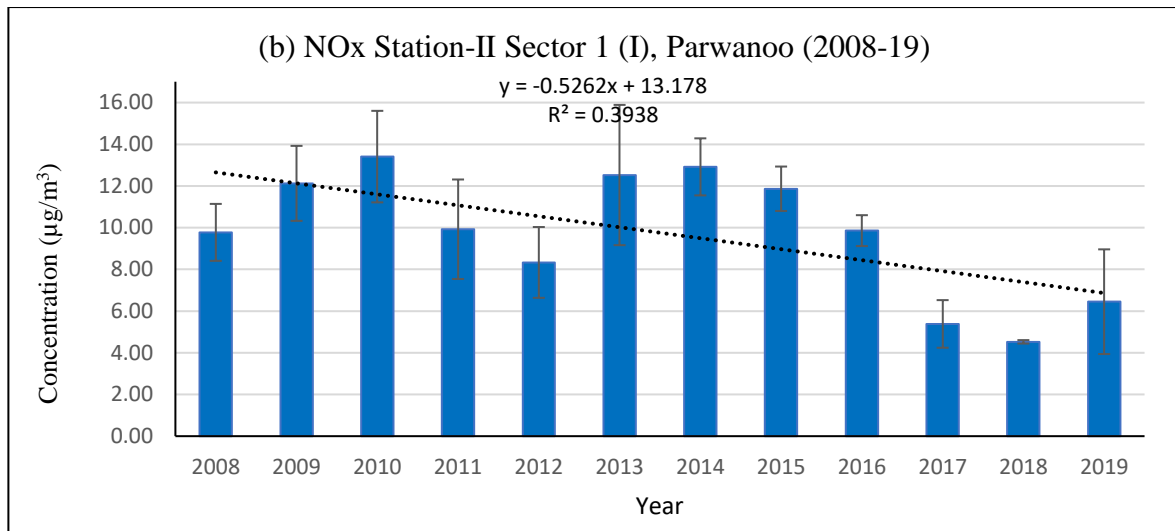


Figure 3.5: Timeseries of annual mean levels of NO_x

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 PM₁₀ and NO_x at two sites in Parwanoo. The statistically significant trends are shown as an upward arrow (↑: increasing trend) and downward arrow (↓: decreasing trend) and a left-right arrow (↔: no trend). In other words, both slope and trend can acquire negative or positive numerical values.

There is no specific trend in PM₁₀ and NO_x in Parwanoo as few months show a decreasing trend and most of months indicate no trend. The annual levels of PM₁₀ and NO_x show no trend at Station-I and decreasing trend at Station-II.

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

Sites	PM ₁₀	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	
Station I	Slope	-3.40	-0.75	-1.32	0.16	-1.80	0.42	0.07	0.98	0.23	0.90	-3.35	-1.73	-0.76	
	Trend (MK)	Yes (↓)	No (↔)	No (↔)	No (↔)	Yes (↓)	No (↔)	No (↔)	No (↔)	No (↔)	No (↔)	No (↔)	No (↔)	No (↔)	
Station II	Slope	-4.40	-6.39	-4.80	-5.75	-5.93	-3.83	-2.09	-1.15	-2.40	-1.48	-4.18	-3.42	-3.74	
	Trend (MK)	Yes (↓)	Yes (↓)	Yes (↓)	Yes (↓)	Yes (↓)	Yes (↓)	No (↔)	No (↔)	No (↔)	No (↔)	Yes (↓)	Yes (↓)	Yes (↓)	
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 2008-2019

Sites	PM ₁₀	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Station I	Slope	-0.32	-0.36	-0.52	-0.35	-0.66	-0.50	-0.40	-0.42	-0.43	-0.29	-0.67	-0.68	-0.38
	Trend (MK)	No (↔)	No (↔)	No (↔)	No (↔)	No (↔)	No (↔)	No (↔)	No (↔)	No (↔)	No (↔)	No (↔)	No (↔)	No (↔)
Station II	Slope	-0.76	-0.84	-0.93	-0.94	-1.00	-0.75	-0.50	-0.50	-0.63	-0.30	-0.79	-0.84	-0.77
	Trend (MK)	No (↔)	Yes (↓)	Yes (↓)	No (↔)	Yes (↓)	No (↔)	No (↔)	No (↔)	No (↔)	No (↔)	No (↔)	Yes (↓)	Yes (↓)
MK: Mann Kendall Test		↑ Increasing Trend				↓ Decreasing Trend				↔ Statistically Insignificant Trend				

4 Emission Inventory

4.1 Introduction

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

4.2 Methodology

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

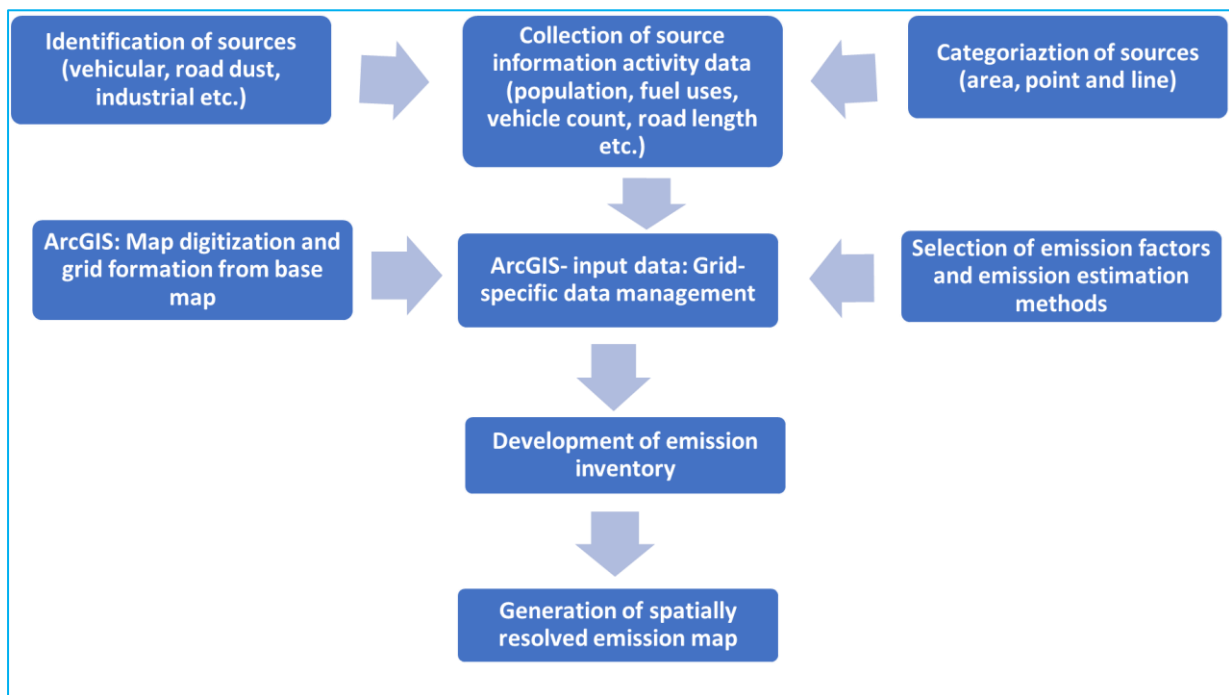


Figure 4.1: Stepwise Methodology adopted for the Study

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.

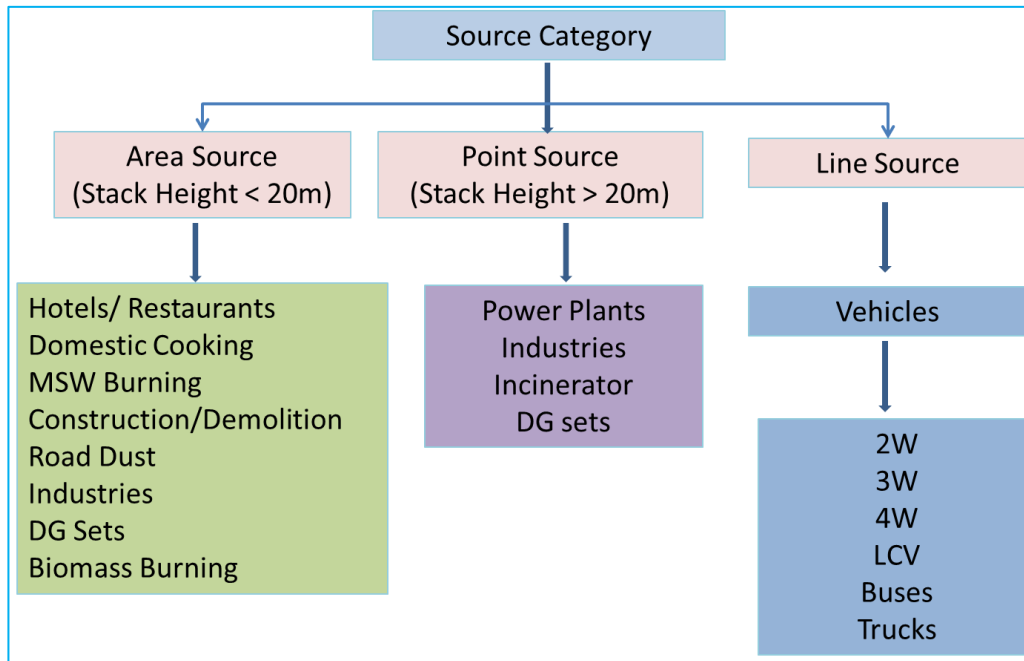


Figure 4.2: Source Category and type of sources

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 three 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, Indian Railways, Central Electricity Authority (CEA), Transport Department, and Toll Plazas. The information has also been collected through the Internet by visiting various websites. Although all possible efforts have been made to collect the data, some information/data could be missing.

4.2.3 Digital Data Generation

The land-use map of the study area is prepared in terms of settlements, agriculture, road network, water bodies, etc., (Figure 4.3 to Figure 4.12).

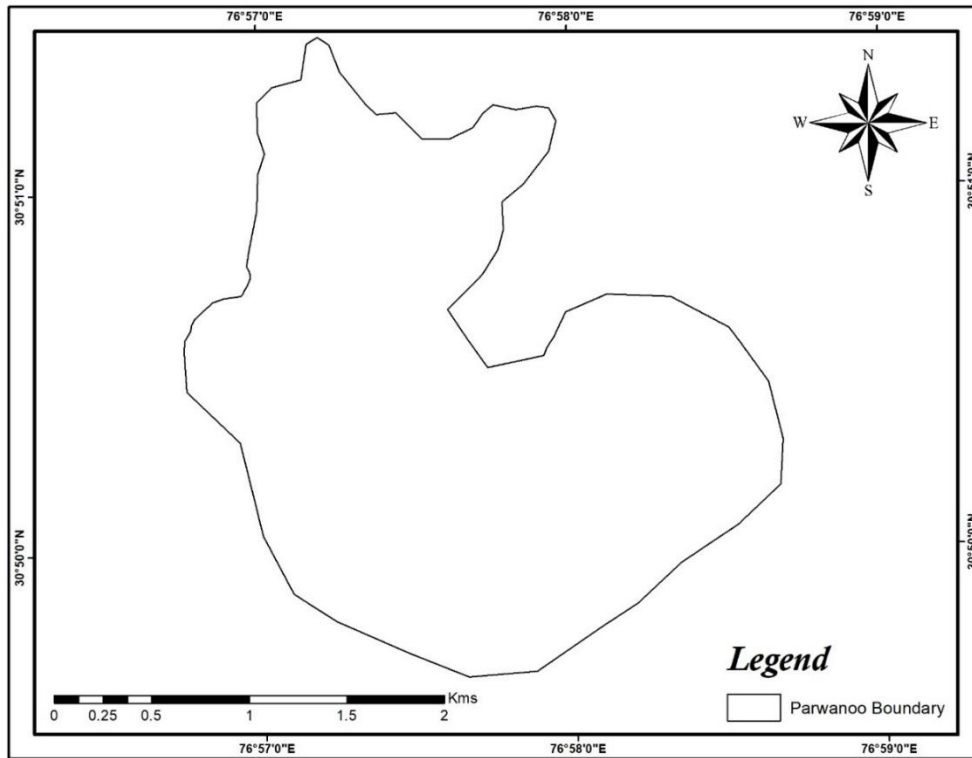


Figure 4.3: Parwanoo City Boundary

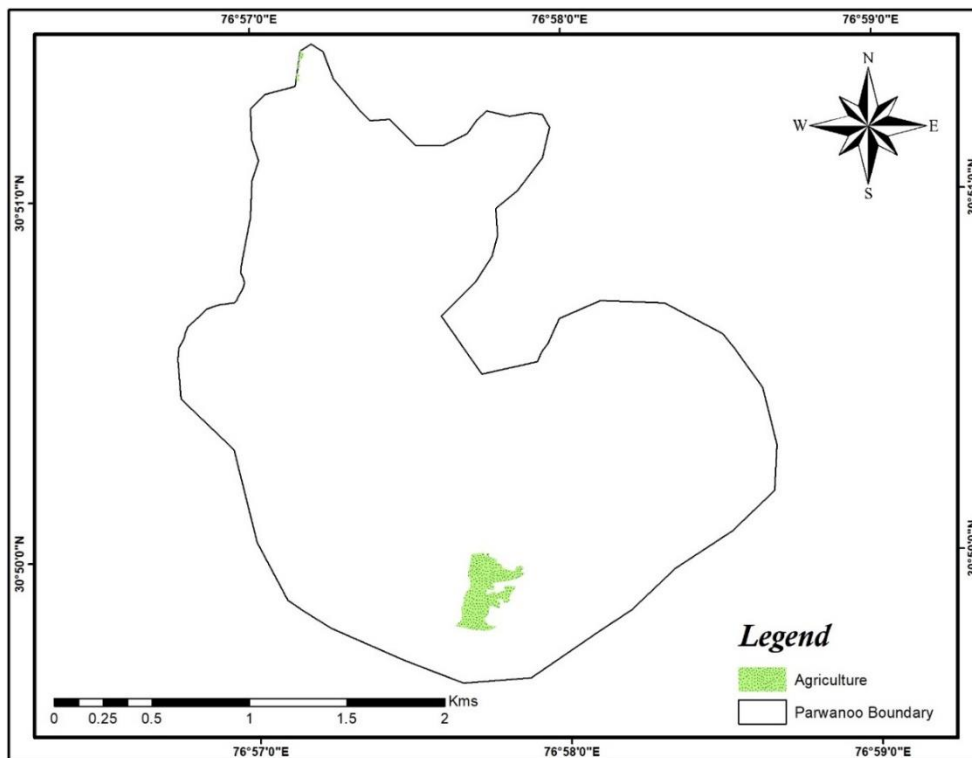


Figure 4.4: Agricultural Area Map

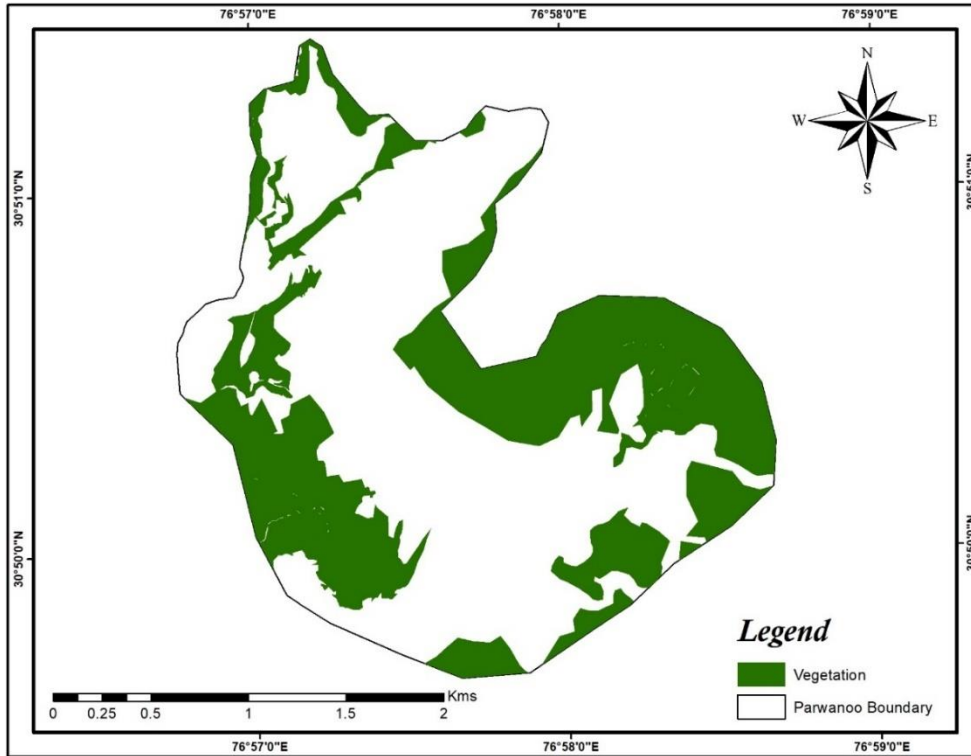


Figure 4.5: Green Area Map

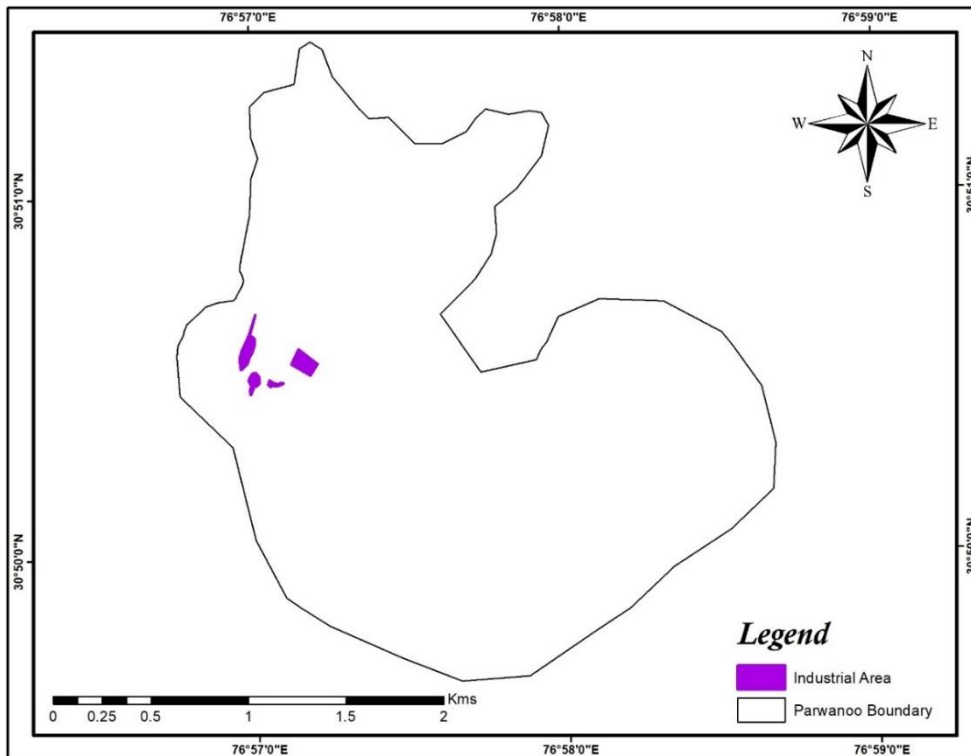


Figure 4.6: Industrial Area Map

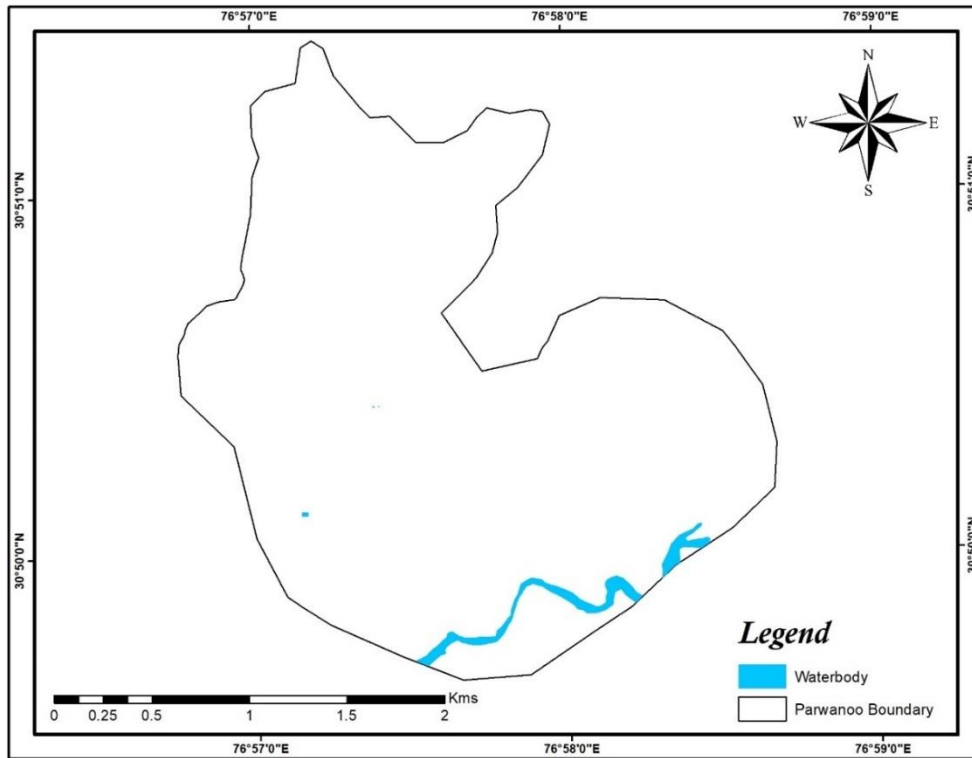


Figure 4.7: Waterbodies Area Map

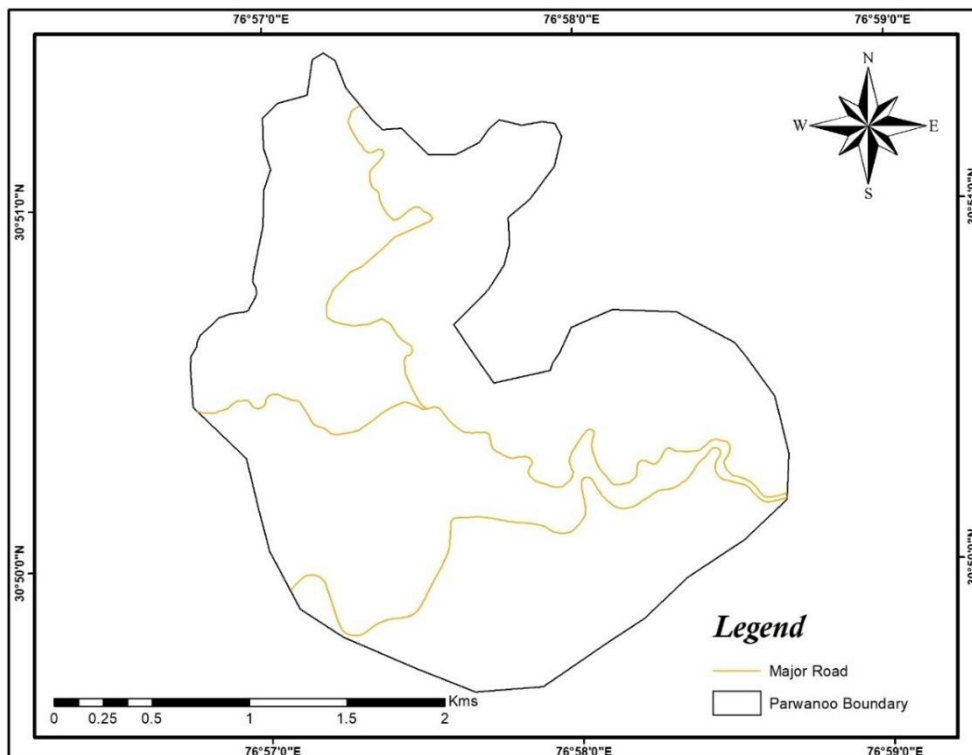


Figure 4.8: Major Road Network Map

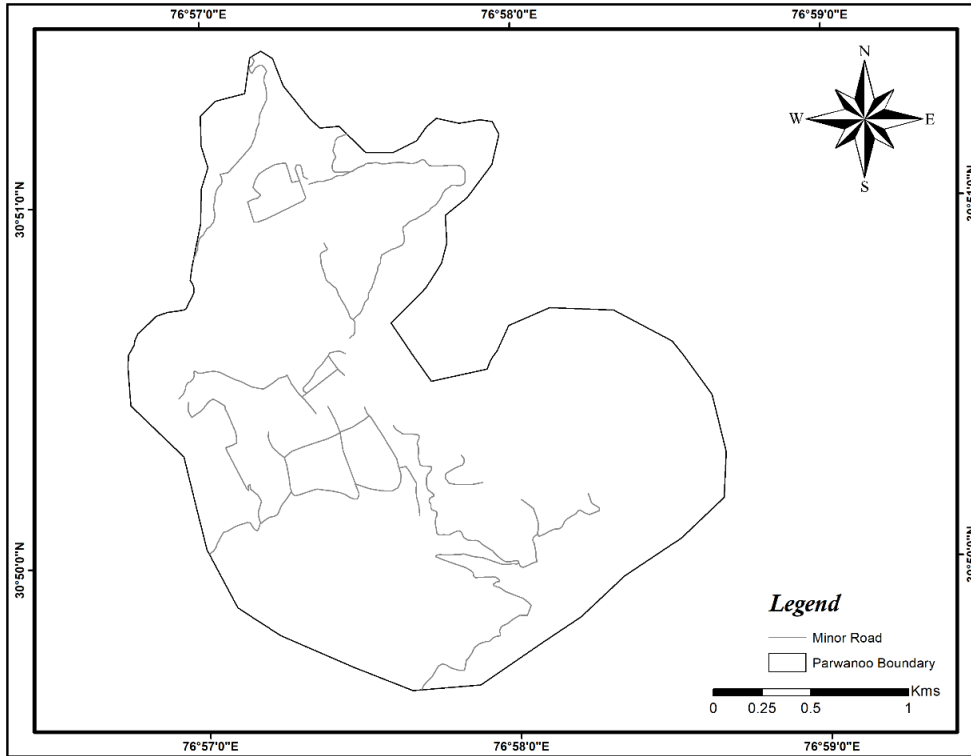


Figure 4.9: Minor Road Network Map

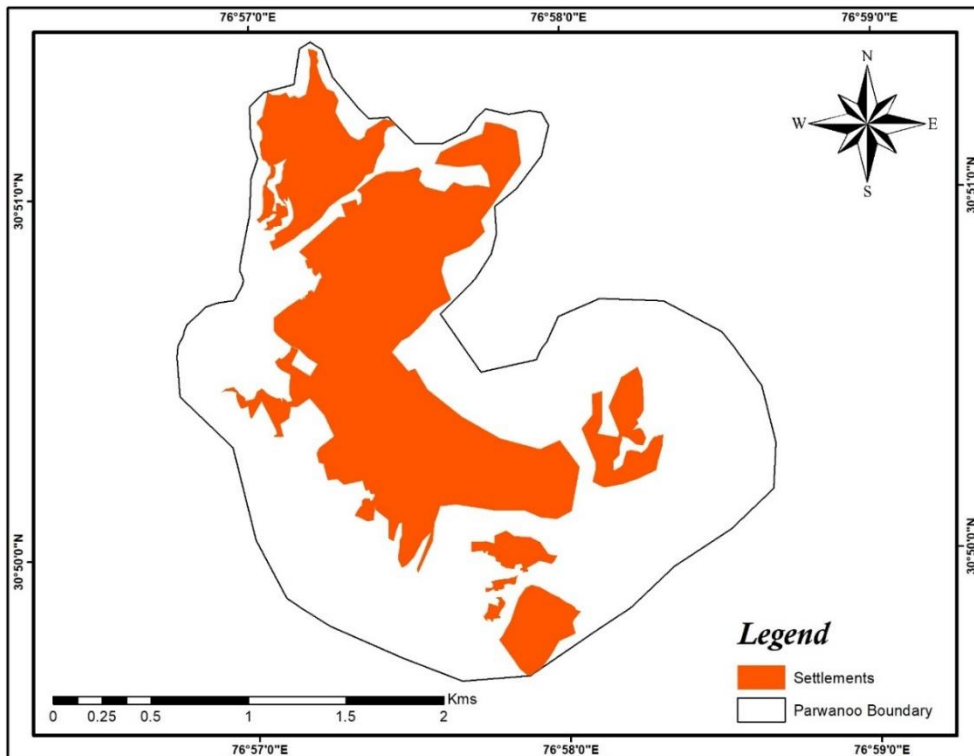


Figure 4.10: Settlement Area Map

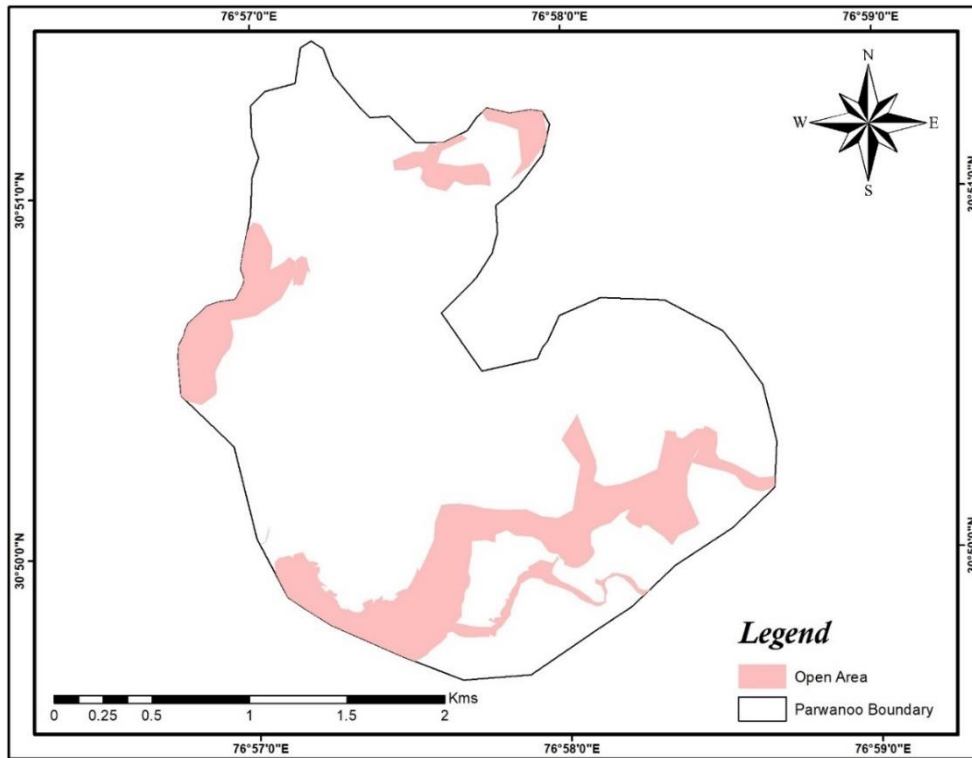


Figure 4.11: Open Area Map

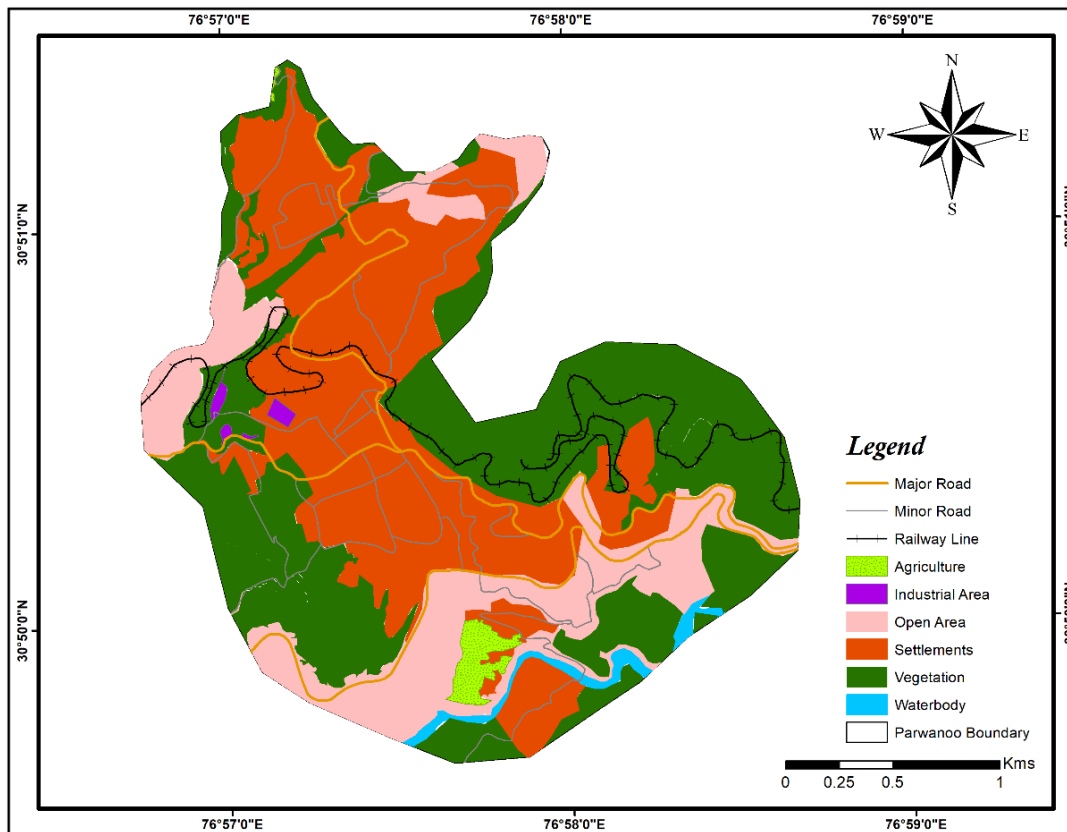


Figure 4.12: Land use Map of Parwanoo City

At the time of the development of the emission inventory, a suitable coding system was adopted to avoid the confusion and misrepresentation of results and interpretation. The emissions have been calculated for Parwanoo city. The Grid map of Parwanoo with grid identity numbers is shown in Figure 4.13. The entire study area was divided into grid cells of 0.5 km × 0.5 km.

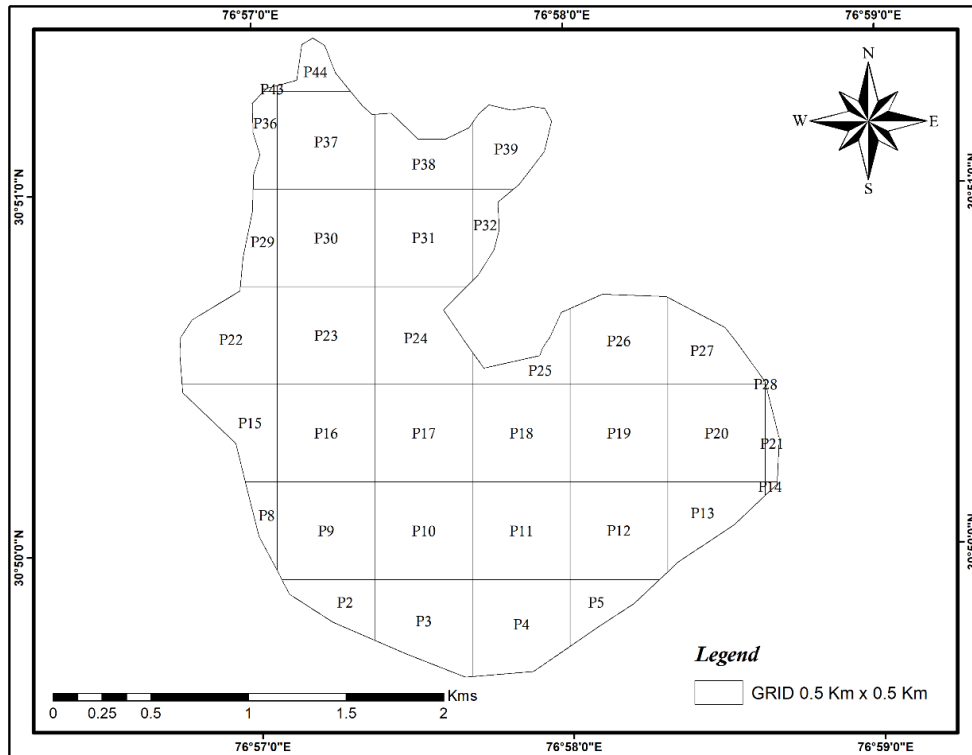


Figure 4.13: Grid Map of Parwanoo City showing Grid Identity Numbers

4.2.4 Emission Factor

An emissions factor is a representative value that attempts to relate the quantity of a pollutant released to the atmosphere with an activity associated with the release of that pollutant. These factors are usually expressed as the mass of pollutant per unit mass of raw material, volume, distance travelled, or duration of the activity (e.g., grams of particulate emitted per kilogram of coal burnt). Such factors facilitate the estimation of emissions from various sources of air pollution. In most cases, these factors are simply averaging of all available data of acceptable quality and are generally assumed to be representative of long-term averages for all facilities in the source category. The emission factors used in the report are mentioned in Annexure 1.

The general equation for emissions estimation is:

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

Where:

E = Emissions;

A = Activity rate;

EF = Emission factor, and

ER = Overall emission reduction efficiency, %

4.2.5 Domestic Sector

The interior boundaries in the map with 9 wards show the administrative boundaries of wards in Parwanoo City. The projected population of Parwanoo for the year 2020 is approximately 12000 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, and the emission density for each ward is calculated for different pollutants (PM₁₀, PM_{2.5}, SO₂, NO_x, and CO). The emission factors given by CPCB (2011) and AP-42 (USEPA, 2000) were used for each fuel type.

The overall emission from domestic sources is presented in Figure 4.14 (a) & (b). The emission contribution from different fuel types to different pollutants is shown in Figure 4.15 to Figure 4.19. For spatial distribution of different pollutants (Figure 4.20 to Figure 4.24), emission per capita, in each ward was calculated, as activity data was available based on per capita.

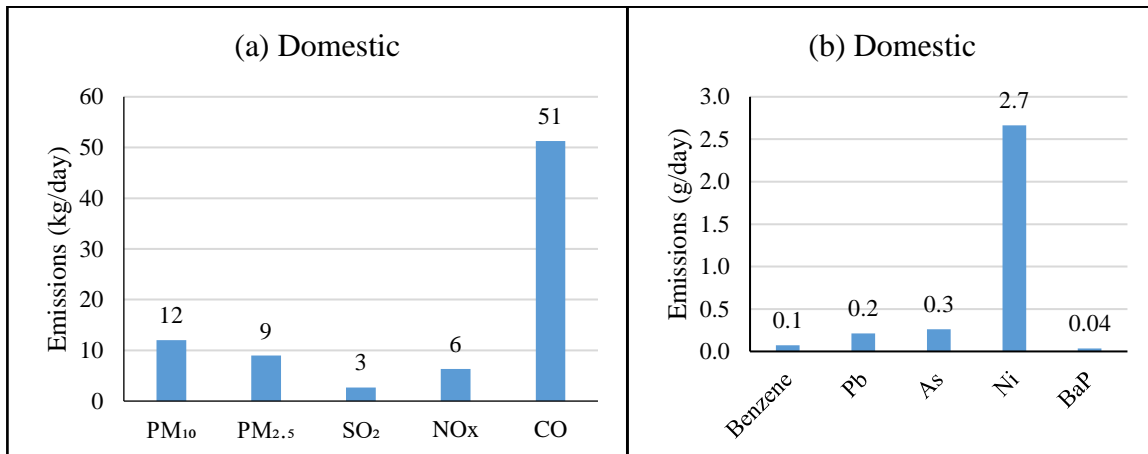
The emission density in terms of kg/day/m² in each ward was calculated based on the population and area of the ward for different pollutants (PM₁₀, PM_{2.5}, SO₂, NO_x, and CO); see below.

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

For calculating emissions in a grid that may contain more than one ward, the area of the fraction of each ward falling inside that grid was calculated, and with the help of the emission density of the ward, the emissions were calculated, see below.

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

Where N= no. of wards in the grid.



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

Figure 4.14: Emission Load from Domestic Sector

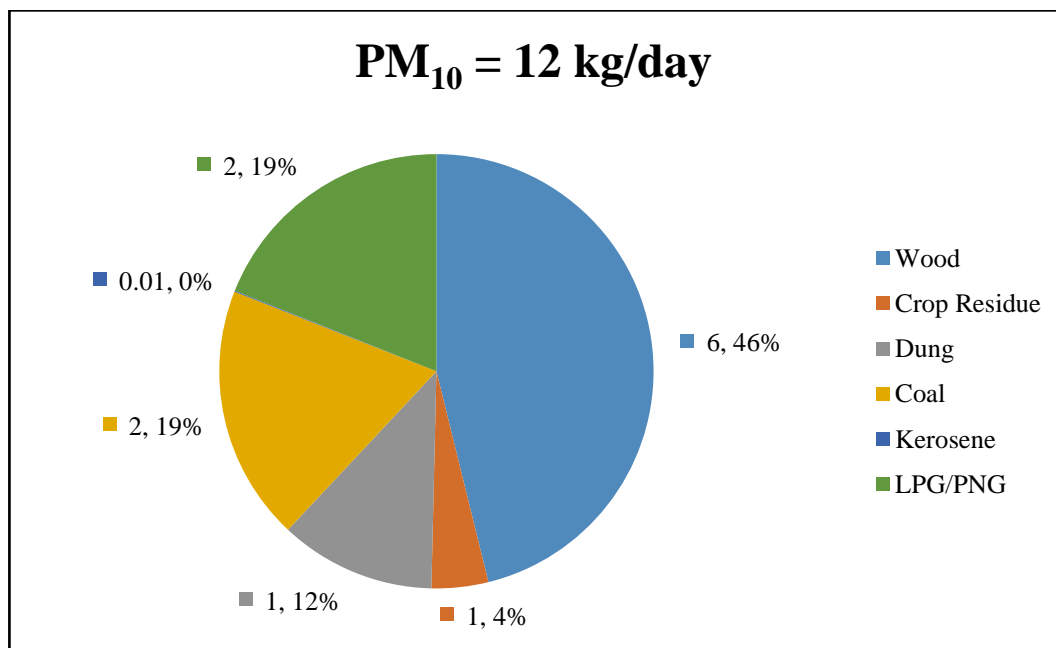


Figure 4.15: PM₁₀ Emission load from Domestic Sector (Kg/day, %)

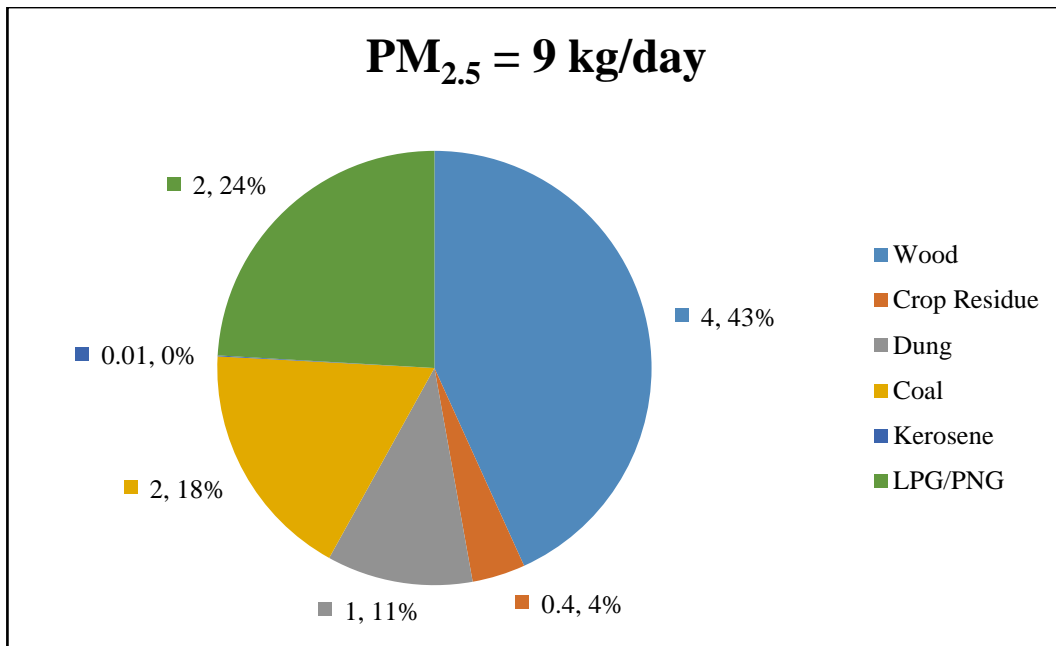


Figure 4.16: PM_{2.5} Emission load from Domestic Sector (Kg/day, %)

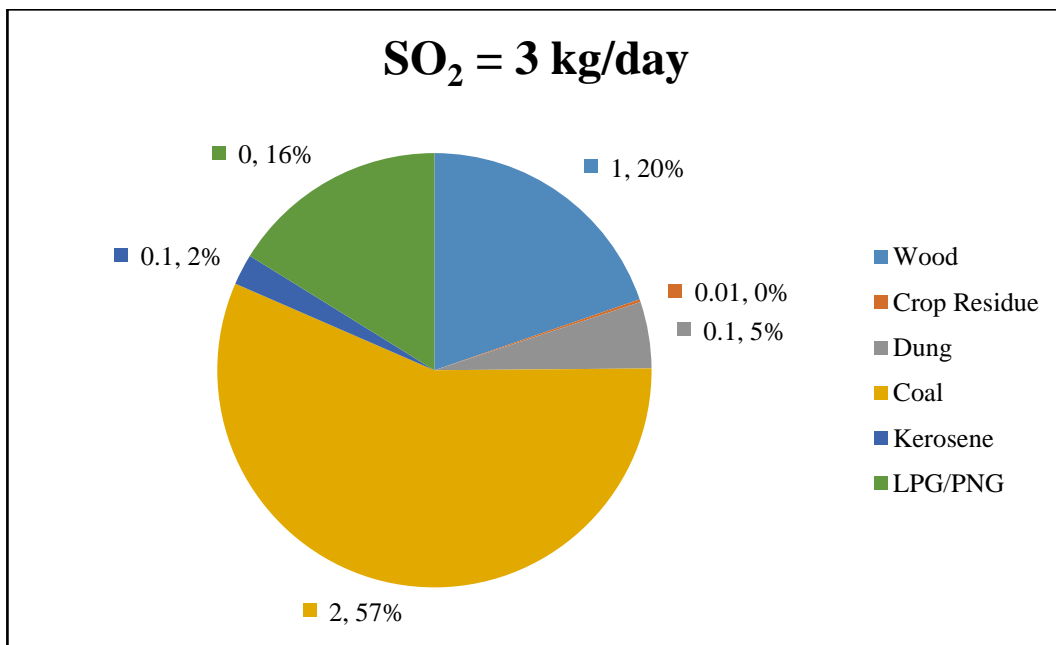


Figure 4.17: SO₂ Emission load from Domestic Sector (Kg/day, %)

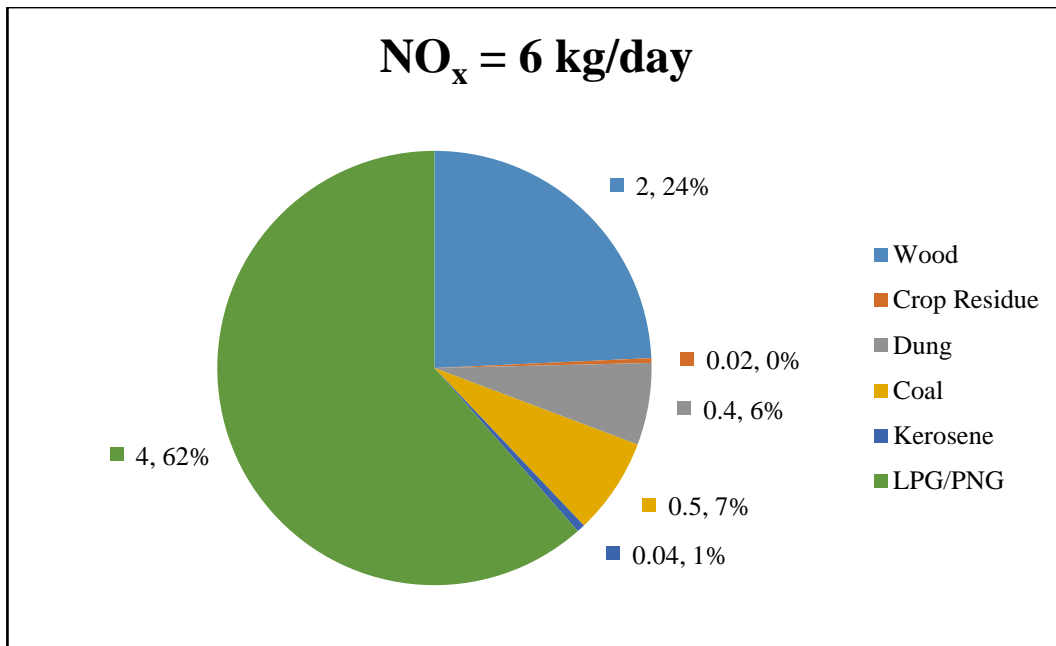


Figure 4.18: NO_x Emission load from Domestic Sector (Kg/day, %)

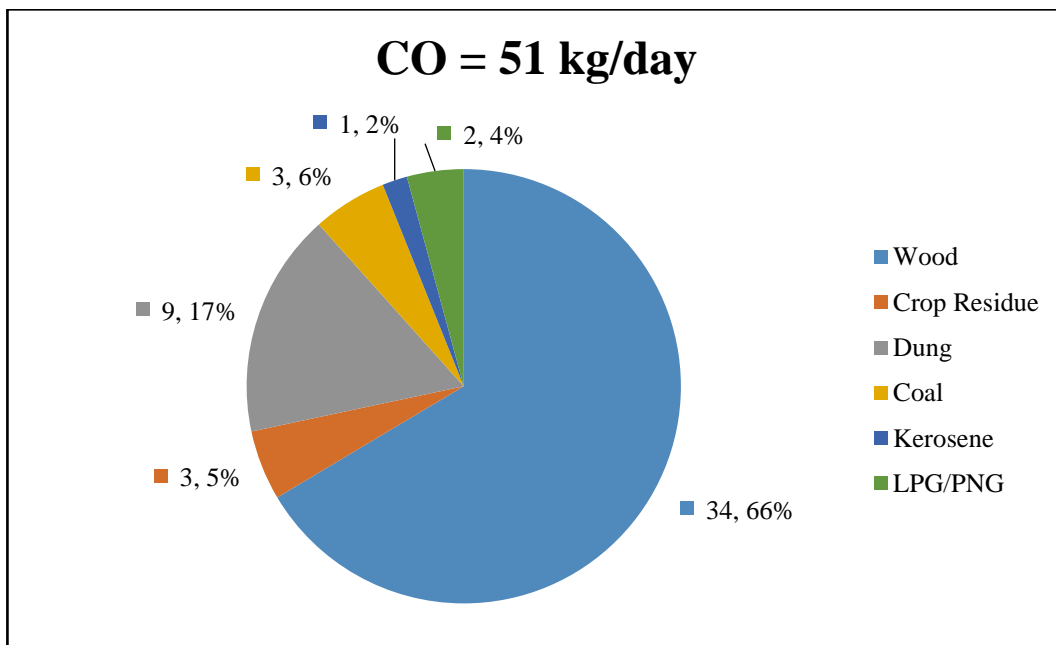


Figure 4.19: CO Emission load from Domestic Sector (Kg/day, %)

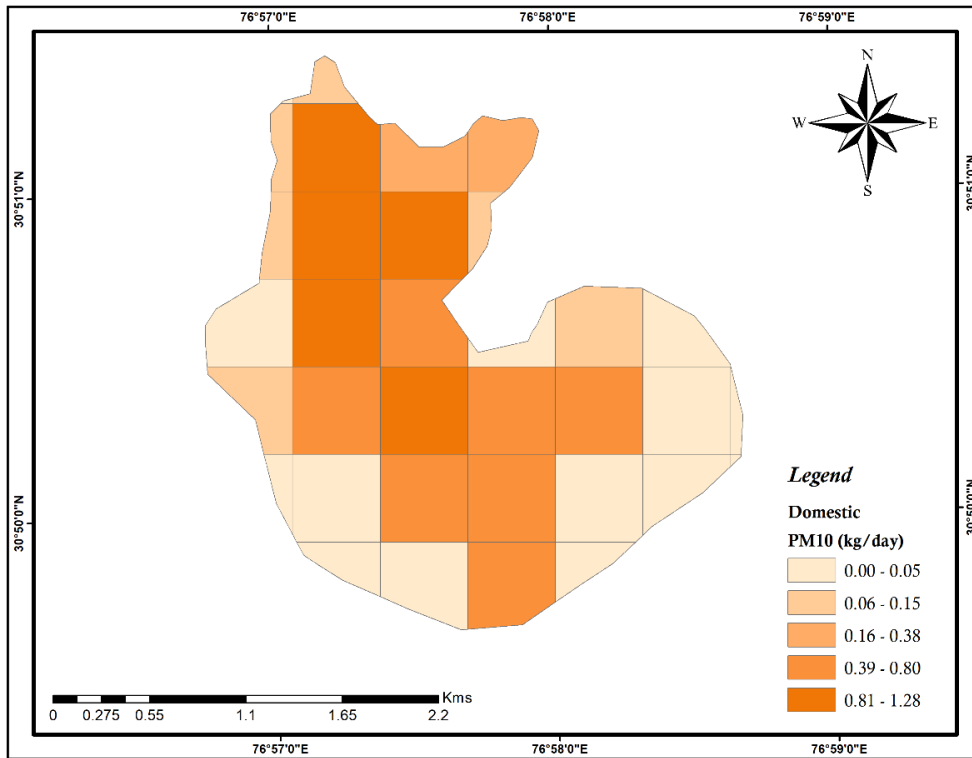


Figure 4.20: Spatial Distribution of PM₁₀ Emissions from Domestic Sector

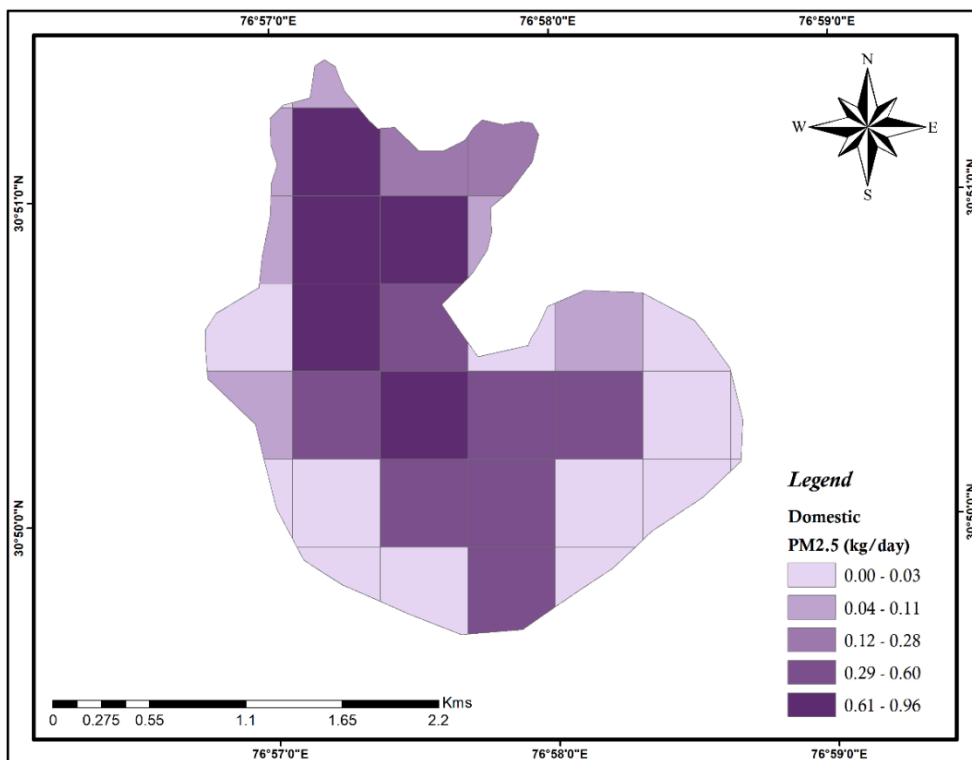


Figure 4.21: Spatial Distribution of PM_{2.5} Emissions from Domestic Sector

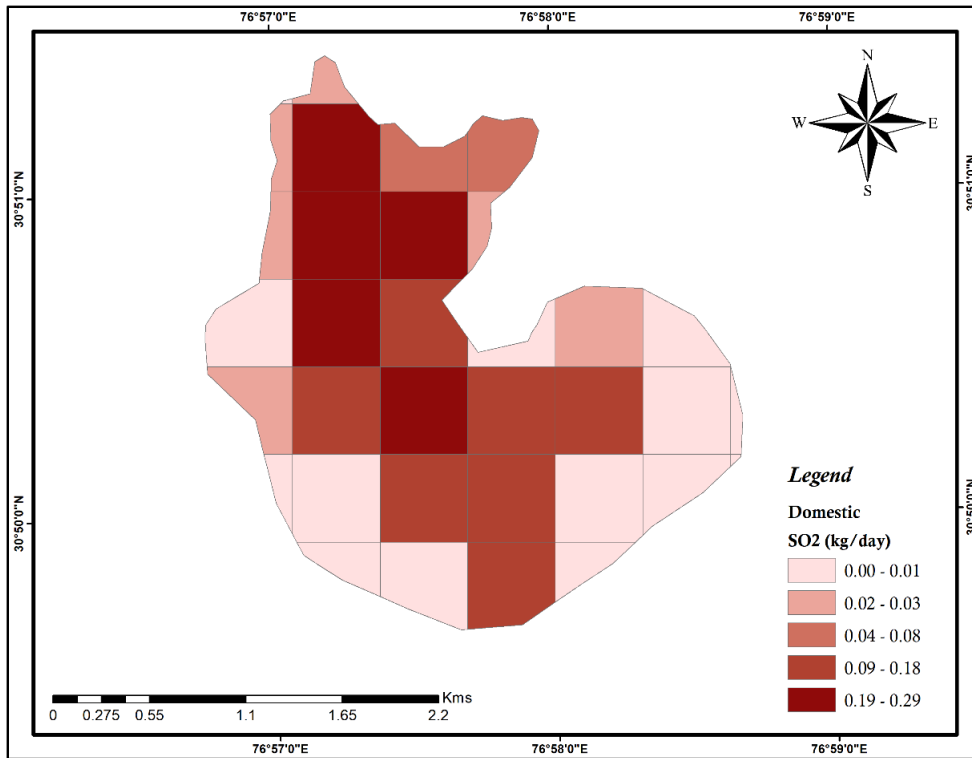


Figure 4.22: Spatial Distribution of SO₂ Emissions from Domestic Sector

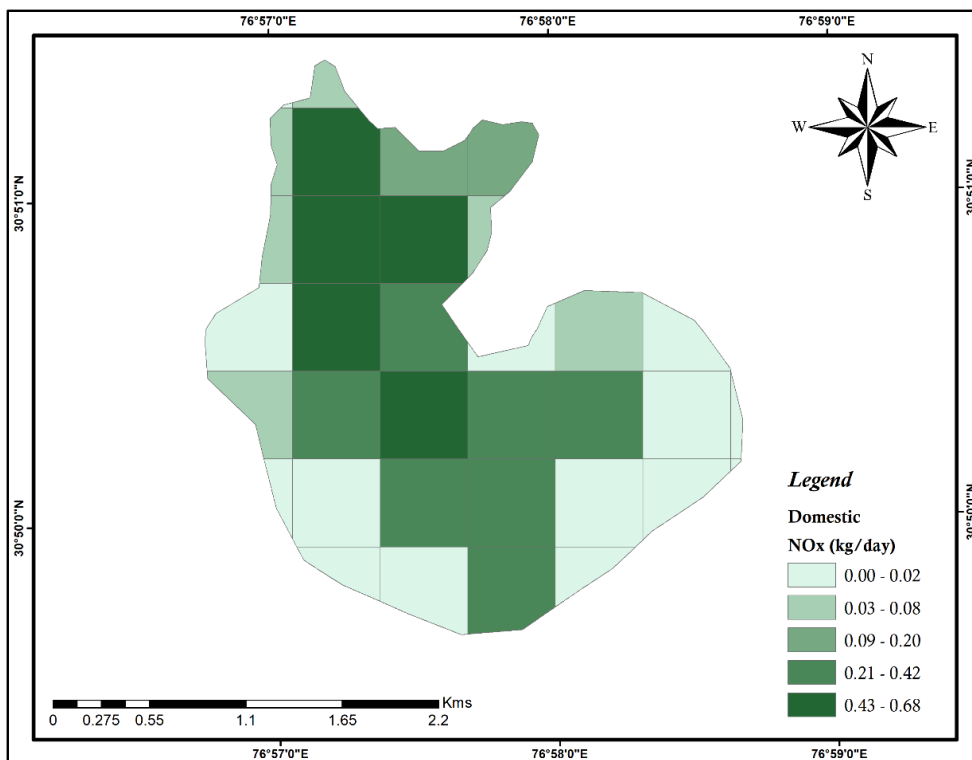


Figure 4.23: Spatial Distribution of NO_x Emissions from Domestic Sector

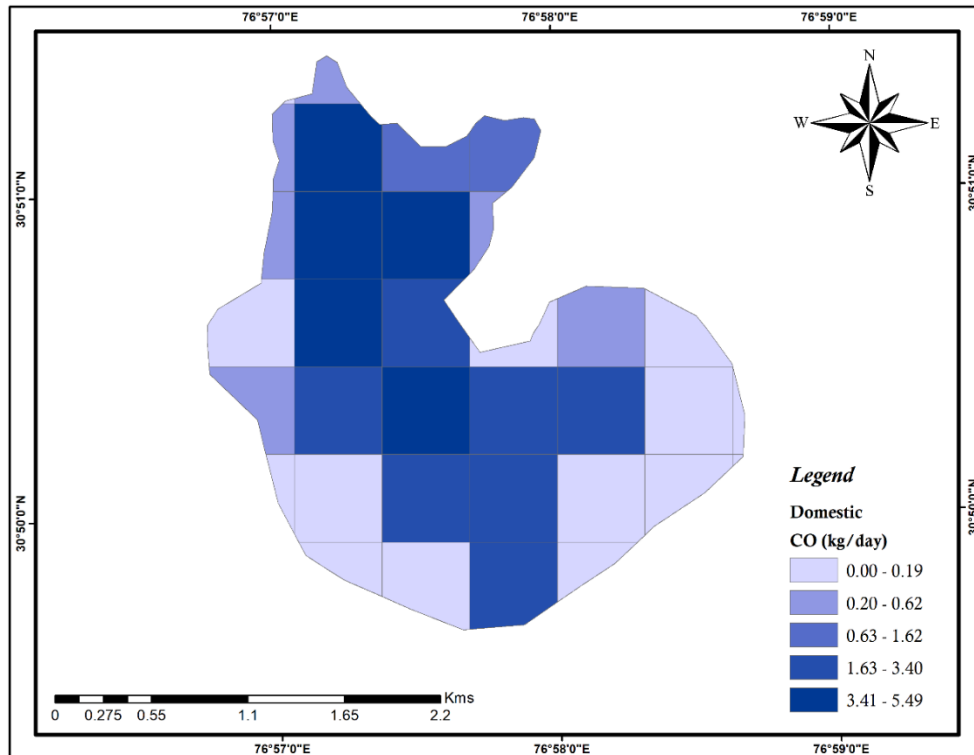


Figure 4.24: Spatial Distribution of CO Emissions from Domestic Sector

4.2.6 Construction and Demolition

A detailed survey was undertaken to assess construction and demolition activities. Satellite imagery (Google Earth, <https://earth.google.com/>) was also used to identify the construction activities. The major construction activities include buildings (including residential housing and apartments) information was obtained from 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 4.25). The areas under construction activities were calculated based on survey data and GIS. The location of construction and demolition sites at Parwanoo is given in Figure 4.26. The emissions were estimated using Eq (4.4) given by AP-42 (USEPA, 2000).

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



Figure 4.25: Construction and Demolition debris near construction sites

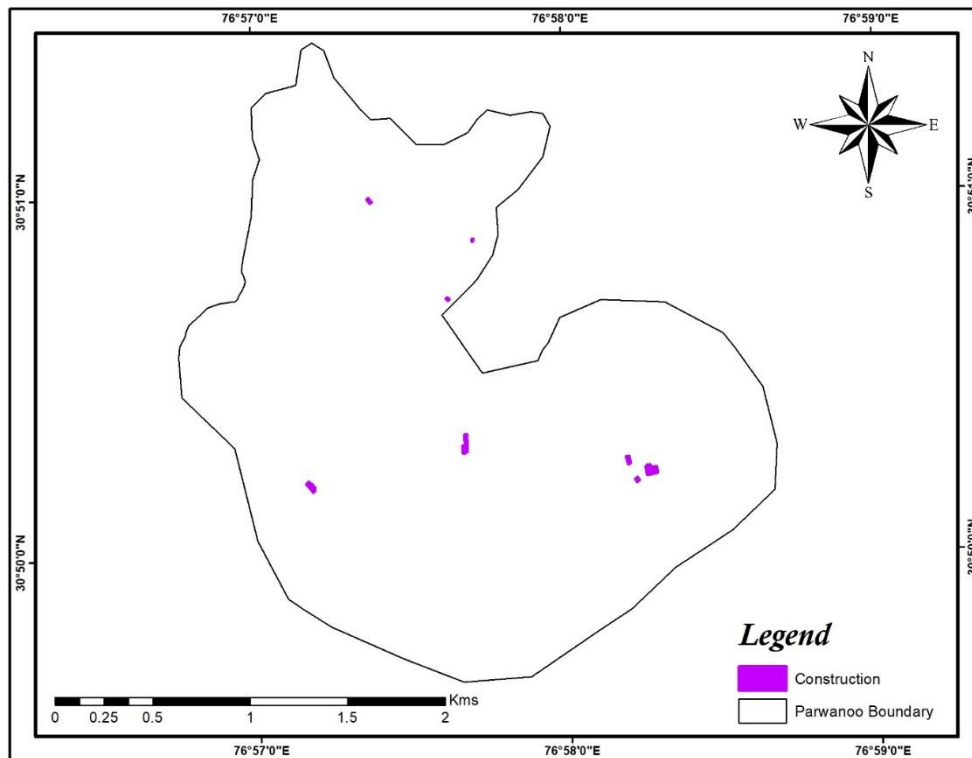
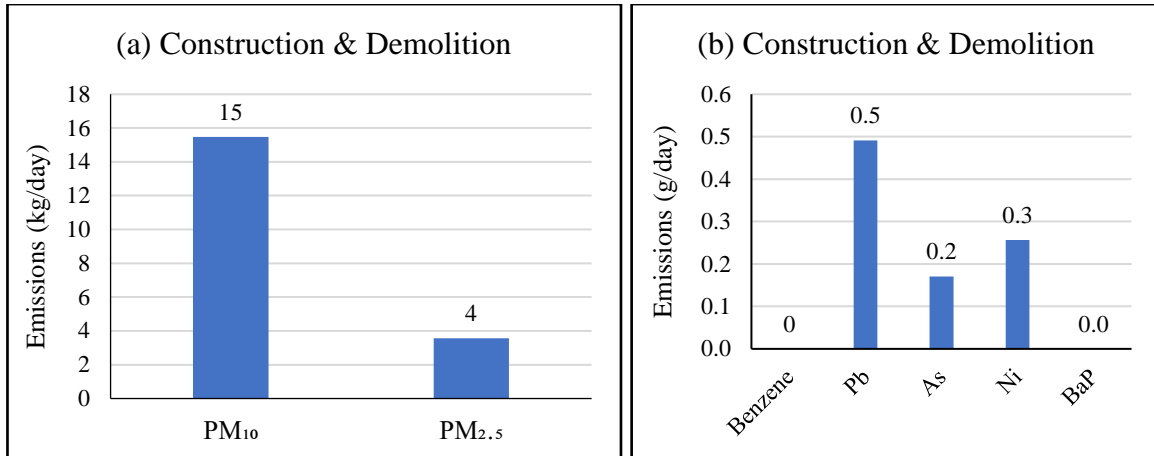


Figure 4.26: Location of Construction and Demolition sites in Parwanoo city

Total emissions from construction and demolition activities are presented in Figure 4.27 (a) & (b). The spatially resolved map of construction and demolition activities is shown in Figure 4.28 to Figure 4.29. The Emission load of PM_{10} and $PM_{2.5}$ from construction and demolition is 15 kg/day and 4 kg/day.



a) PM Emission in kg/day

b) Other Pollutants Emission in g/day

Figure 4.27: Emission Load from Construction and Demolition activities

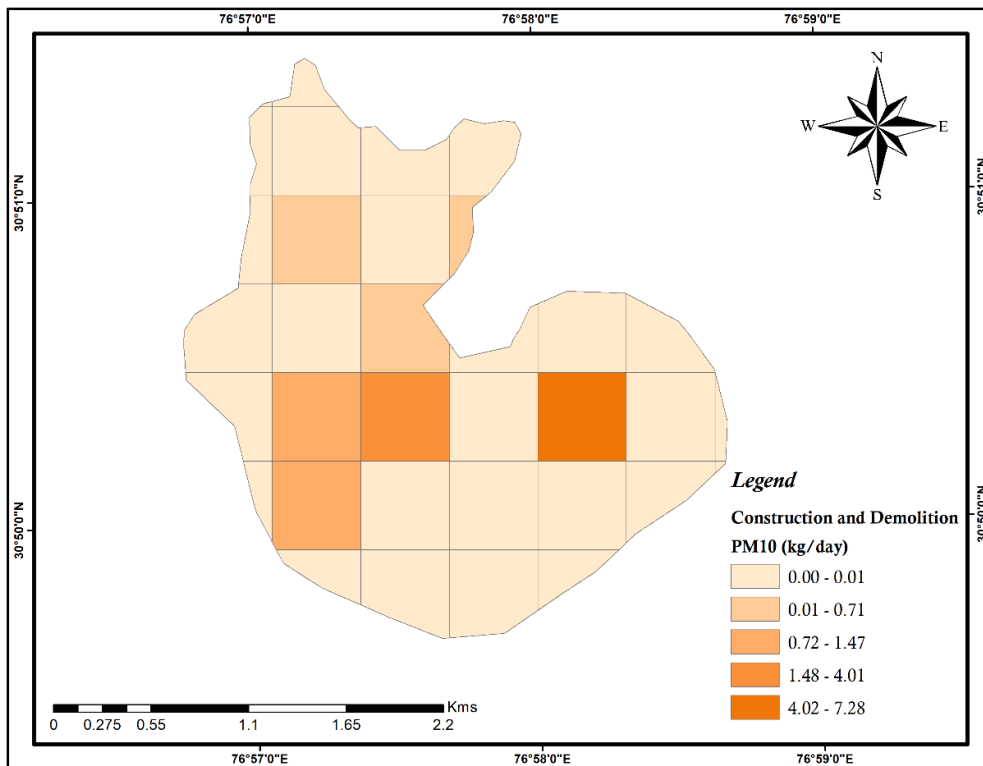


Figure 4.28: Spatial Distribution of PM₁₀ Emissions from Construction/Demolition

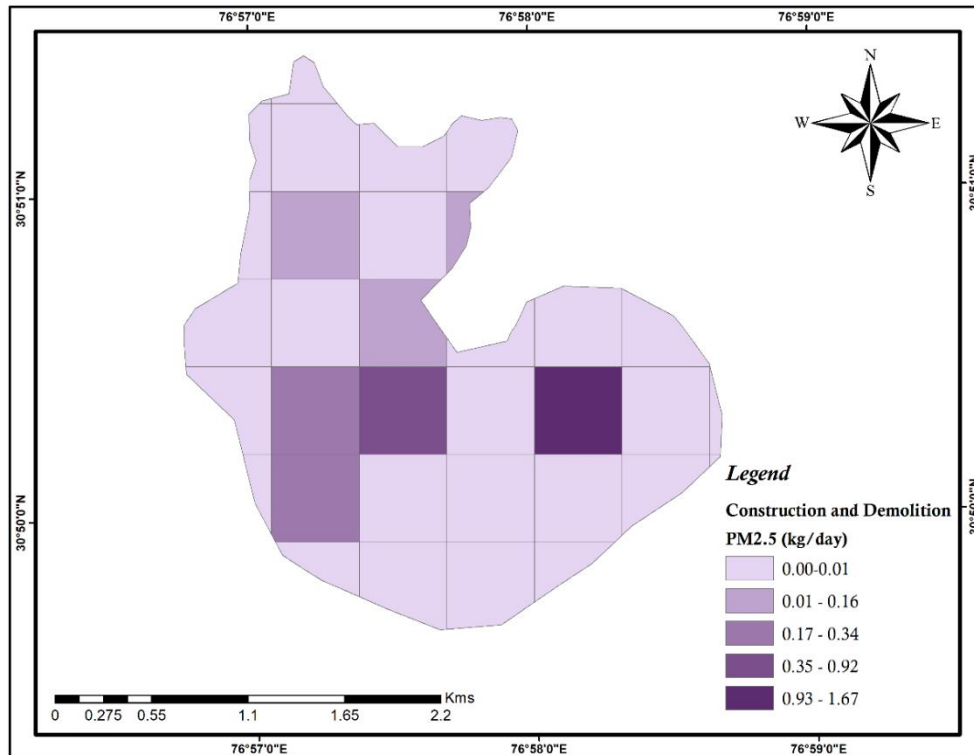


Figure 4.29: Spatial Distribution of PM_{2.5} Emissions from Construction/Demolition

4.2.7 Industrial Diesel Generator Sets (Industrial DG sets)

The location of the 20 Industrial DG sets (lying within the boundary) out of a total of 22 Industrial DG sets is shown in Figure 4.30 (source: consent data). The capacities of DG sets are in the range of 125 KVA to 600 KVA with an average capacity of 300 KVA. During the industrial survey, it was found that DG sets operate for two hours per day. Most industries use diesel as fuel for generator sets. The calculation is based on Eq (4.1), where ER, overall efficiency reduction was taken as zero. The CPCB (2011) emission factors were used for emission estimation. The total emissions from Industrial DG sets are shown in Figure 4.31 (a) & (b), and the spatial distribution of emissions from Industrial DG Sets is shown in Figure 4.32 to Figure 4.36.

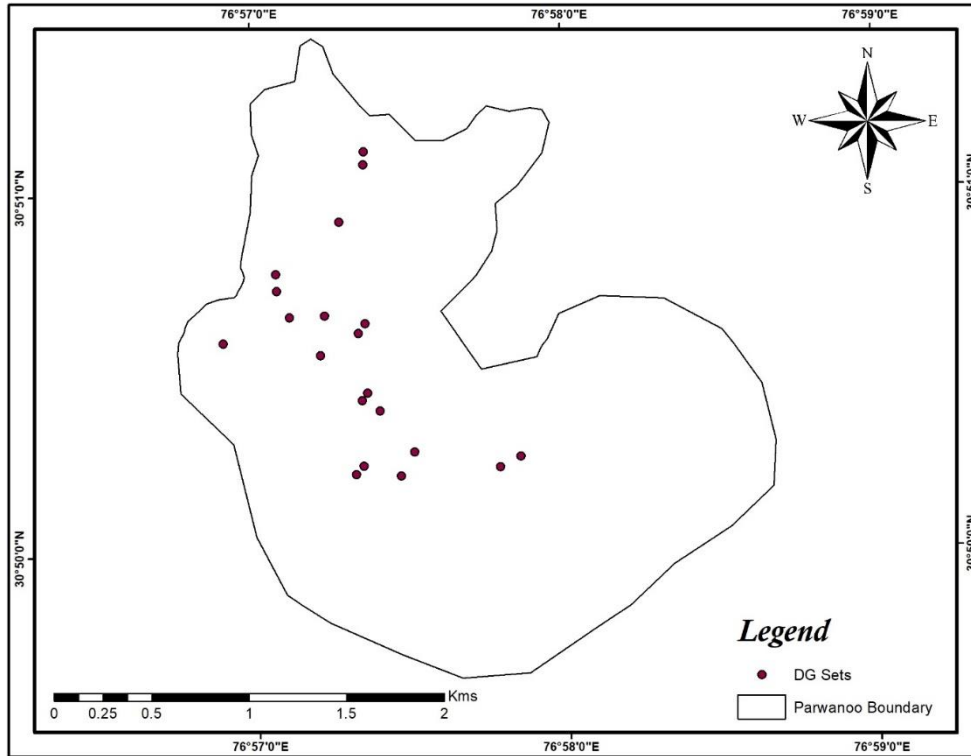
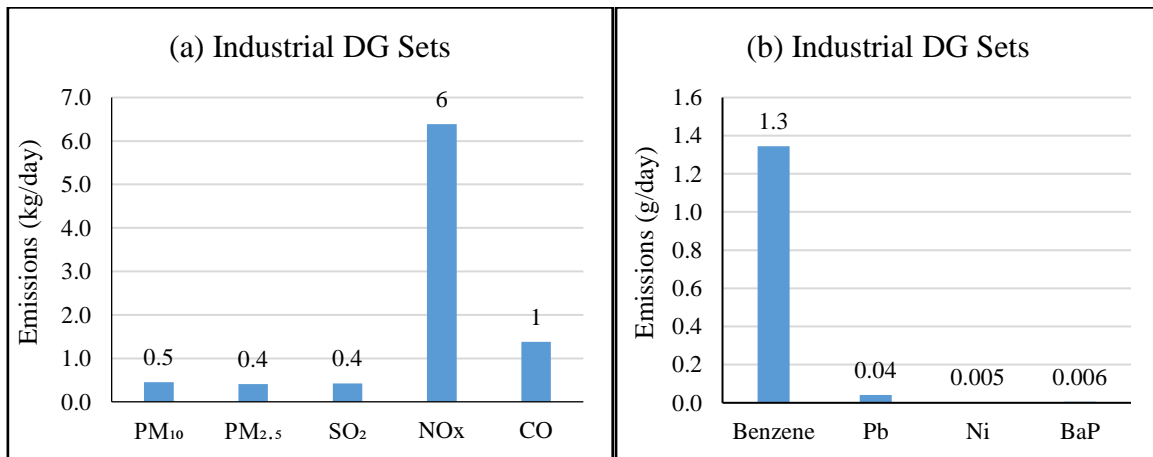


Figure 4.30: Location of Industrial DG Sets



a) PM and Gaseous Emission in kg/day

b) Other Pollutants Emission in g/day

Figure 4.31: Emission Load from Industrial DG sets

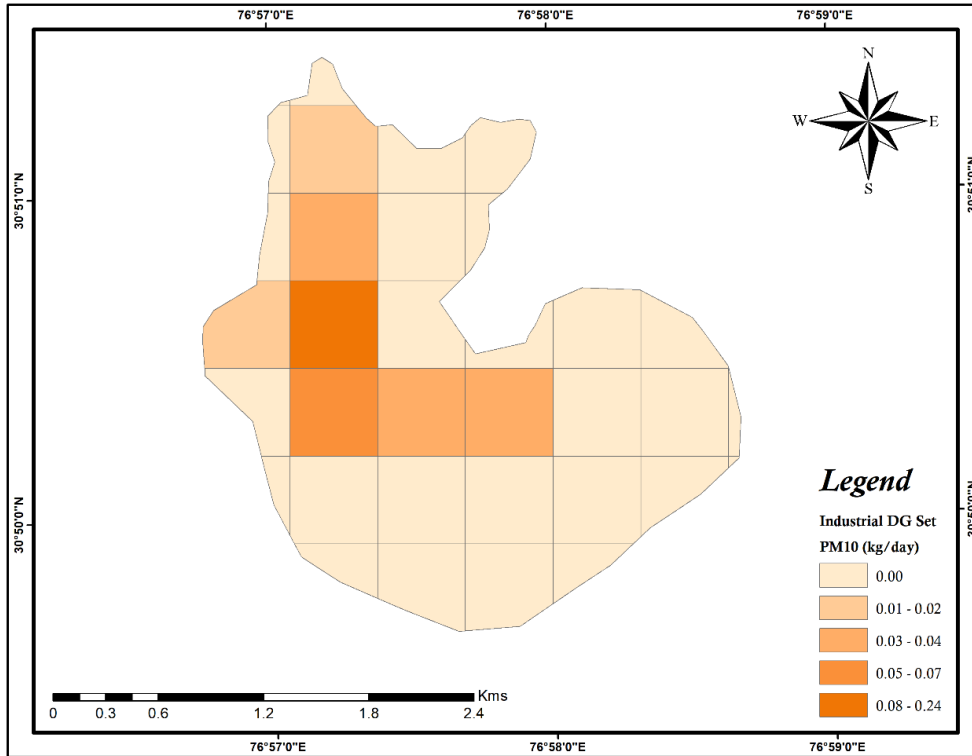


Figure 4.32: Spatial Distribution of PM₁₀ Emissions from Industrial DG Sets

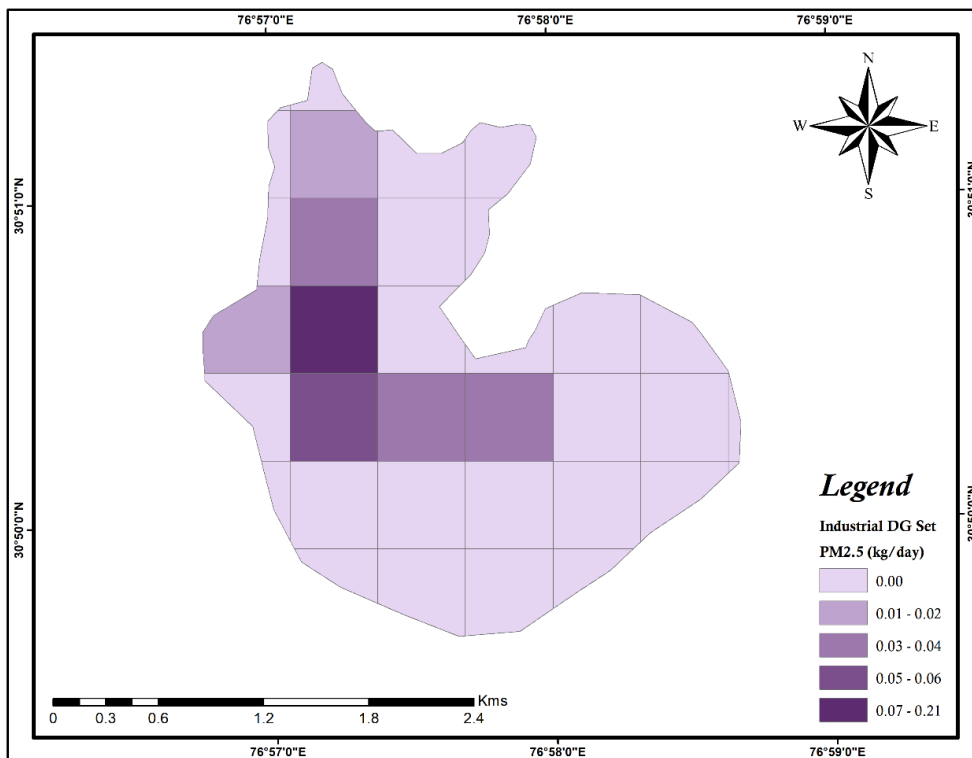


Figure 4.33: Spatial Distribution of PM_{2.5} Emissions from Industrial DG Sets

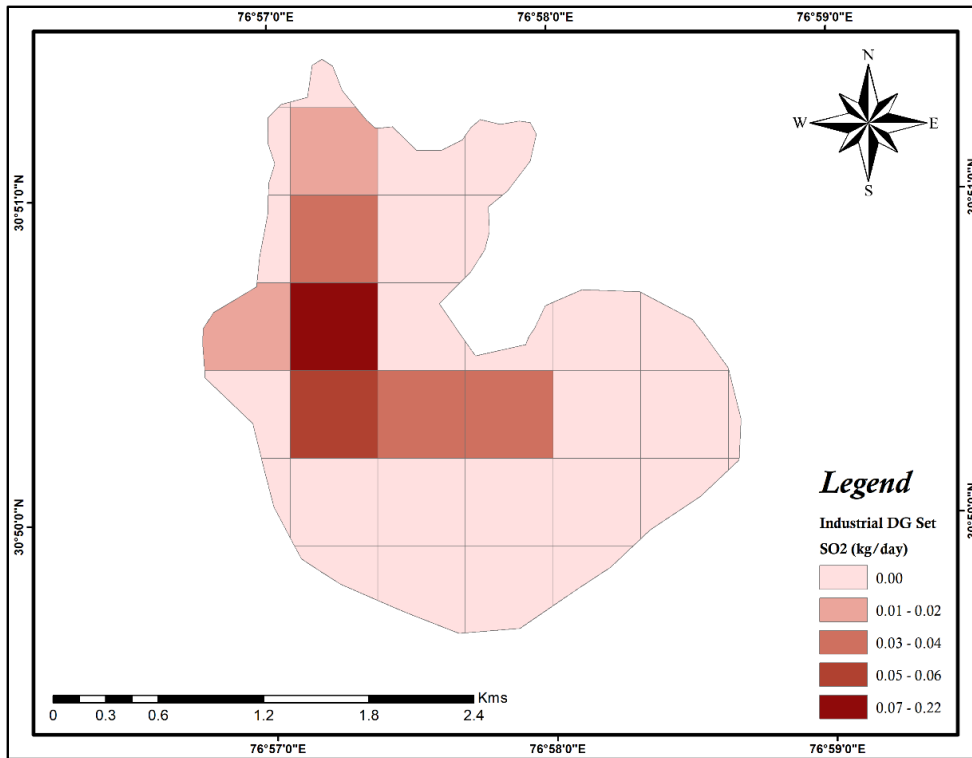


Figure 4.34: Spatial Distribution of SO₂ Emissions from Industrial DG Sets

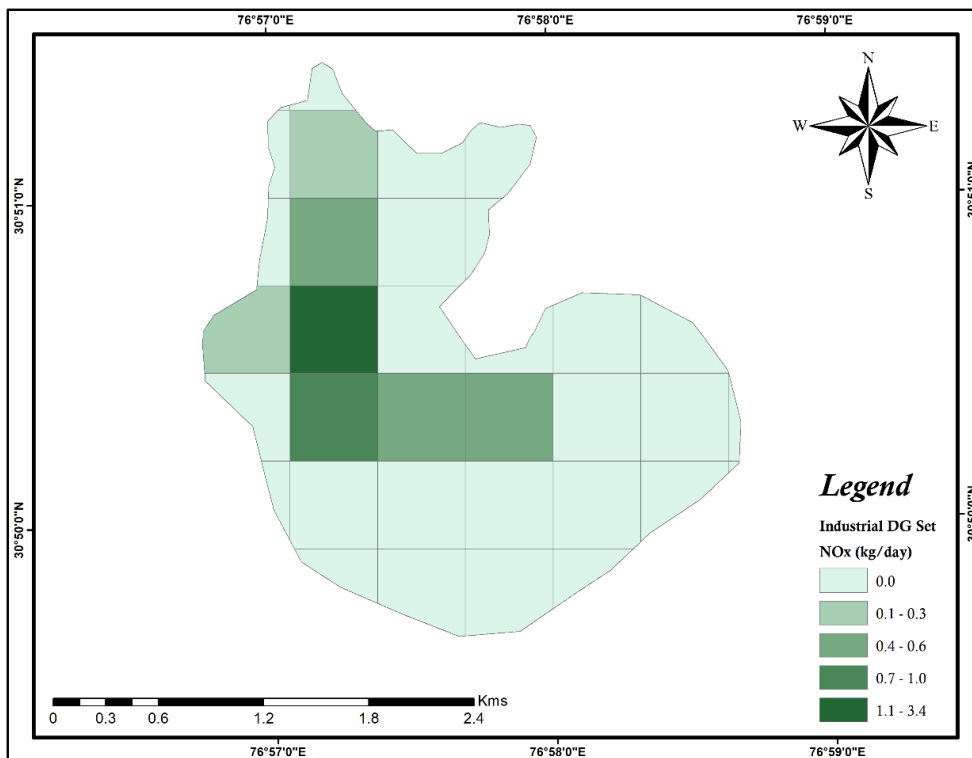


Figure 4.35: Spatial Distribution of NO_x Emissions from Industrial DG Sets

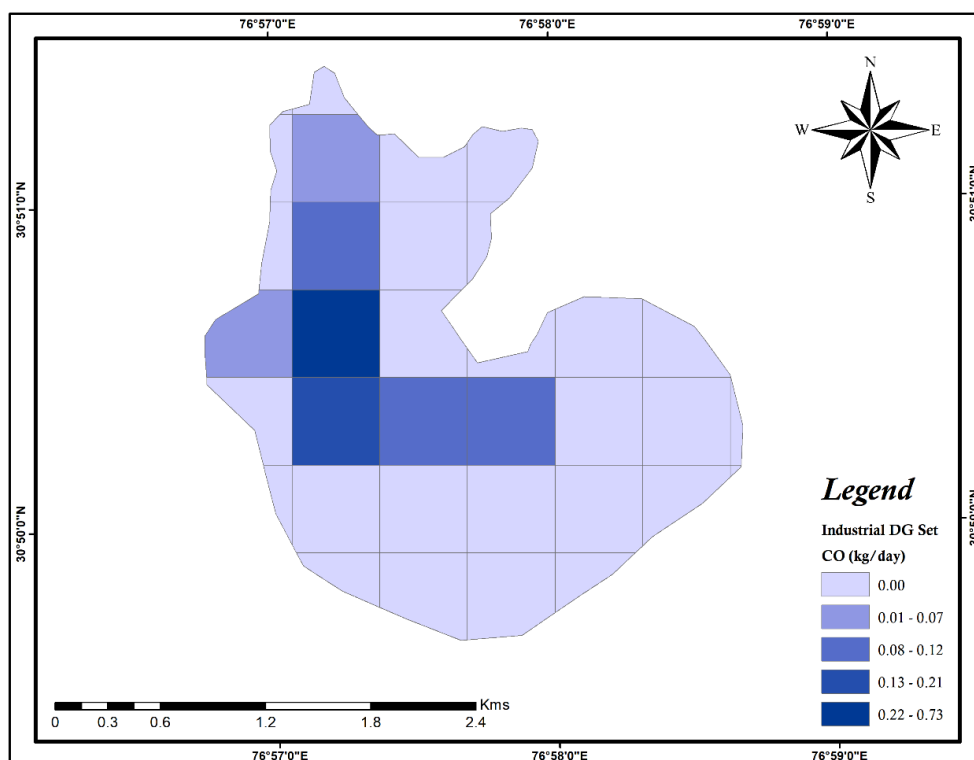


Figure 4.36: Spatial Distribution of CO Emissions from Industrial DG Sets

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

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

During the field survey, it was observed that hotels, restaurants, etc. use coal as fuel in tandoors. The total number of Hotels, Restaurants & GHs was approximately 32 (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 during these activities. The emissions of various parameters such as PM₁₀, PM_{2.5}, SO₂, NO_x, and CO were estimated from the activity data from each fuel type and then summed up in each grid cell. The emission factors given by CPCB (2011) were used. The overall emission from this area source (Hotels, Restaurants & GHs) is shown in Figure 4.38 (a) & (b). The spatial distribution of emissions from Hotels, Restaurants & GHs is shown in Figure 4.39 to Figure 4.43.

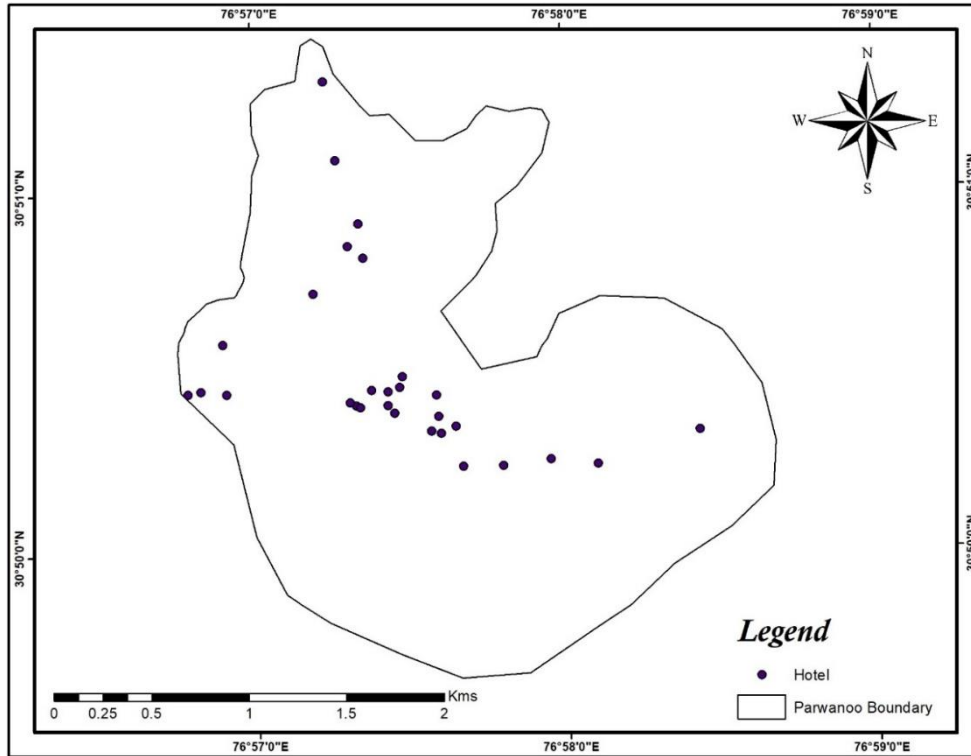
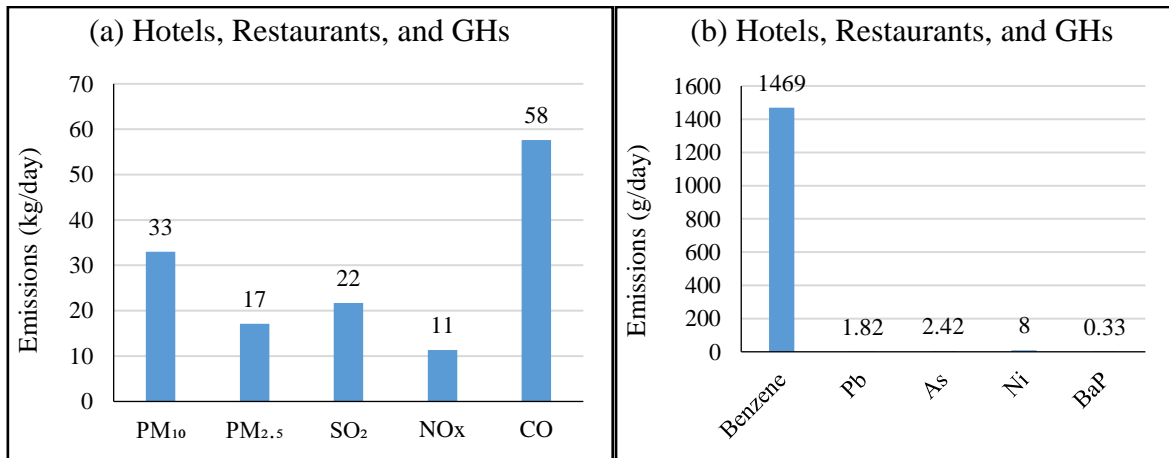


Figure 4.37: Location of Hotels, Restaurants & GHs



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

Figure 4.38: Emission Load from Hotels, Restaurants & GHs

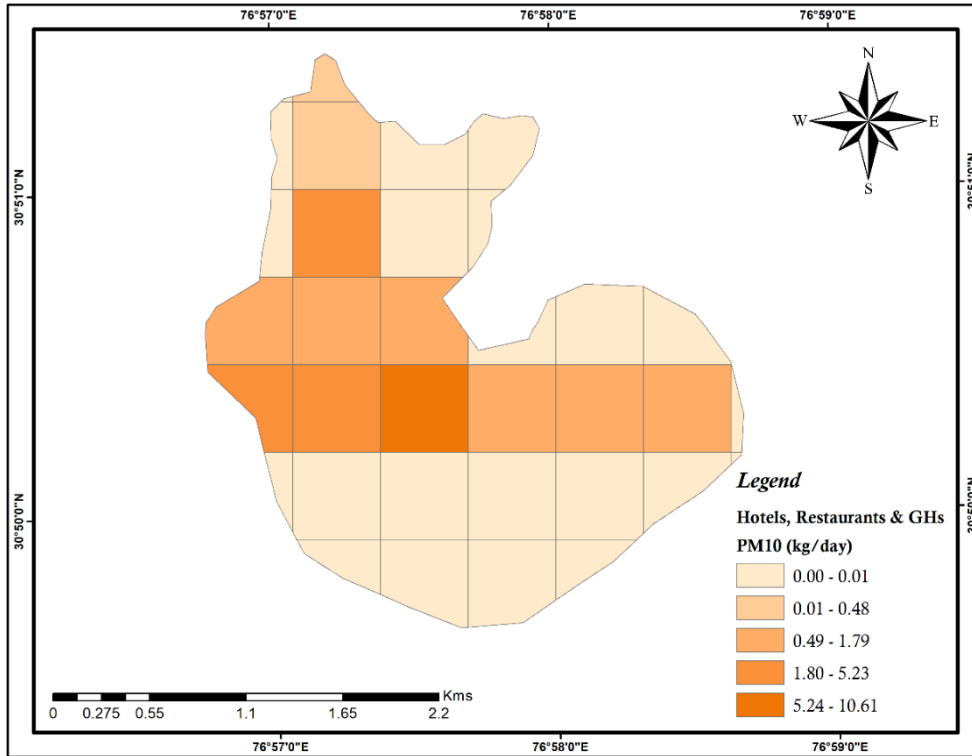


Figure 4.39: Spatial Distribution of PM₁₀ Emissions from Hotels, Restaurants & GHs

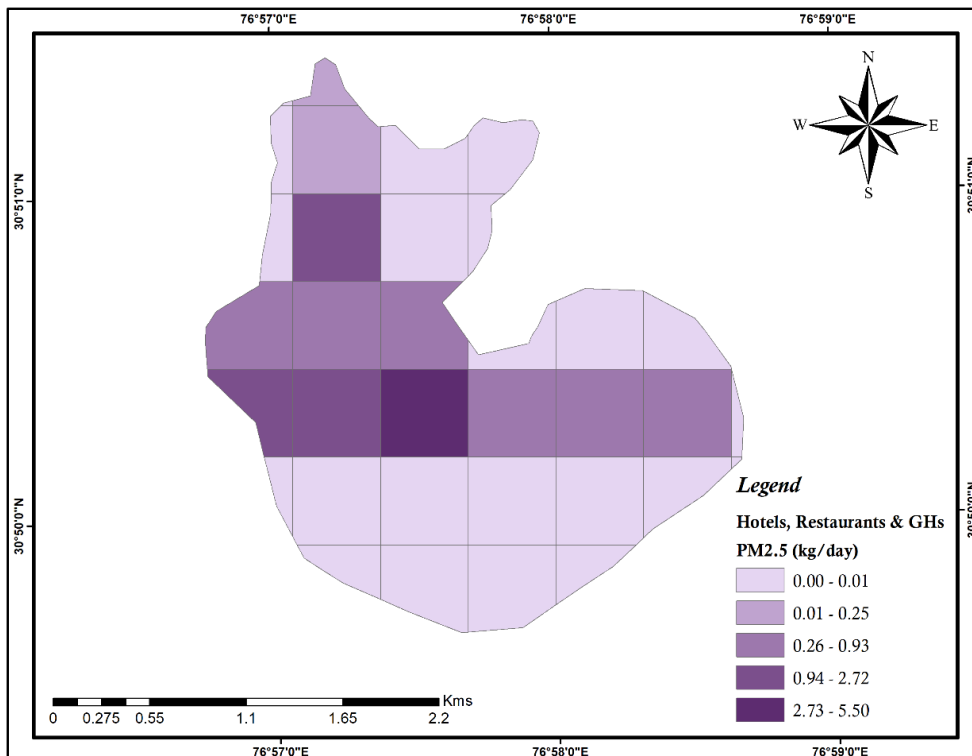


Figure 4.40: Spatial Distribution of PM_{2.5} Emissions from Hotels, Restaurants & GHs

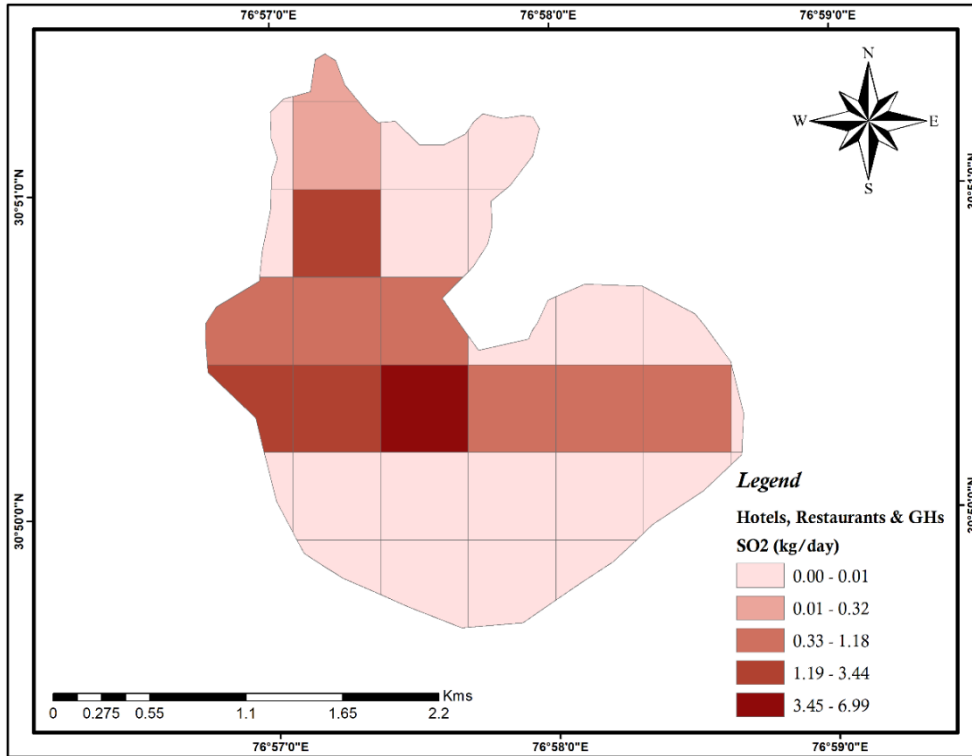


Figure 4.41: Spatial Distribution of SO₂ Emissions from Hotels, Restaurants & GHs

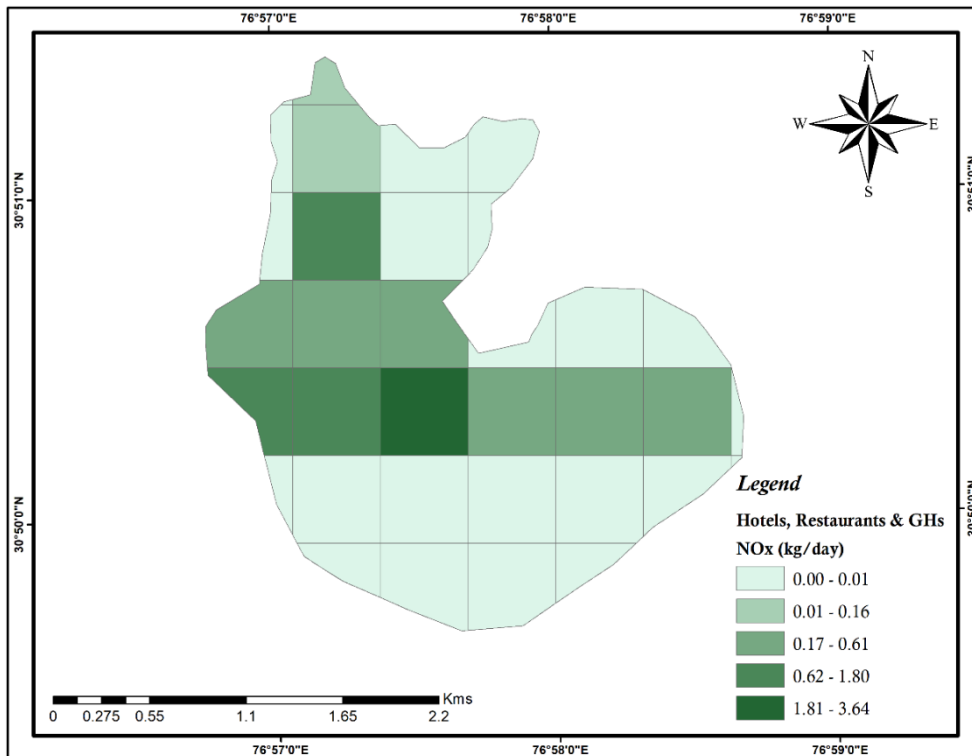


Figure 4.42: Spatial Distribution of NO_x Emissions from Hotels, Restaurants & GHs

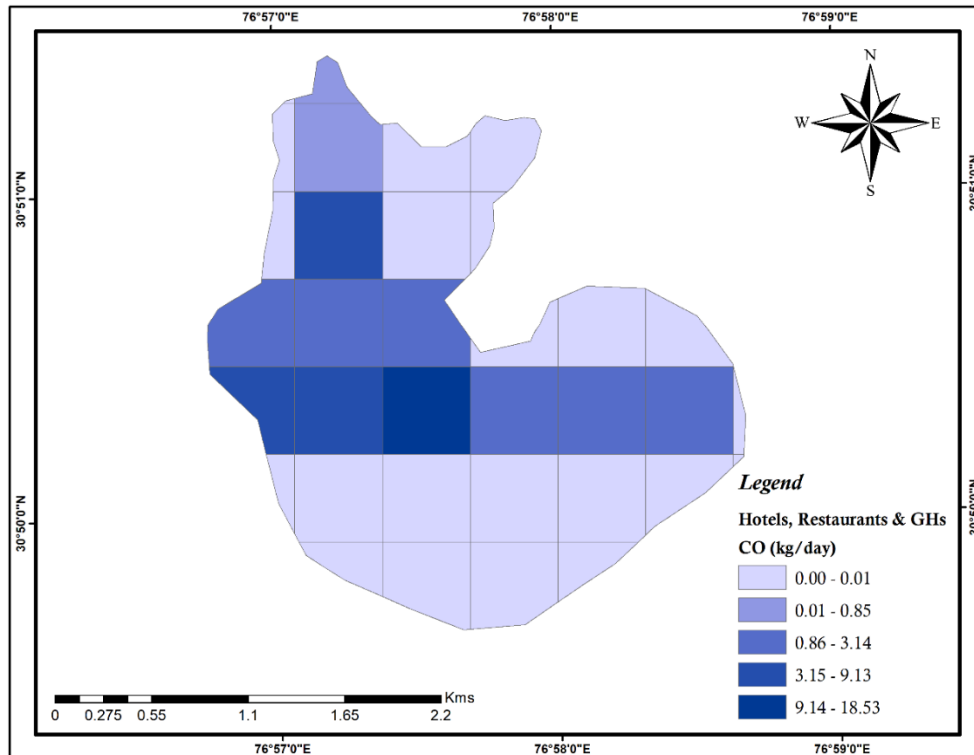


Figure 4.43: Spatial Distribution of CO Emissions from Hotels, Restaurants & GHs

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 3.92 MT/day and the waste collected is about 2.35 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 Parwanoo city (Sharma, 2018) and several events of MSW burning have been observed during the city survey. The survey was conducted on weekdays and weekends and the frequency of MSW events is calculated in the low-, middle- and higher-income areas. The MSW burning at different locations in Parwanoo city is shown in Figure 4.44.



Figure 4.44: MSW Burning in parts of Parwanoo city

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

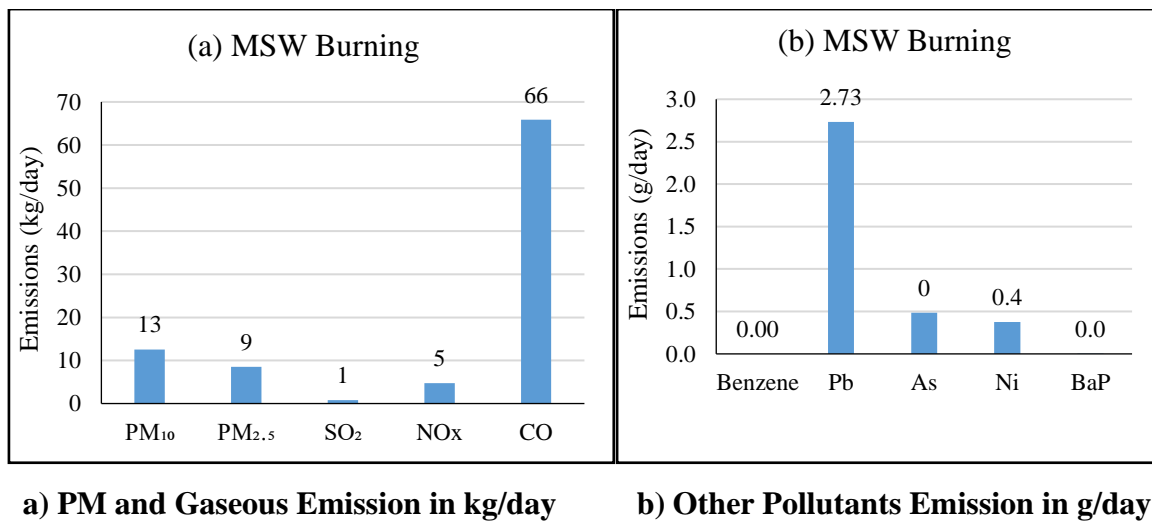


Figure 4.45: Emission Load from MSW Burning

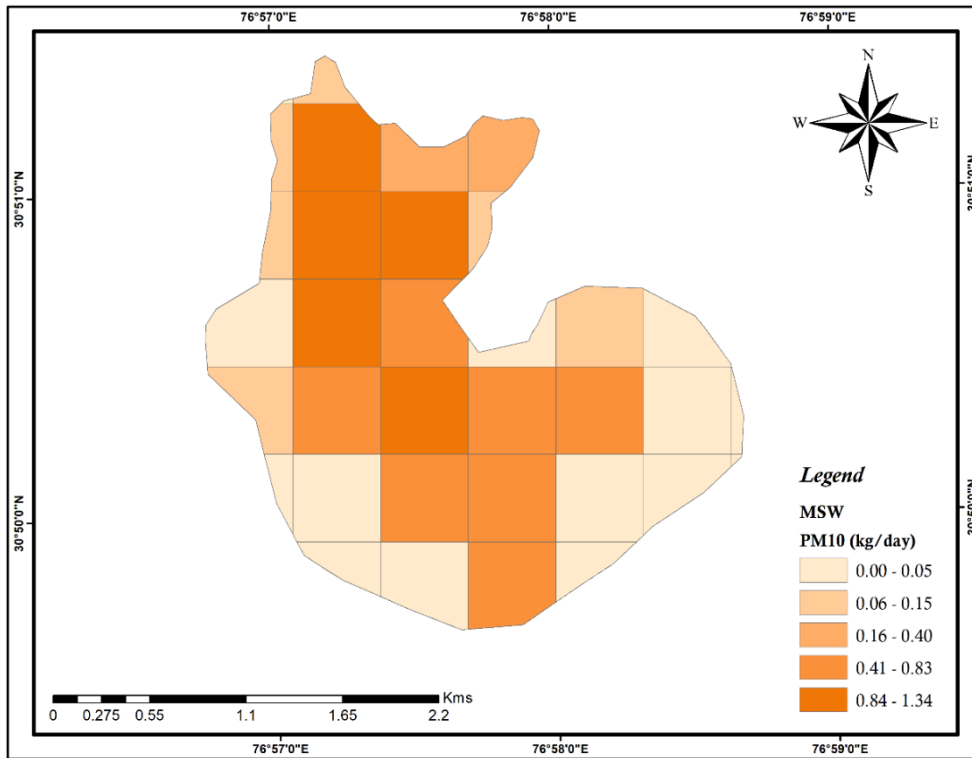


Figure 4.46: Spatial Distribution of PM₁₀ Emissions from MSW Burning

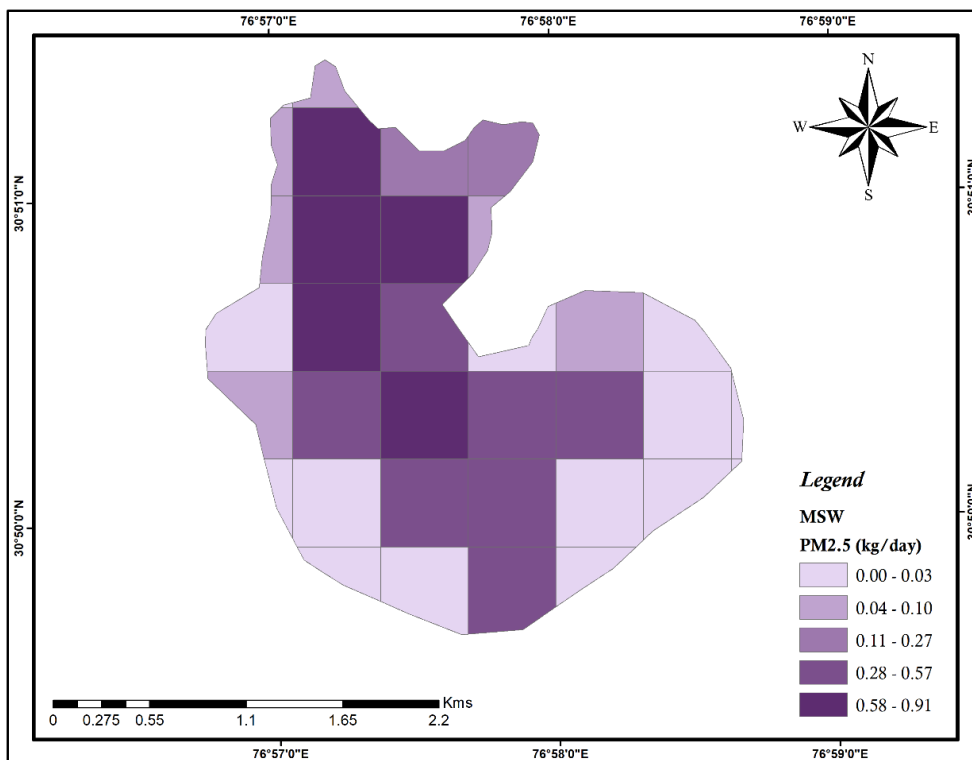


Figure 4.47: Spatial Distribution of PM_{2.5} Emissions from MSW Burning

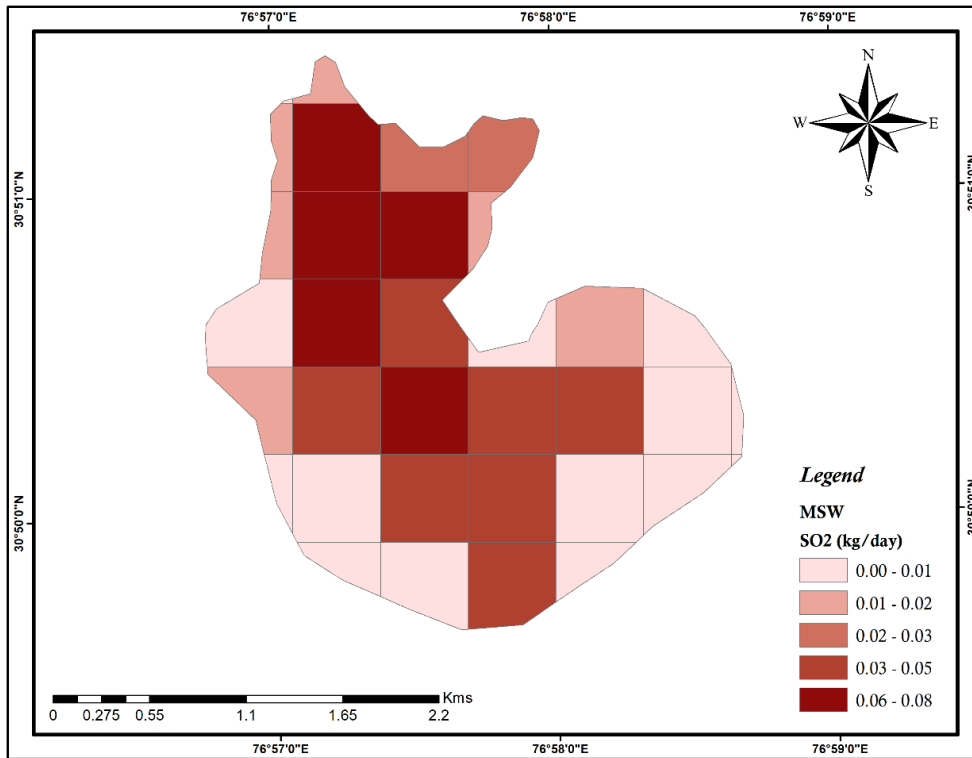


Figure 4.48: Spatial Distribution of SO₂ Emissions from MSW Burning

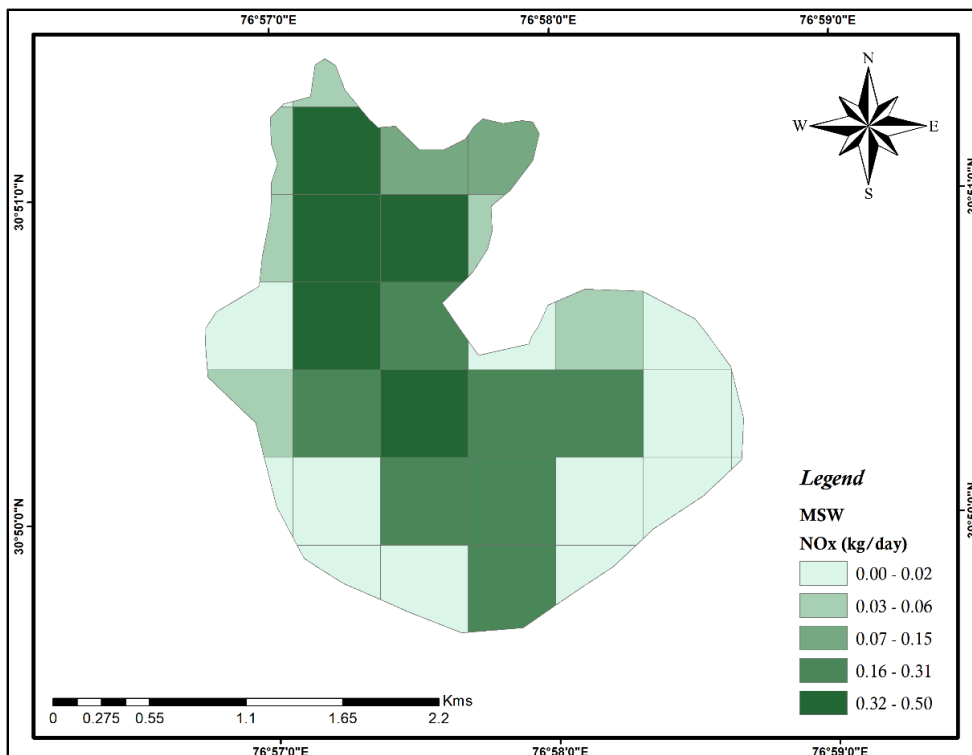


Figure 4.49: Spatial Distribution of NO_x Emissions from MSW Burning

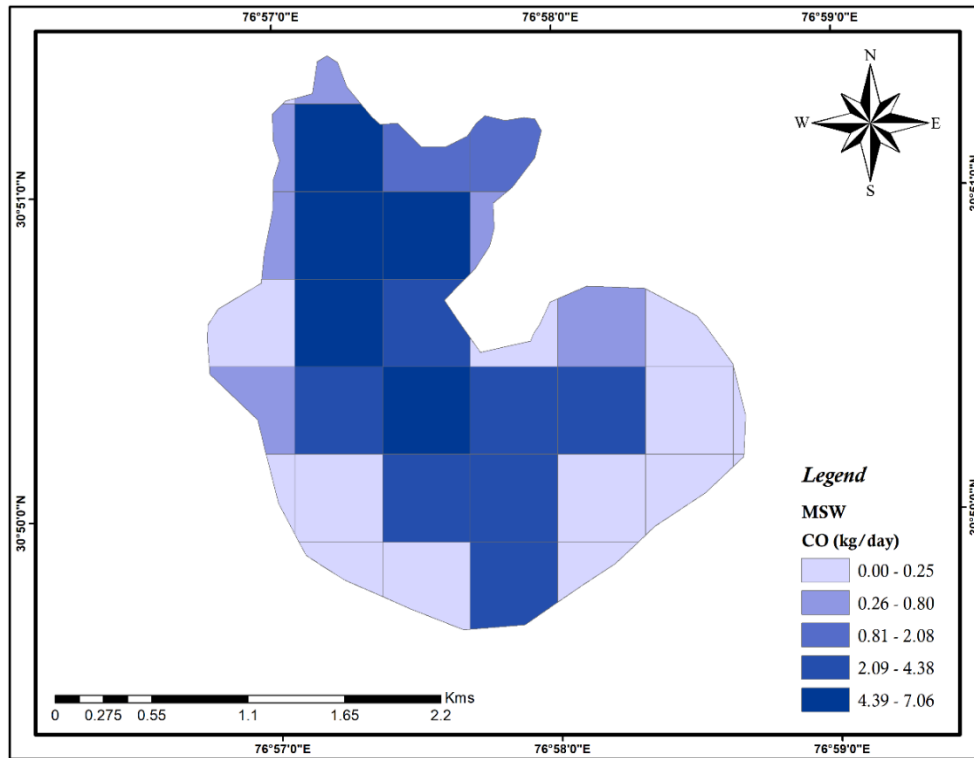


Figure 4.50: Spatial Distribution of CO Emissions from MSW Burning

4.2.10 Hospitals

A detailed survey was undertaken to estimate the emission from hospitals in Parwanoo City. There are approximately 5 hospitals present in the city. The locations of Hospitals in Parwanoo are given in Figure 4.51. The emission of pollutants from hospitals is shown 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.

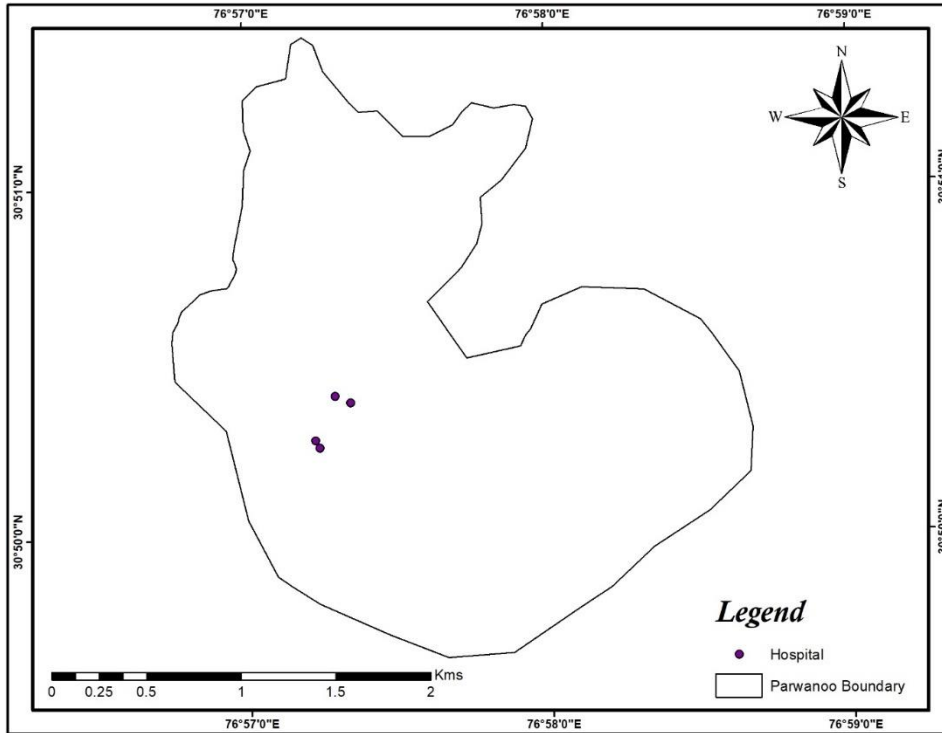
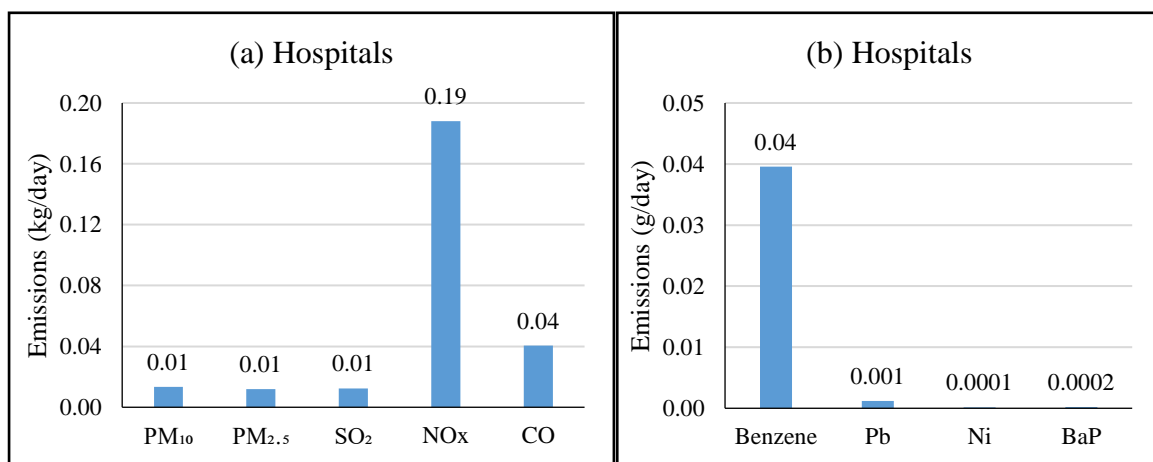


Figure 4.51: Locations of Hospitals in Parwanoo City

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

No. of Hospitals	DG set Average Capacity		PM ₁₀ (kg/d)	PM _{2.5} (kg/d)	SO ₂ (kg/d)	NO _x (kg/d)	CO (kg/d)	Benzene (g/d)	Pb (g/d)	As (g/d)	Ni (g/d)	BaP (g/d)
	KVA	Running Hour										
5	62.5	2	0.01	0.01	0.01	0.19	0.04	0.04	0.001	0	0.0001	0.0002

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 17 industrial units in Parwanoo City (Table 4.2) having boilers/furnaces that are operational in Parwanoo city and contribute to particulate as well as in gaseous emissions. The overall emissions estimated from the different types of boilers, furnaces, etc are presented in Table 4.2. Major fuels that contribute to emissions are HSD, wood, and fire oil. Industrial units that are present at. The industrial locations are given in Figure 4.53. The information on stacks, fuel, and their consumption was obtained from HPPCB. The AP-42 (USEPA, 2000) emission factors were used to calculate the emission. The emission of pollutants from industries is shown in Figure 4.54 (a) & (b). The Spatial distribution of emissions from the industries is given in Figure 4.55 to Figure 4.59.

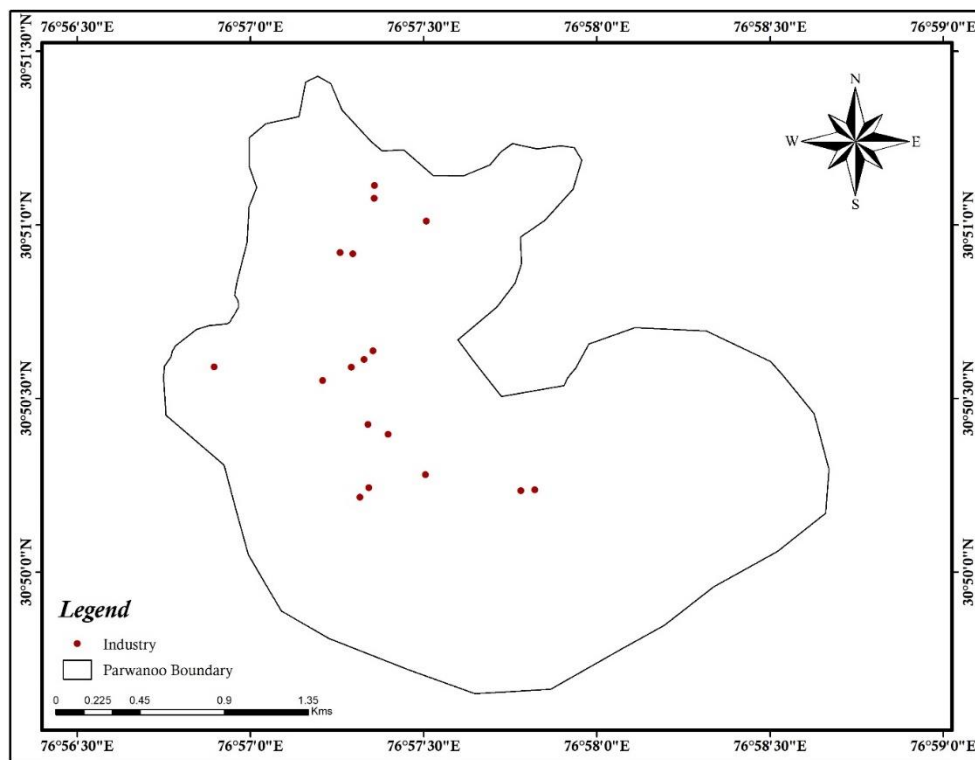
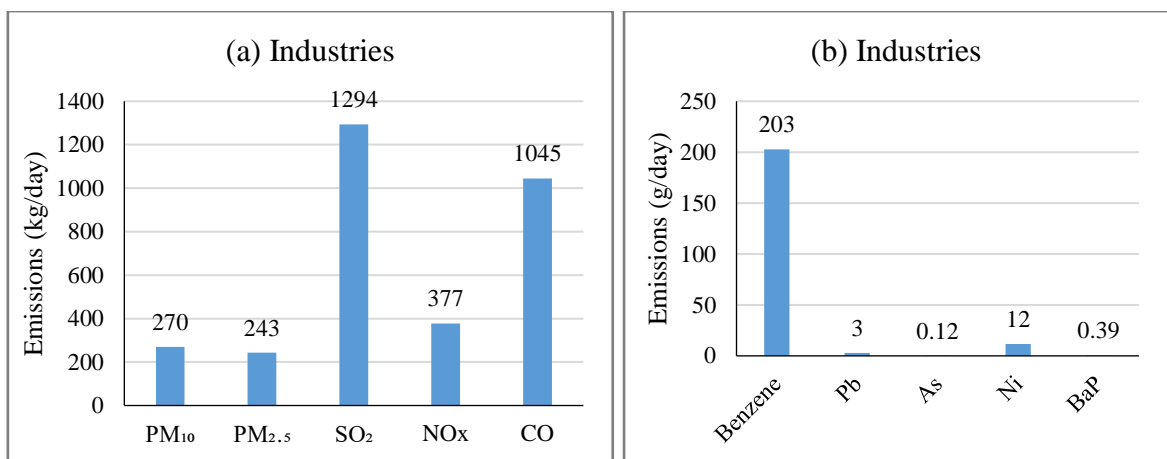


Figure 4.53: Location of Industries in Parwanoo city



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 Parwanoo city (emissions in kg/day and g/day)

Boiler/ Furnace Type	Fuel	No of Furnaces / Boilers	PM ₁₀ (kg/d)	PM _{2.5} (kg/d)	SO ₂ (kg/d)	NO _x (kg/d)	CO (kg/d)	Benzene (g/d)	Pb (g/d)	As (g/d)	Ni (g/d)	BaP (g/d)
Boiler	Wood, HSD	7	76	69	73	110	956	60	1.1	0.12	0.1	0.12
Furnace	Electricity, Pyrolysis Oil, FO, LPG	6	171	154	1221	266	38	111	1.4	0	11.6	0.21
Re-heating Furnace	LDO	1	9.5	8.5	271	53	5	32	0.4	0	0.05	0.12
Thermic Fluid Heater	Wood	1	3.46	3.11	0.08	0.52	50.52	0	0.02	6.2 ×10 ⁻³	0	3.7 ×10 ⁻⁴
Foundry	Electricity	2	134	120	0	0	0	0	0	0	0	0
Total		17	270	243	1294	377	1045	203	3	0.12	11.75	17

Data Source: Consent Data

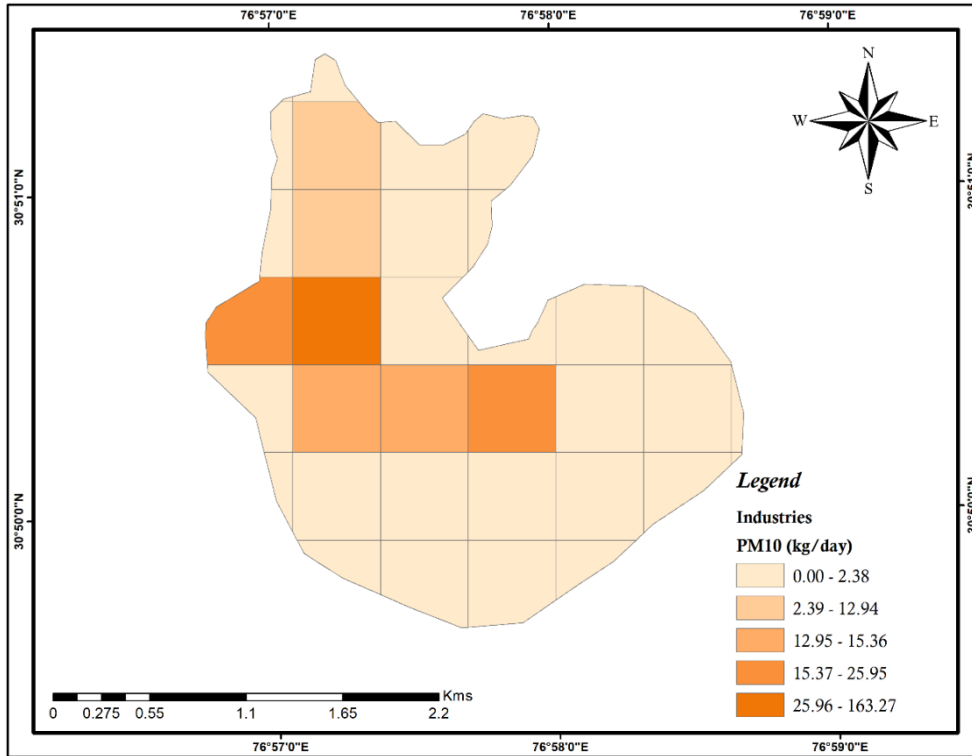


Figure 4.55: Spatial Distribution of PM₁₀ Emissions from Industries

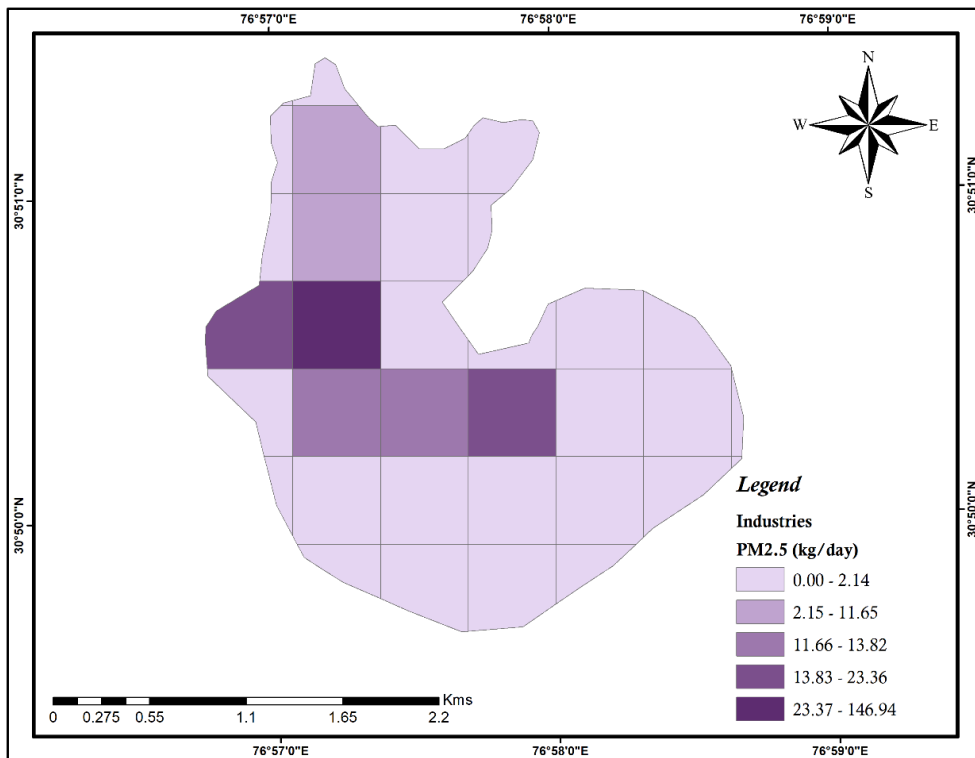


Figure 4.56: Spatial Distribution of PM_{2.5} Emissions from Industries

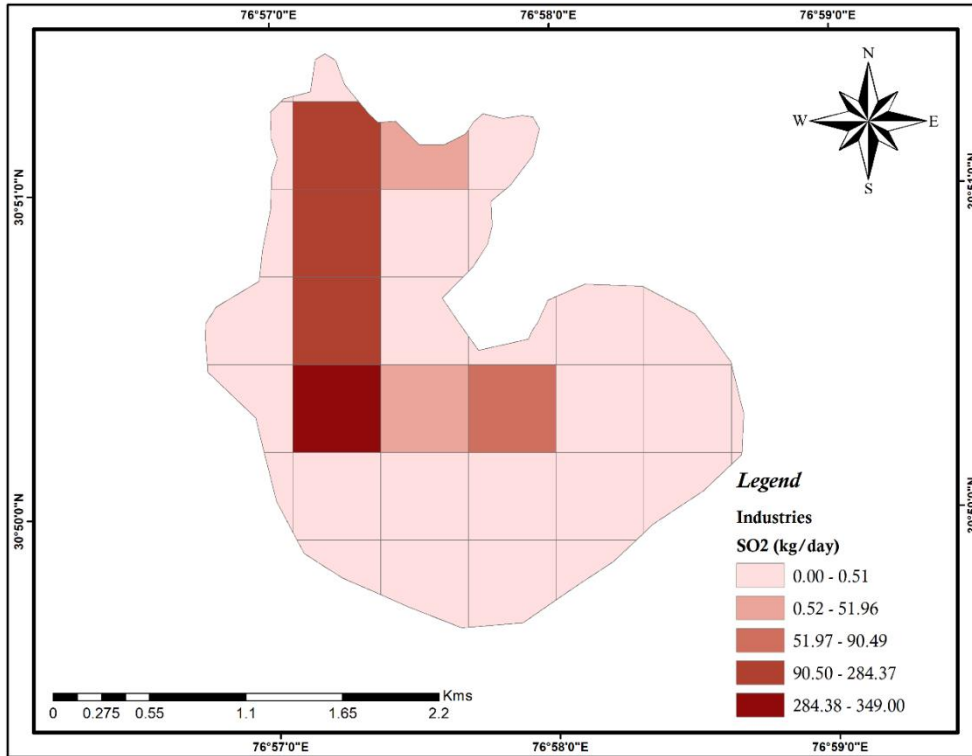


Figure 4.57: Spatial Distribution of SO₂ Emissions from Industries

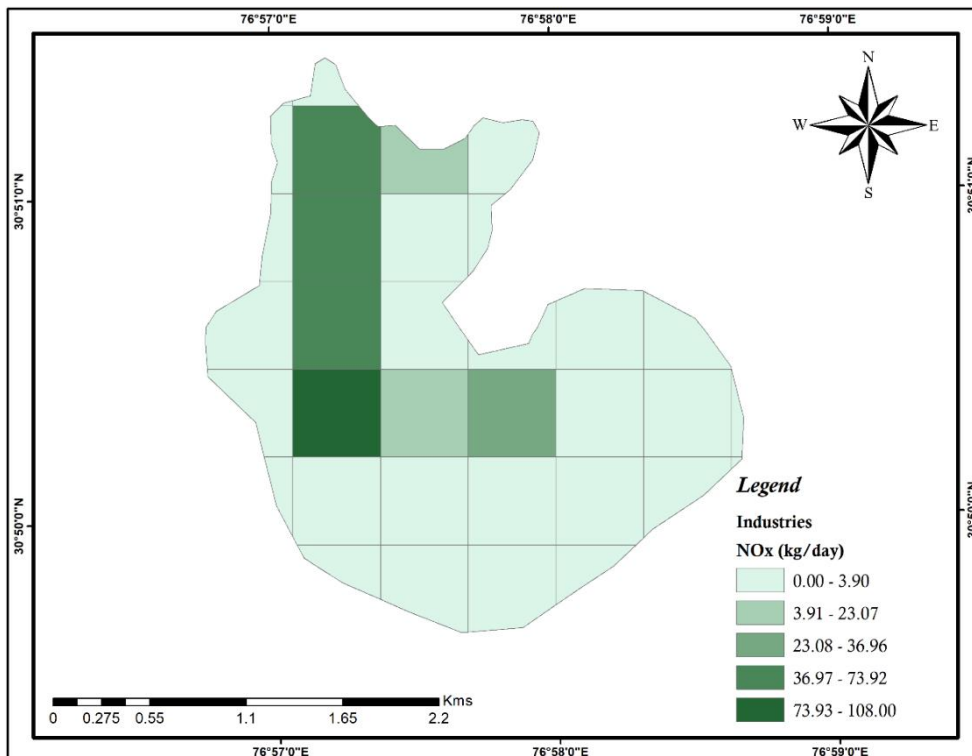


Figure 4.58: Spatial Distribution of NO_x Emissions from Industries

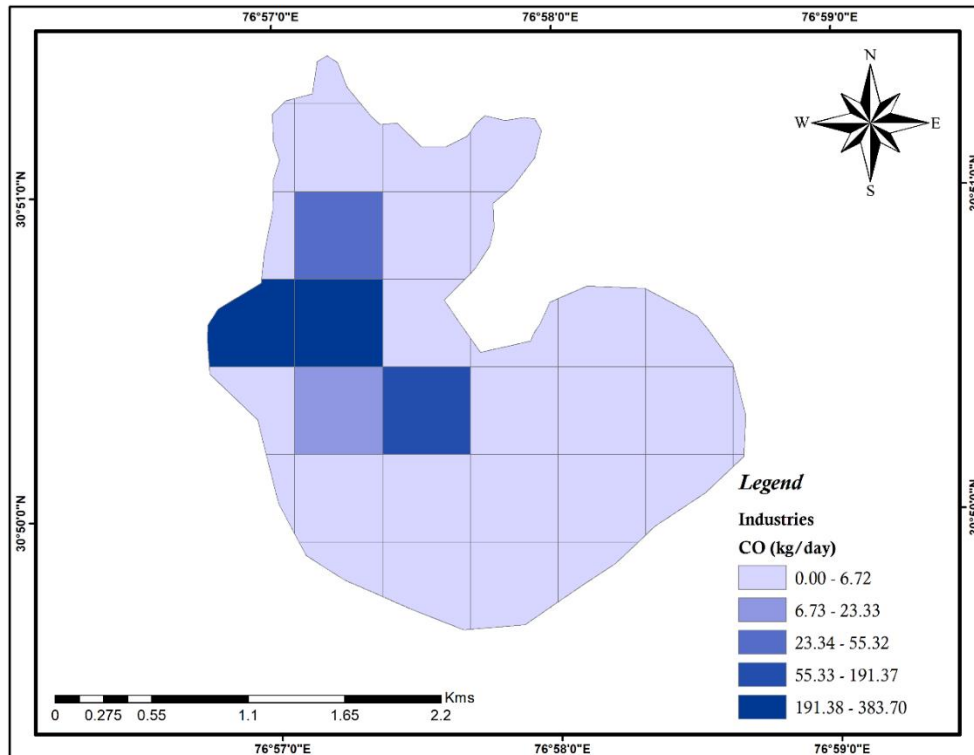


Figure 4.59: Spatial Distribution of CO Emissions from Industries

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 (Kalka highway, Parwanoo bus stop, Dharampur Solan road) in the city of Parwanoo. 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 use, and age of the vehicles.

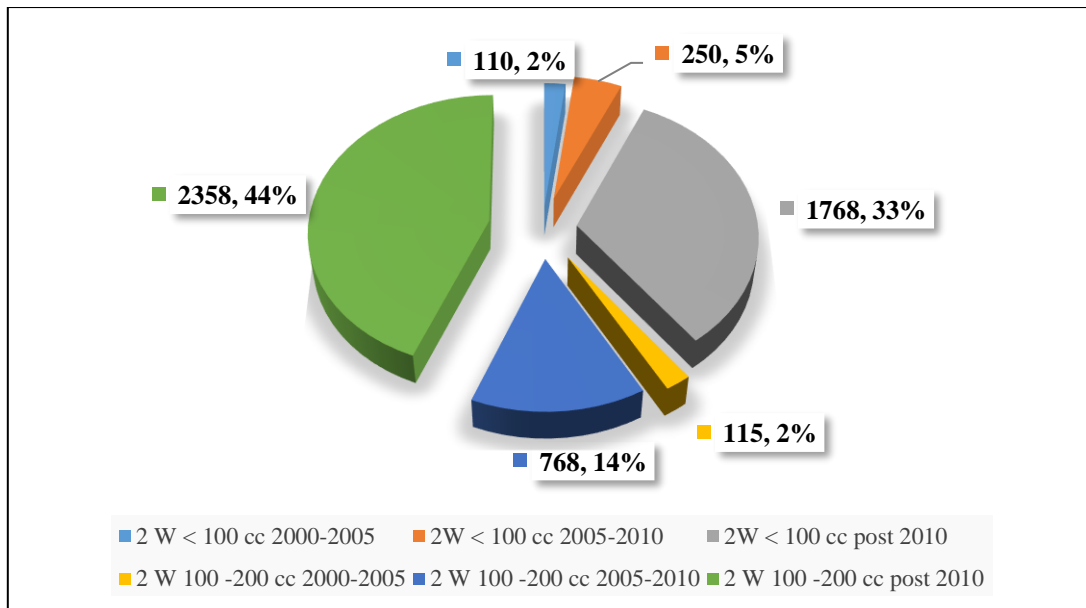


Figure 4.60: Distribution of 2-Ws in the study area (parking lot survey)

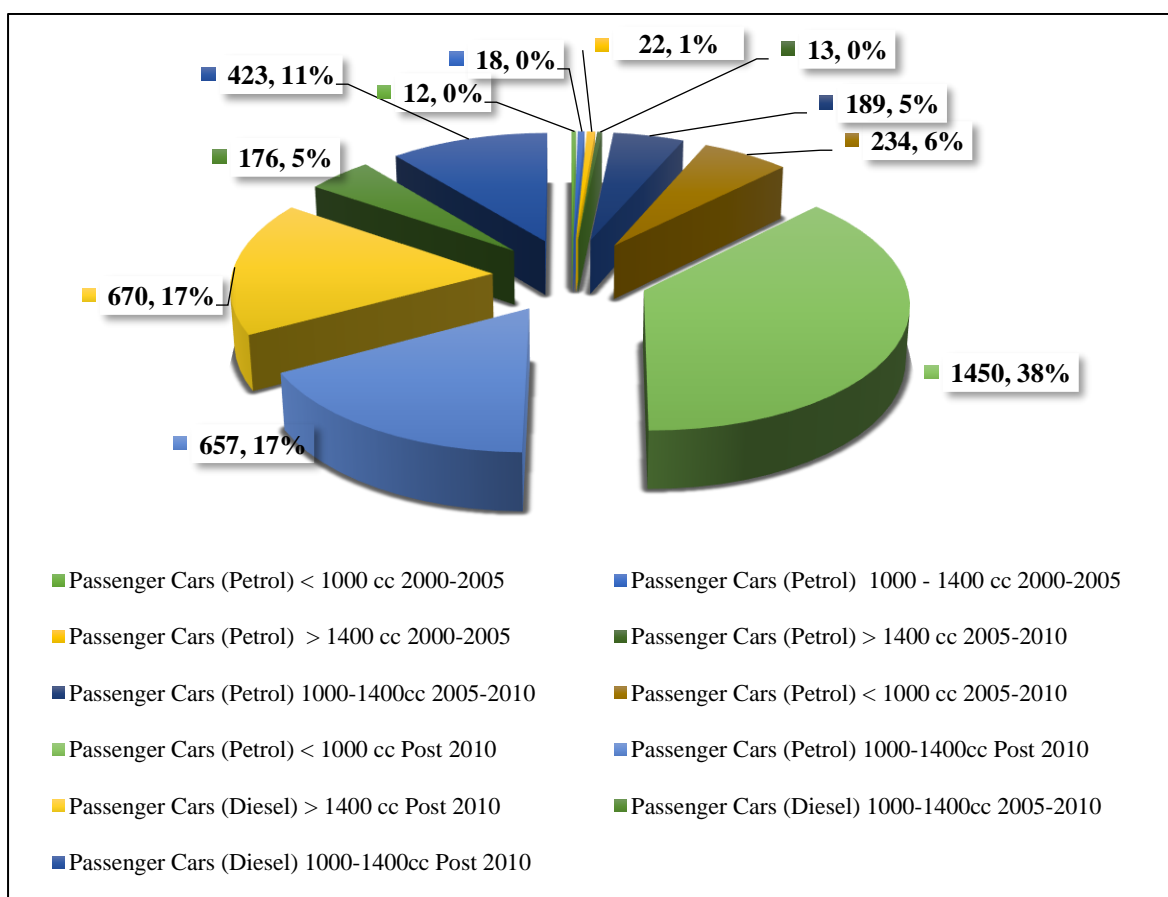


Figure 4.61: Distribution of 4-Ws in the study area (parking lot survey)

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 was 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 are estimated and summed up.

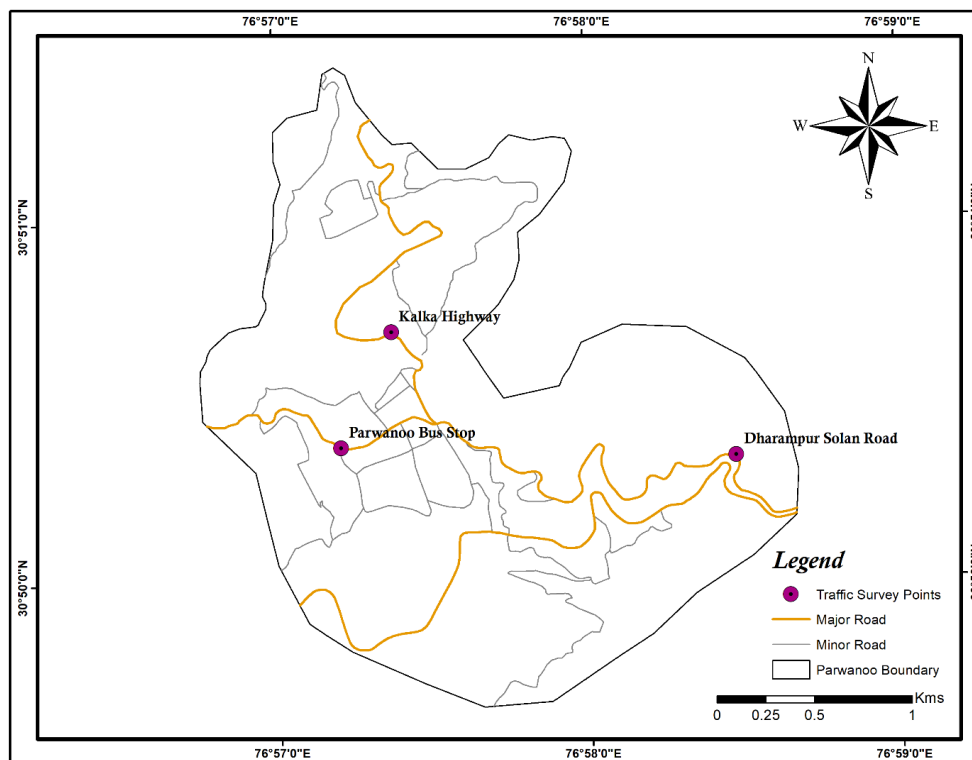
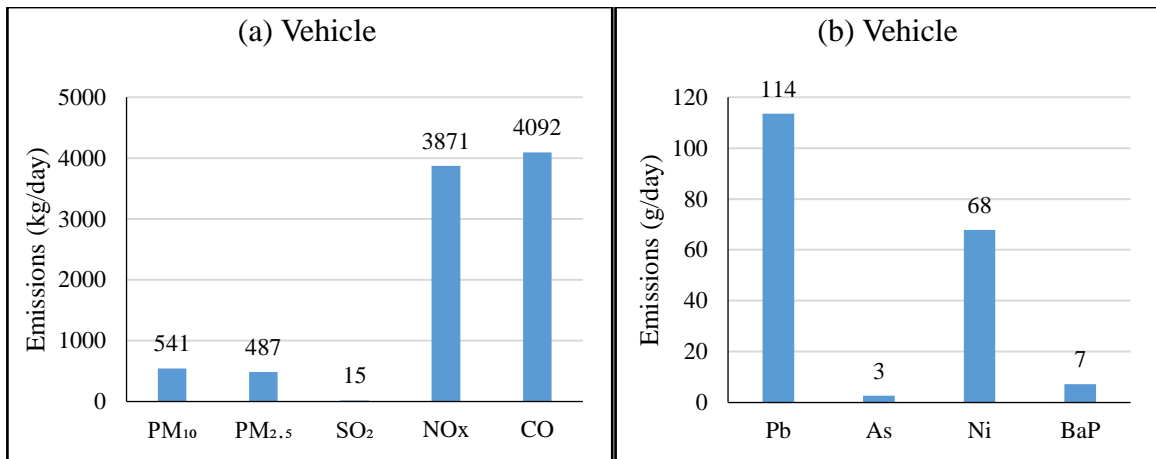


Figure 4.62: Traffic location considered for vehicle emission in Parwanoo city

The emissions from railway locomotives are not taken into consideration, as the emissions are negligible in comparison with the vehicles and other sources. The emission from vehicles is shown in Figure 4.63 (a) & (b).

The emission contribution of each vehicle type in Parwanoo city 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

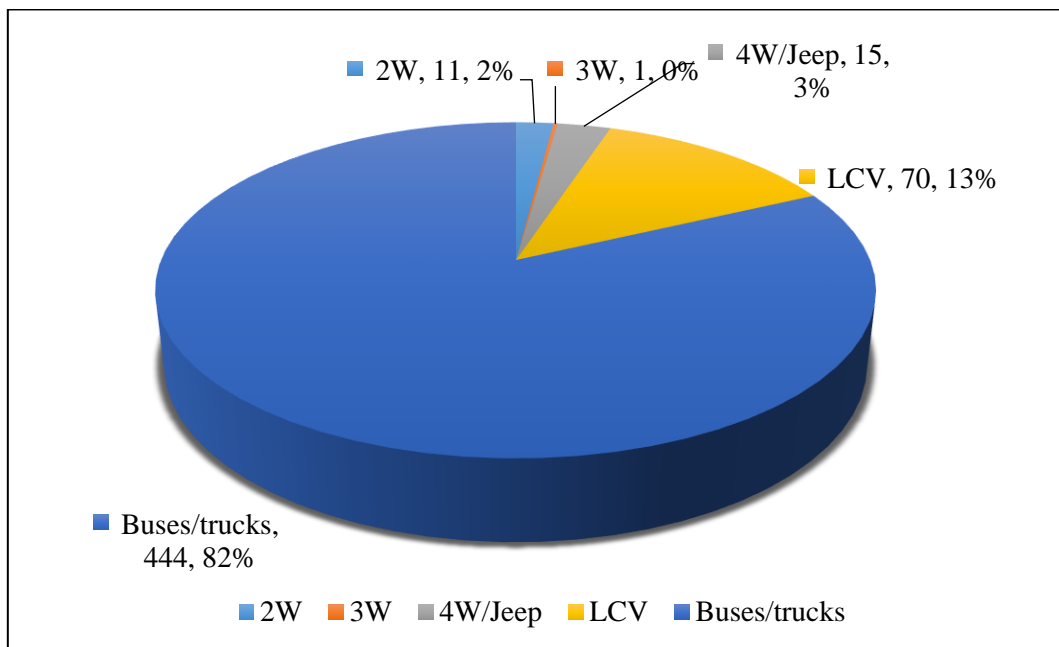


Figure 4.64: PM₁₀ Emission Load contribution of each vehicle type (kg/day)

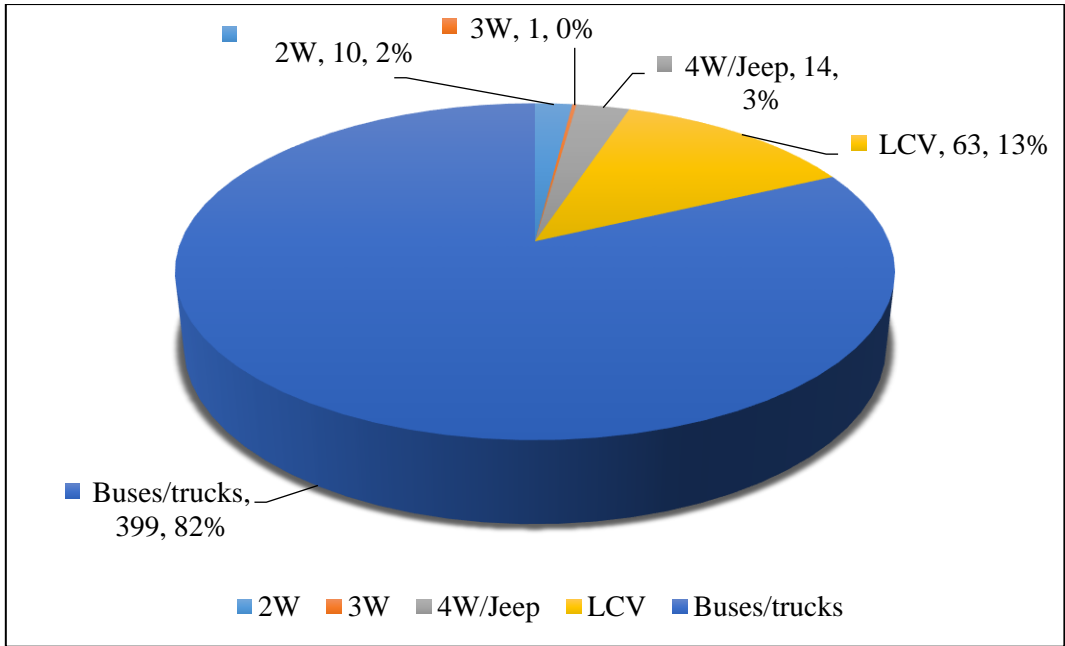


Figure 4.65: PM_{2.5} Emission Load contribution of each vehicle type (kg/day)

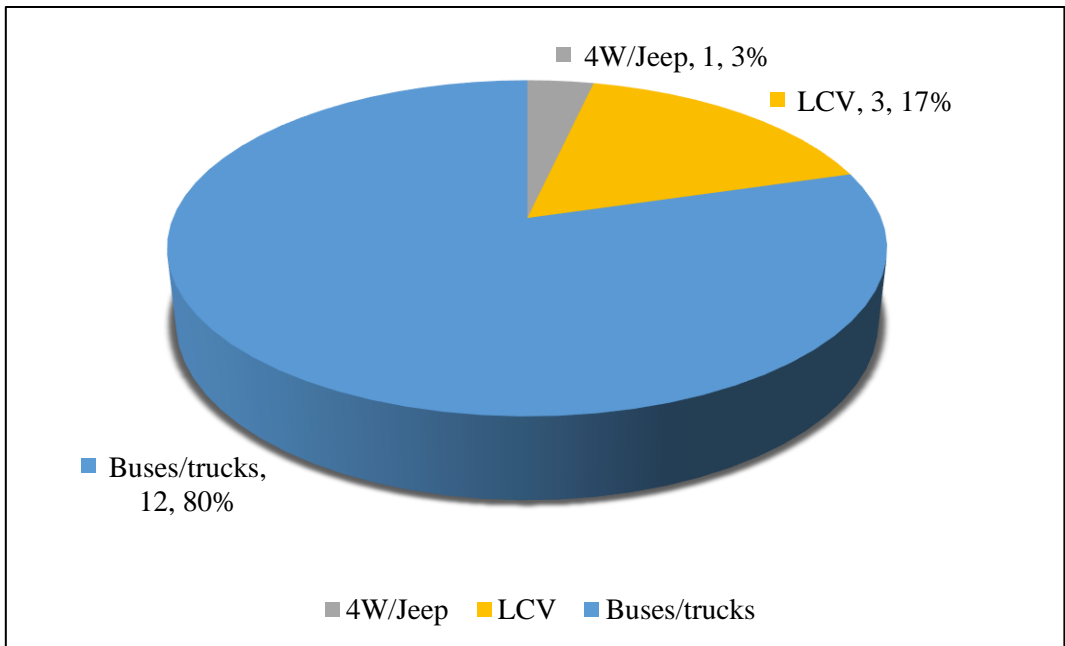


Figure 4.66: SO₂ Emission Load contribution of each vehicle type (kg/day)

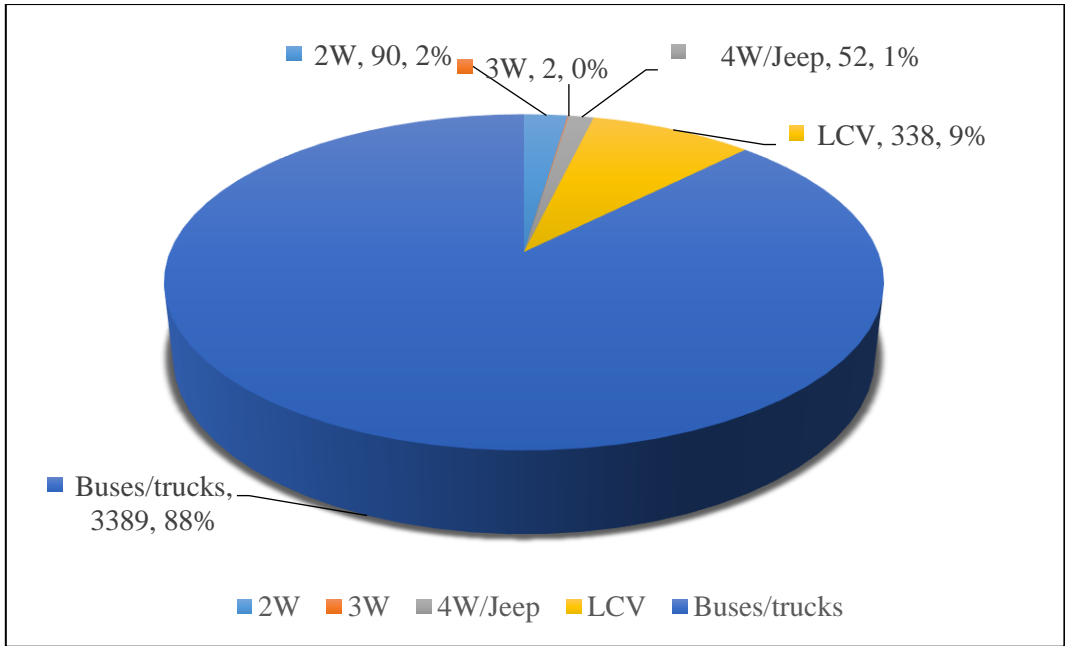


Figure 4.67: NO_x Emission Load contribution of each vehicle type (kg/day)

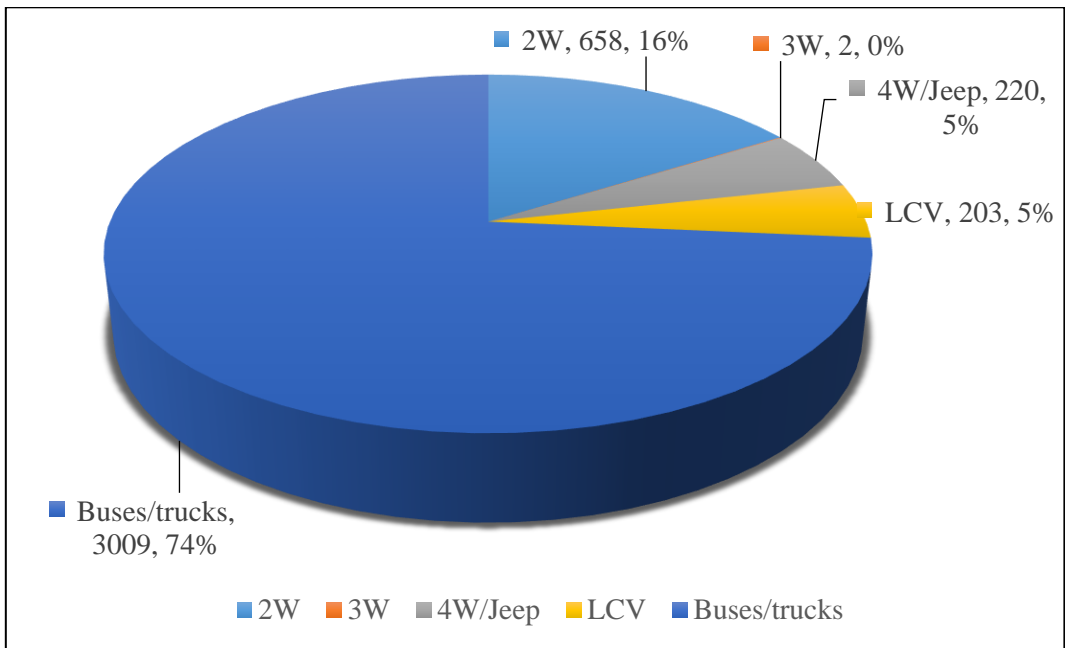


Figure 4.68: CO Emission Load contribution of each vehicle type (kg/day)

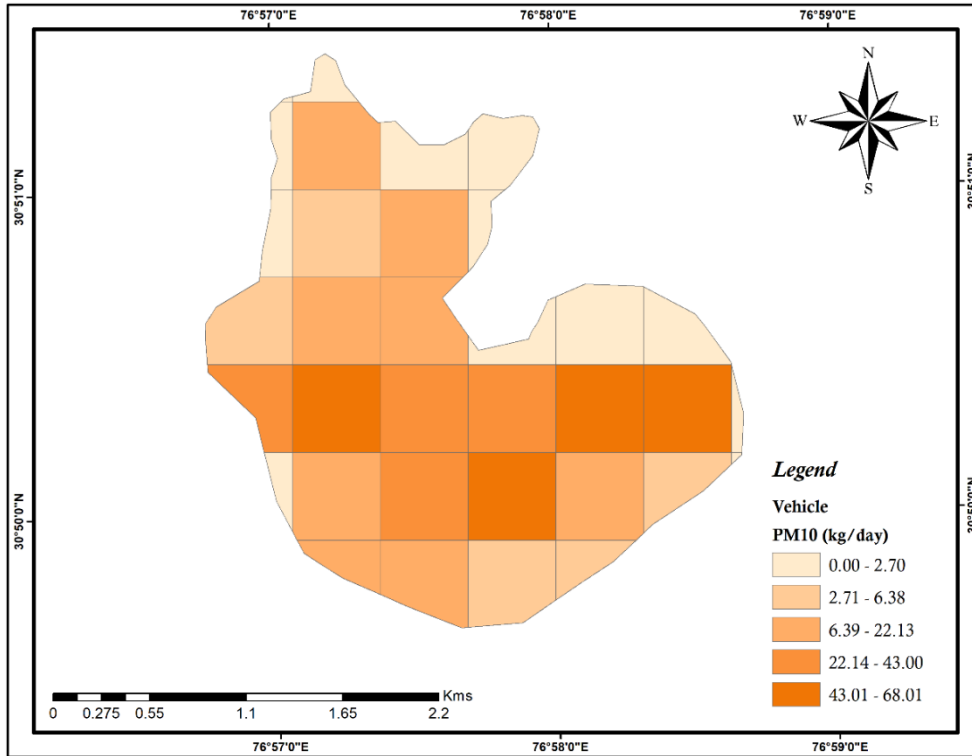


Figure 4.69: Spatial Distribution of PM₁₀ Emissions from Vehicles

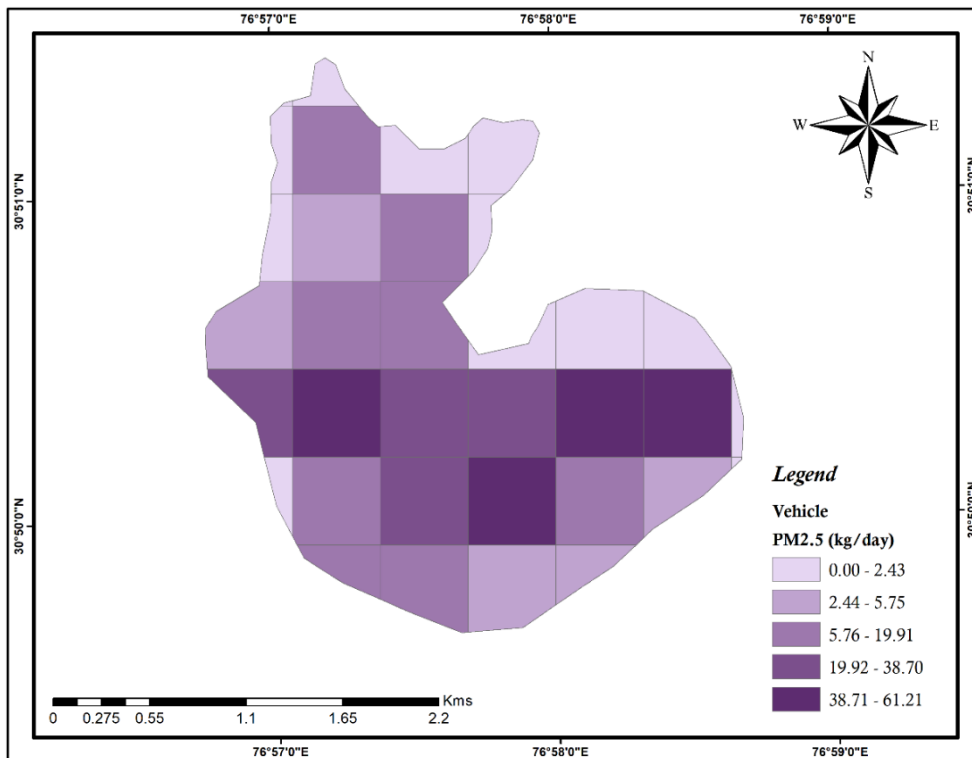


Figure 4.70: Spatial Distribution of PM_{2.5} Emissions from Vehicles

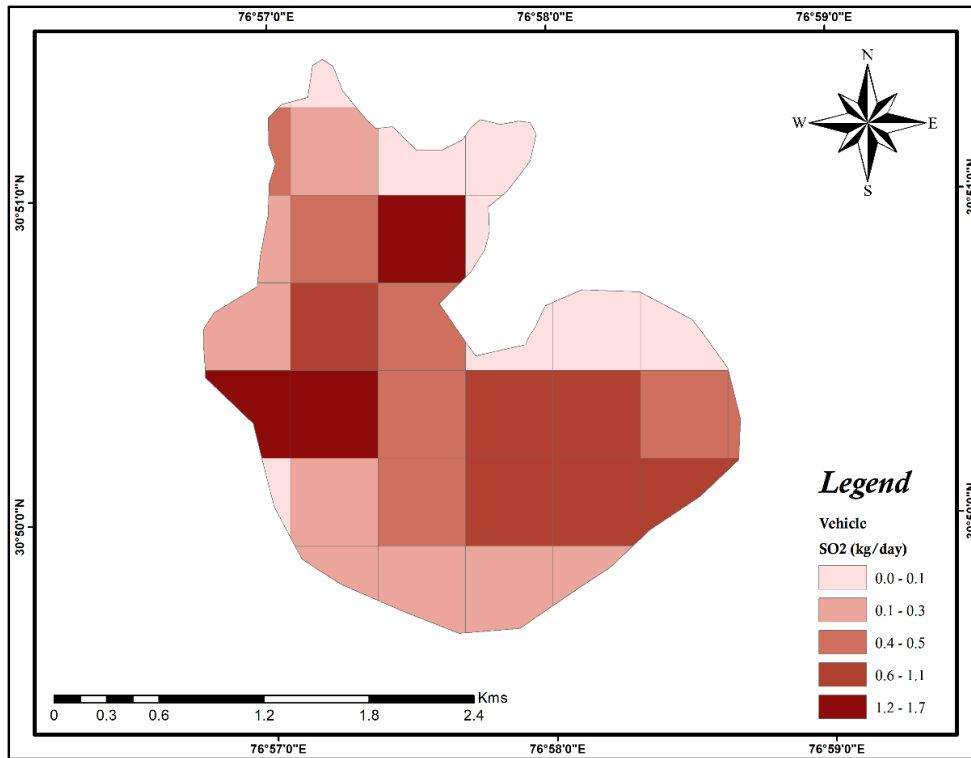


Figure 4.71: Spatial Distribution of SO₂ Emissions from Vehicles

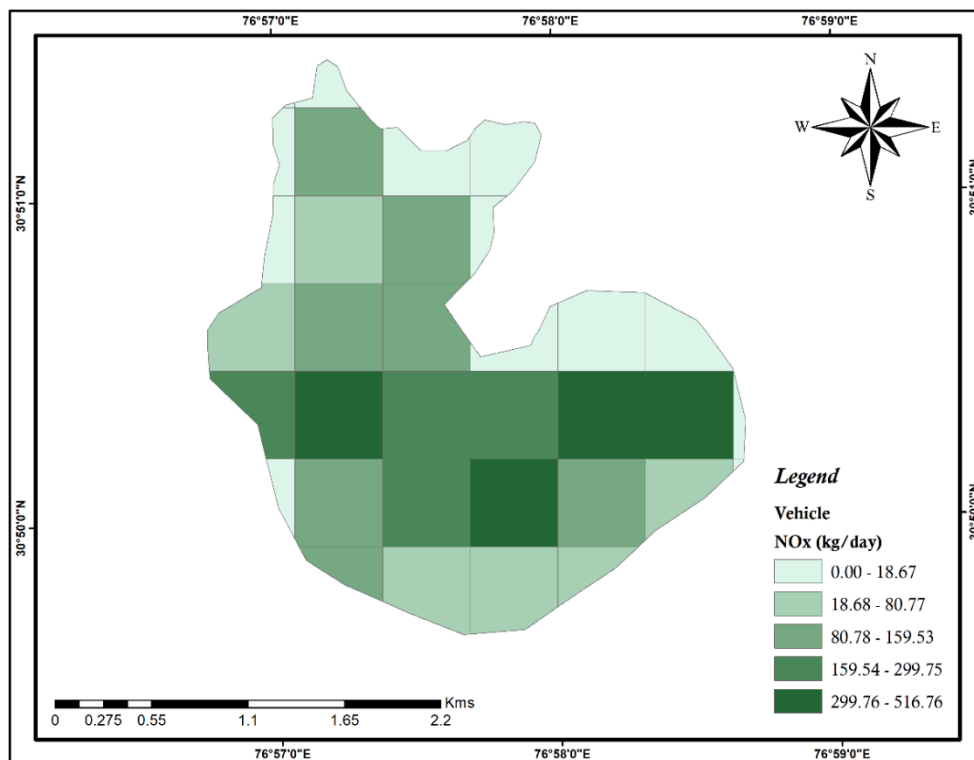


Figure 4.72: Spatial Distribution of NO_x Emissions from Vehicles

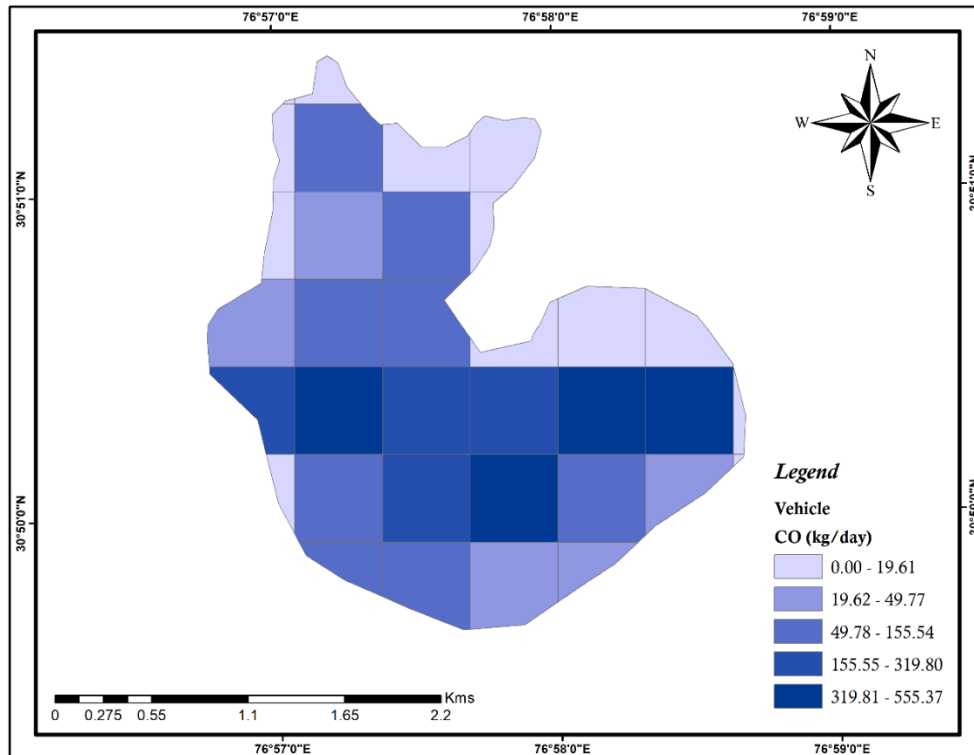


Figure 4.73: Spatial Distribution of CO Emissions from Vehicles

4.2.14 Traffic Congestion

The typical Traffic conditions at different locations for Parwanoo are given in Figure 4.74. Consequently, the major Traffic bottlenecks are mentioned in Table 4.3. The figure depicts the traffic report of Parwanoo for 3 traffic hotspots of the city for the 7 days of the week. The colour coding used here is Red, Orange, and Green indicating the slow traffic to fast traffic movement respectively. Kalka Highway and Parwanoo Bus Stop have been seeing a moderate amount of traffic throughout the weekdays, resulting in most of the people accessing roads for the conveyance to their respective working spaces.

Table 4.3: Major Traffic Bottleneck at Parwanoo

Kalka Highway	Parwanoo Bus Stop
Dharampur Solan Road	

S.NO	DAY	Kalka Highway	Parwanoo Bus Stop	Dharampur Solan Road
1	Sunday	8am-10am	8am-10am	8am-10am
		10am-12pm	10am-12pm	10am-12pm
		12pm-2pm	12pm-2pm	12pm-2pm
		2pm-4pm	2pm-4pm	2pm-4pm
		4pm-6pm	4pm-6pm	4pm-6pm
		6pm-8pm	6pm-8pm	6pm-8pm
2	Monday	8am-10am	8am-10am	8am-10am
		10am-12pm	10am-12pm	10am-12pm
		12pm-2pm	12pm-2pm	12pm-2pm
		2pm-4pm	2pm-4pm	2pm-4pm
		4pm-6pm	4pm-6pm	4pm-6pm
		6pm-8pm	6pm-8pm	6pm-8pm
3	Tuesday	8am-10am	8am-10am	8am-10am
		10am-12pm	10am-12pm	10am-12pm
		12pm-2pm	12pm-2pm	12pm-2pm
		2pm-4pm	2pm-4pm	2pm-4pm
		4pm-6pm	4pm-6pm	4pm-6pm
		6pm-8pm	6pm-8pm	6pm-8pm
4	Wednesday	8am-10am	8am-10am	8am-10am
		10am-12pm	10am-12pm	10am-12pm
		12pm-2pm	12pm-2pm	12pm-2pm
		2pm-4pm	2pm-4pm	2pm-4pm
		4pm-6pm	4pm-6pm	4pm-6pm
		6pm-8pm	6pm-8pm	6pm-8pm
5	Thursday	8am-10am	8am-10am	8am-10am
		10am-12pm	10am-12pm	10am-12pm
		12pm-2pm	12pm-2pm	12pm-2pm
		2pm-4pm	2pm-4pm	2pm-4pm
		4pm-6pm	4pm-6pm	4pm-6pm
		6pm-8pm	6pm-8pm	6pm-8pm
6	Friday	8am-10am	8am-10am	8am-10am
		10am-12pm	10am-12pm	10am-12pm
		12pm-2pm	12pm-2pm	12pm-2pm
		2pm-4pm	2pm-4pm	2pm-4pm
		4pm-6pm	4pm-6pm	4pm-6pm
		6pm-8pm	6pm-8pm	6pm-8pm
7	Saturday	8am-10am	8am-10am	8am-10am
		10am-12pm	10am-12pm	10am-12pm
		12pm-2pm	12pm-2pm	12pm-2pm
		2pm-4pm	2pm-4pm	2pm-4pm
		4pm-6pm	4pm-6pm	4pm-6pm
		6pm-8pm	6pm-8pm	6pm-8pm

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

Figure 4.74: Typical Traffic conditions at different locations in Parwanoo

4.2.15 Paved and Unpaved Road Dust

Dust emissions from paved and unpaved roads have been found that vary with the ‘silt loading’ present on the road surface and the average weight of vehicles travelling on the road. The term silt loading (sL) refers to the mass of the silt-sized material (equal to or less than 75 µm in physical diameter) per unit area of the travel surface. The quantity of dust emissions

from the movement of vehicles on a paved or unpaved road can be estimated using the following empirical expression:

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

Where

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

sL = road surface silt loading (grams per square meter) (g/m²), 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); PM₁₀ = 0.62 g/VKT, PM_{2.5} = 0.15 g/VKT.

The silt loads (sL) samples from 3 locations were collected (Figure 4.75). The road dust sampling locations are given in Figure 4.76. Then mean weight of the vehicle fleet (W) was estimated by giving the weightage to the percentage of vehicles of all types with their weight. Then emission rate (g VKT⁻¹) was calculated based on Eq (4.4). VKT for each grid was calculated by considering the tonnage of each road. Then finally the emission loads from paved and unpaved roads were found by using Eq (4.4). 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 4.77). In the winter and monsoon season, it is less due to moisture and dew atmospheric conditions. The emission load from road dust in Parwanoo is given in Figure 4.78 (a) & (b). The Spatial distribution of Emissions from Road Dust Re-suspension is presented in Figure 4.79 to Figure 4.80.

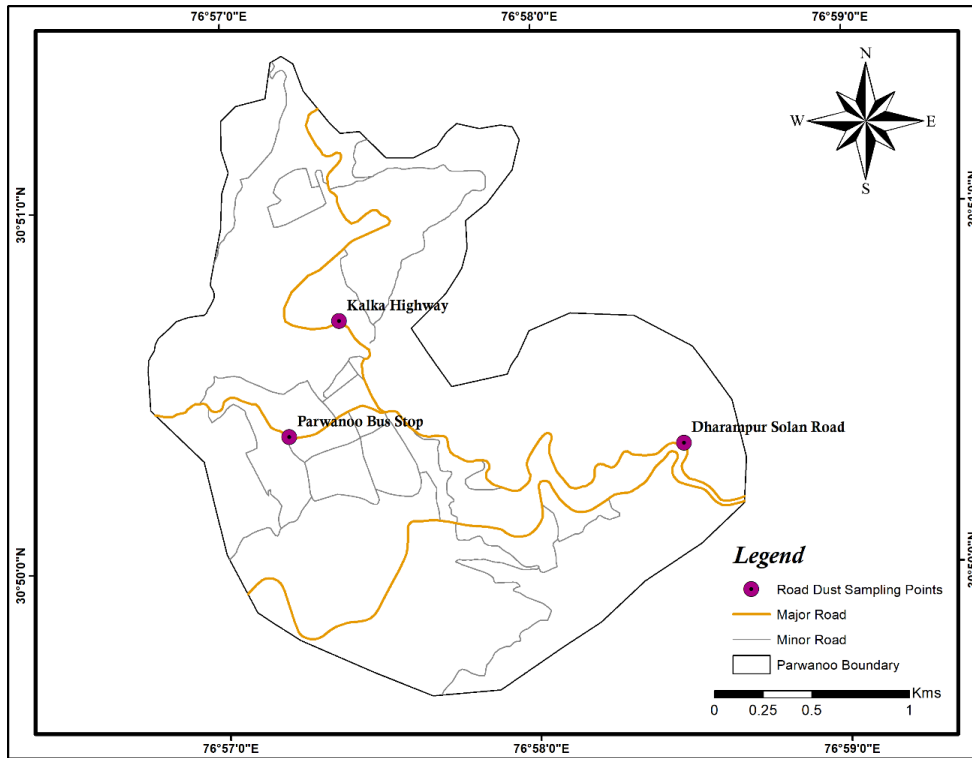


Figure 4.75: Road Dust Sampling Location

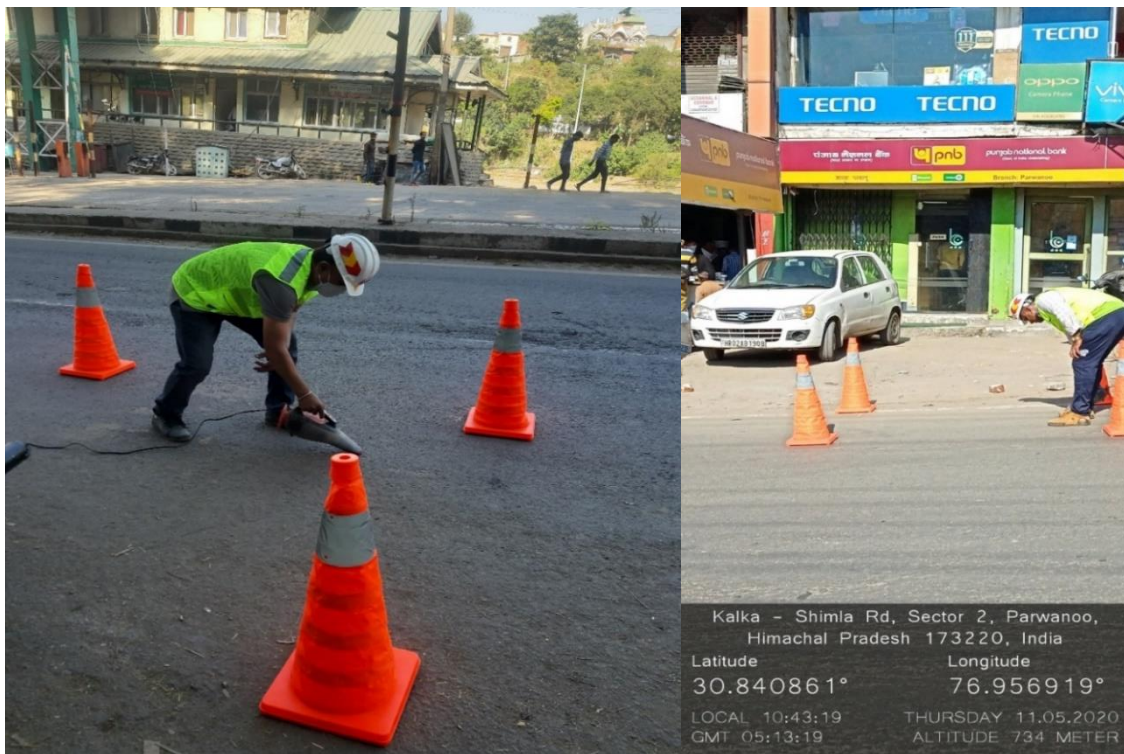


Figure 4.76: Road Dust Sampling in the City of Parwanoo



Figure 4.77: Road dust deposition on the paved road

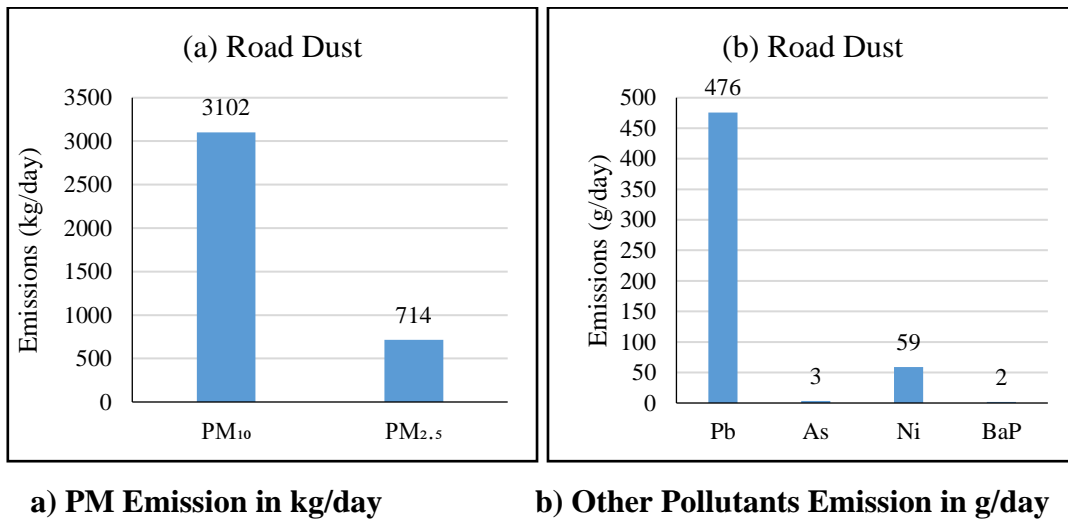


Figure 4.78: Emissions from Road Dust in Parwanoo city

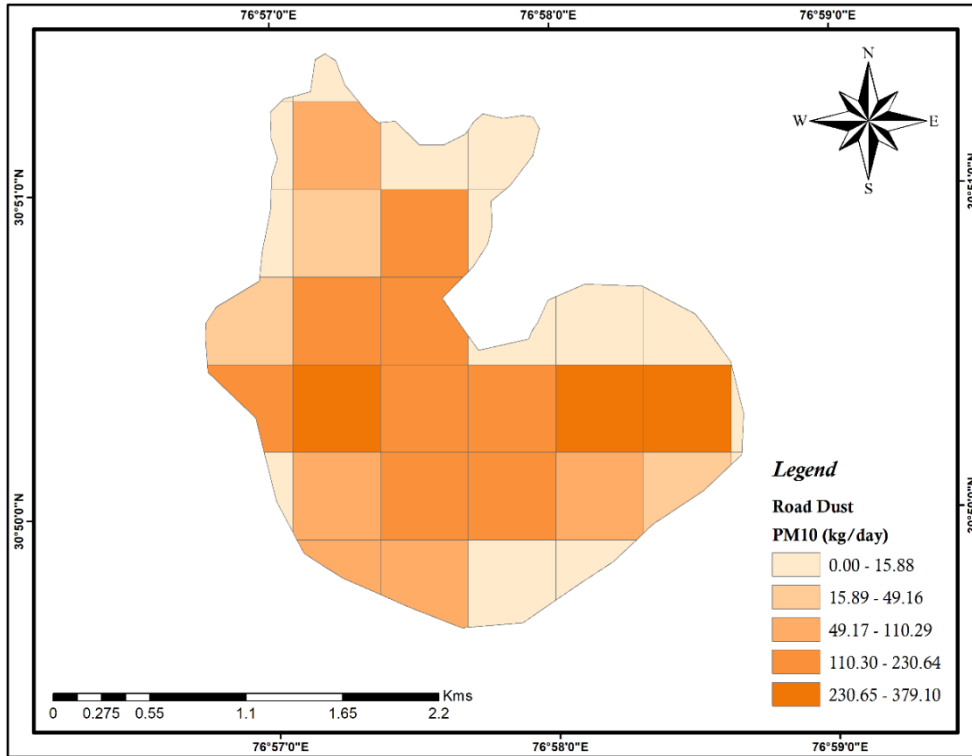


Figure 4.79: Spatial Distribution of PM₁₀ Emissions from Road Dust Re-suspension

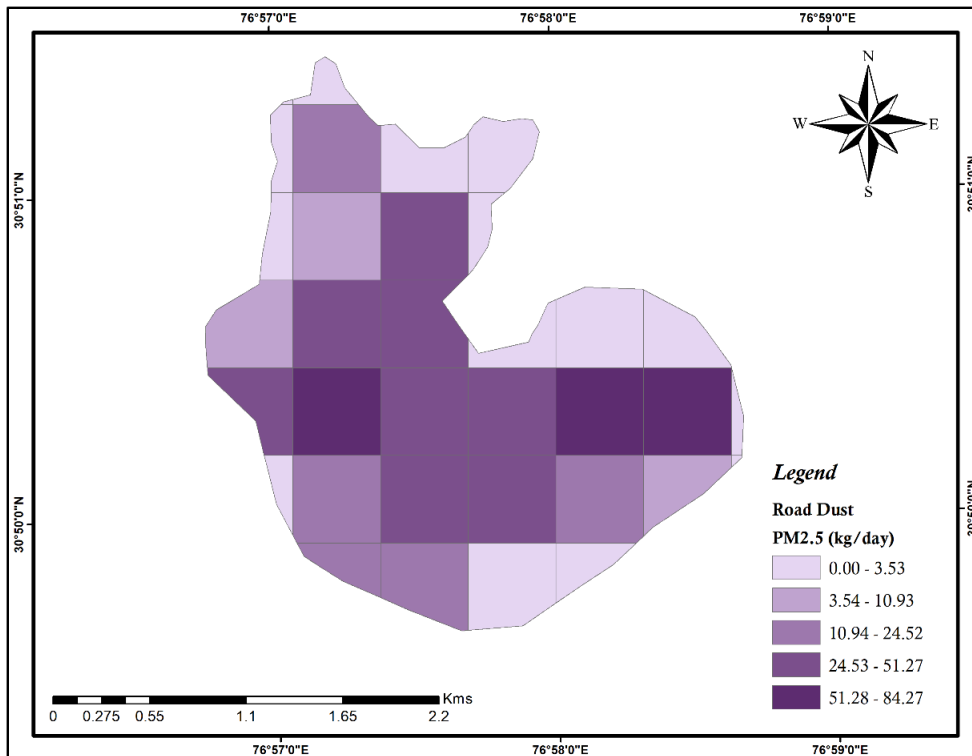


Figure 4.80: Spatial Distribution of PM_{2.5} Emissions from Road Dust Re-suspension

4.3 City Level Emission Inventory

The overall baseline emission inventory for the entire city is presented in Table 4.4. The pollutant wise contribution is shown in Figure 4.81 to Figure 4.85. The spatial distribution of pollutant Emissions from all sources is presented in Figure 4.86 to Figure 4.90. The pollutant wise gridded emissions are provided in Annexure 2.

The total PM₁₀ emission load in the city is estimated to be 3987 kg/day. The top three contributors to PM₁₀ emissions are Road Dust (78%), Vehicles (14%), and Industries (7%); these are based on annual emissions. Seasonal and daily emissions could be highly variable. The estimated emission suggests that there are many important sources and a composite emission abatement including most of the sources will be required to obtain the desired air quality.

PM_{2.5} emission load in the city is estimated to be 1482 kg/day. The top three contributors to PM_{2.5} emissions are Road Dust (48%), Vehicles (33%), and Industries (16%); these are based on annual emissions. Seasonal and daily emissions could be highly variable.

SO₂ emission load in the city is estimated to be 1335 kg/day. Major sources that contribute to SO₂ emissions are Industries (97%), and Hotels, restaurants, GHs & BHs (2%).

NO_x emissions load in the city is estimated to be 4277 kg/day. The majority of total emissions are attributed to Vehicular (91%), and Industries (9%). Vehicular emissions that occur at ground level, probably making it the most important emission. NO_x apart from being a pollutant itself is an important component in the formation of secondary particles (nitrates) and ozone. NO_x from vehicles and industry are potential sources for controlling NO_x emissions.

The estimated CO emission is about 5313 kg/day. The major contributors to CO emissions are Vehicles (77%), Industries (20%), and MSW burning (1%). Vehicles and Industries could be the main target for controlling CO for improving air quality with respect to CO.

The estimated emissions are for benzene: 1673 g/d, Pb: 598 g/d, As: 9 g/d, Ni: 150 g/d and BaP: 10 g/d from all sources.

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

Sources	PM₁₀ (kg/d)	PM_{2.5} (kg/d)	SO₂ (kg/d)	NO_x (kg/d)	CO (kg/d)	NH₃ (kg/d)	Benzene (g/d)	Pb (g/d)	As (g/d)	Ni (g/d)	BaP (g/d)
Domestic	12	9	3	6	51	0	0.1	0.2	0.3	2.7	0.04
MSW Burning	13	9	1	5	66	0	0	2.73	0	0.49	0
Hotels, Restaurants & GHs	33	17	22	11	58	0	1469	1.82	2.42	8	0.33
Construction & Demolition	15	4						0.5	0.2	0.3	0
Industrial DG Sets	0.5	0.4	0.4	6	1	0	1.3	0.04	0	0.005	0.006
Hospitals	0.01	0.01	0.01	0.19	0.04	0	0.04	0.001	0	0.0001	0.0002
Industries	270	243	1294	377	1045	0	203	3	0.12	12	0.39
Vehicle	541	487	15	3871	4092	0	0	114	3	68	7
Road Dust	3102	714						476	3	59	2
Agriculture						35					
Livestock						49					
Total	3987	1482	1335	4277	5313	84	1673	598	9	150	10

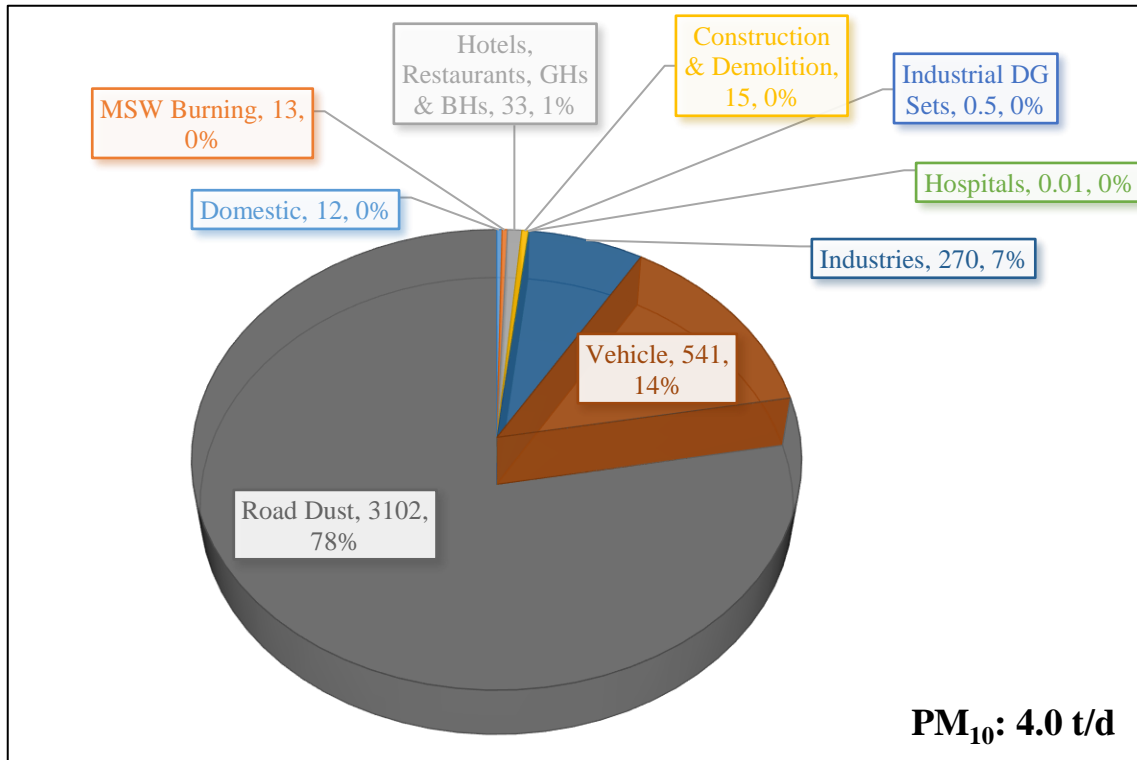


Figure 4.81: PM₁₀ Emission Load Contribution of Different Sources

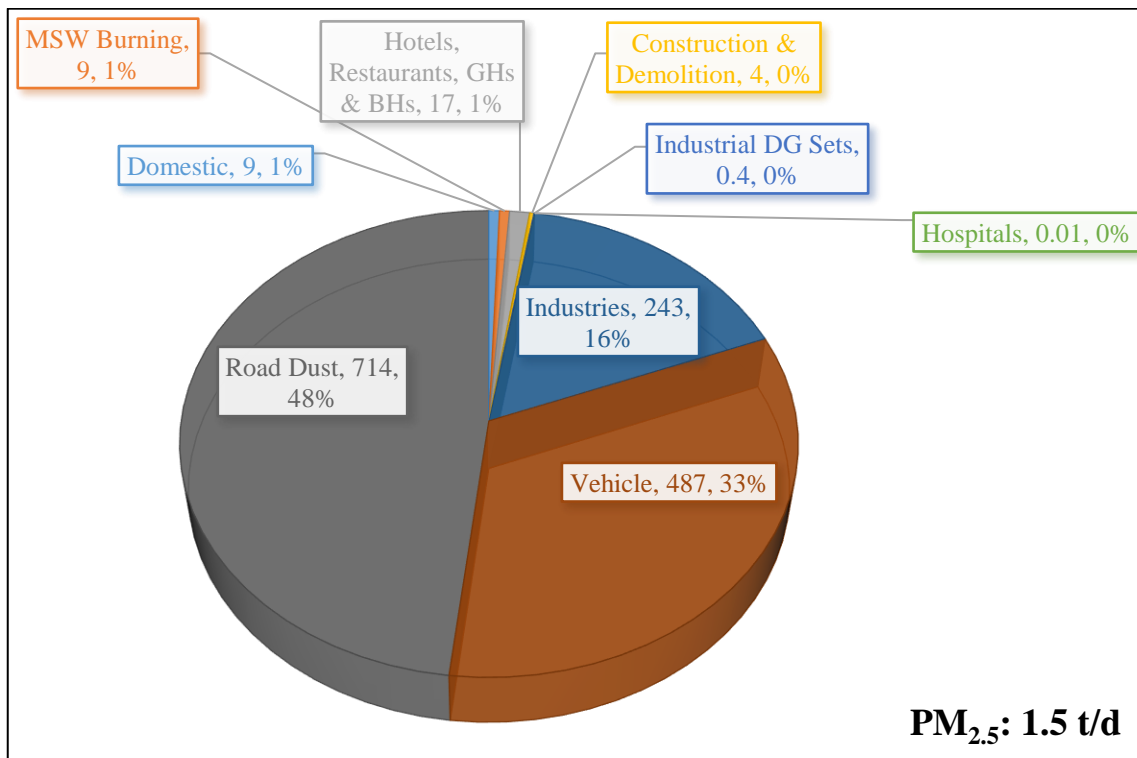


Figure 4.82: PM_{2.5} Emission Load Contribution of Different Sources

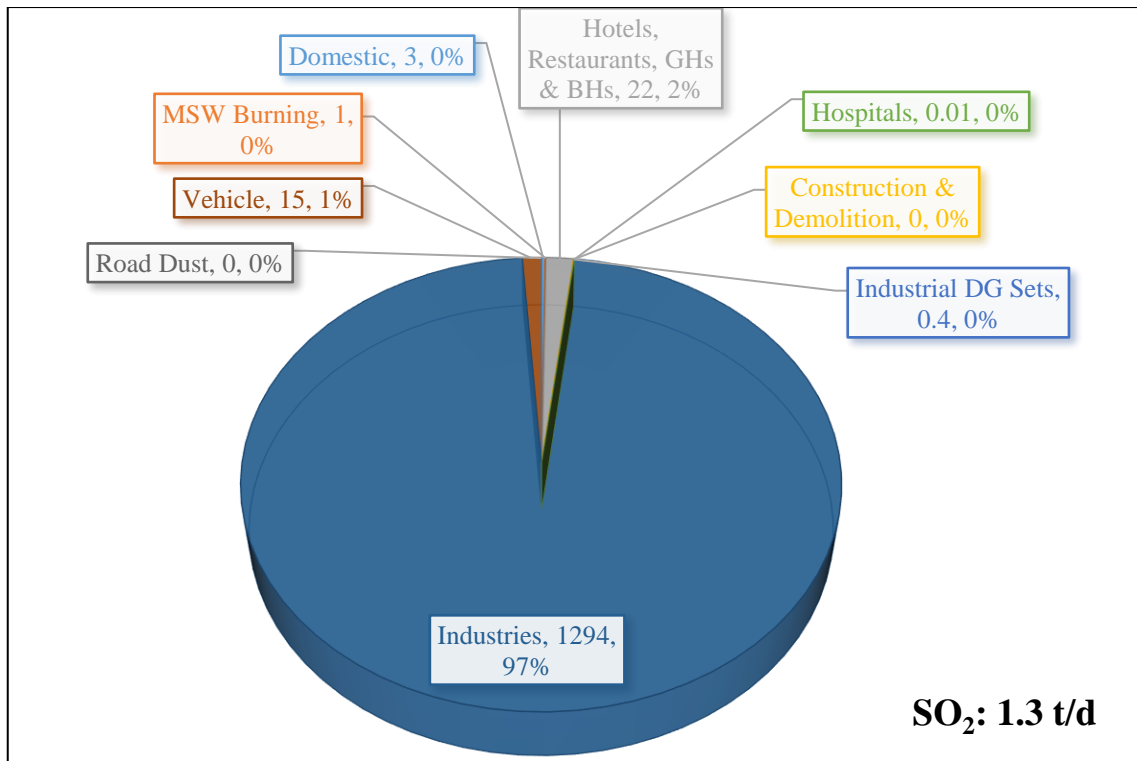


Figure 4.83: SO₂ Emission Load Contribution of Different Sources

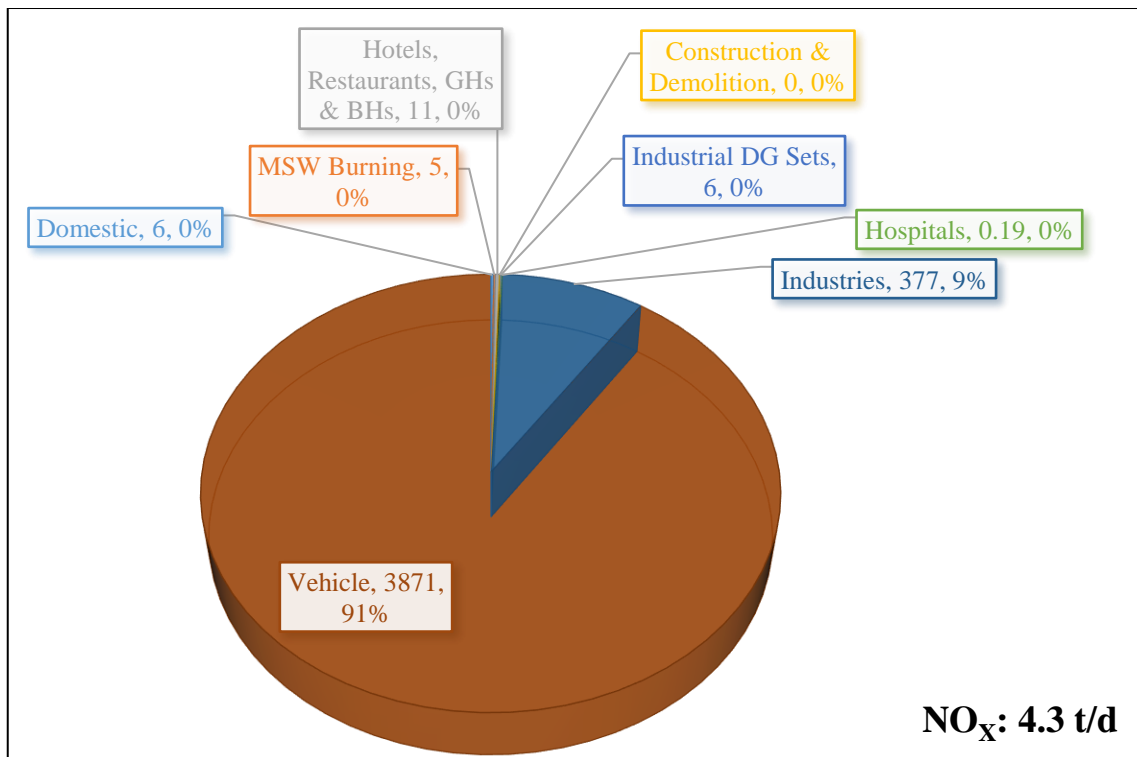


Figure 4.84: NO_x Emission Load Contribution of Different Sources

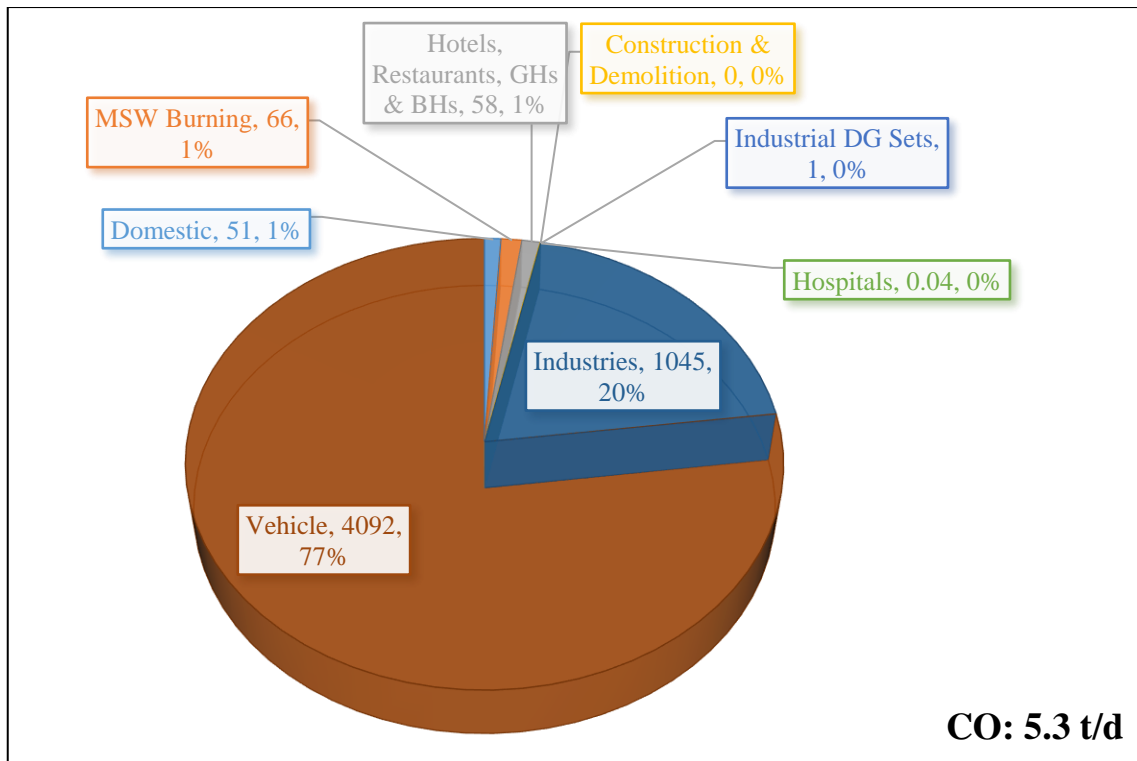


Figure 4.85: CO Emission Load Contribution of Different Sources

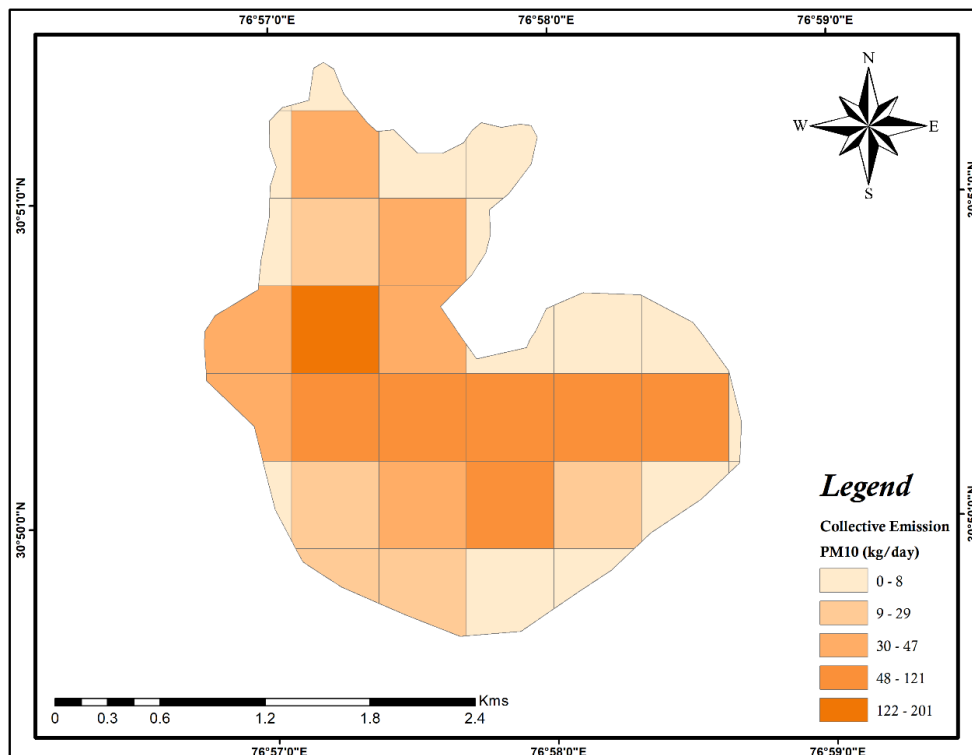


Figure 4.86: Spatial Distribution of PM₁₀ Emissions in the City of Parwanoo

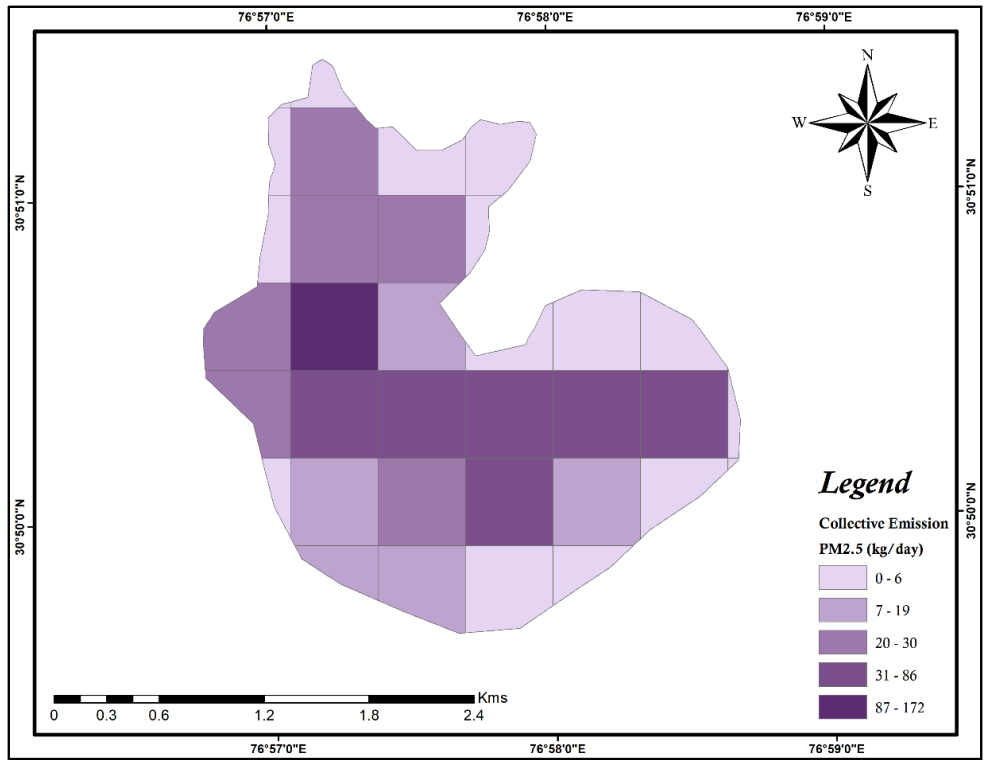


Figure 4.87: Spatial Distribution of PM_{2.5} Emissions in the City of Parwanoo

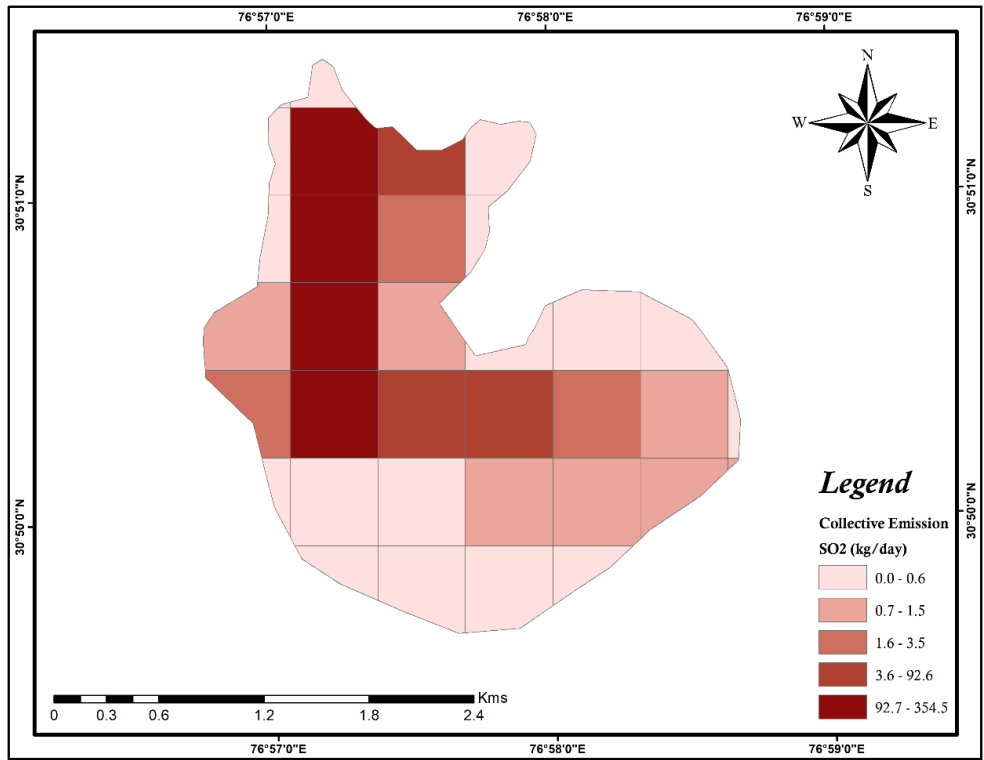


Figure 4.88: Spatial Distribution of SO₂ Emissions in the City of Parwanoo

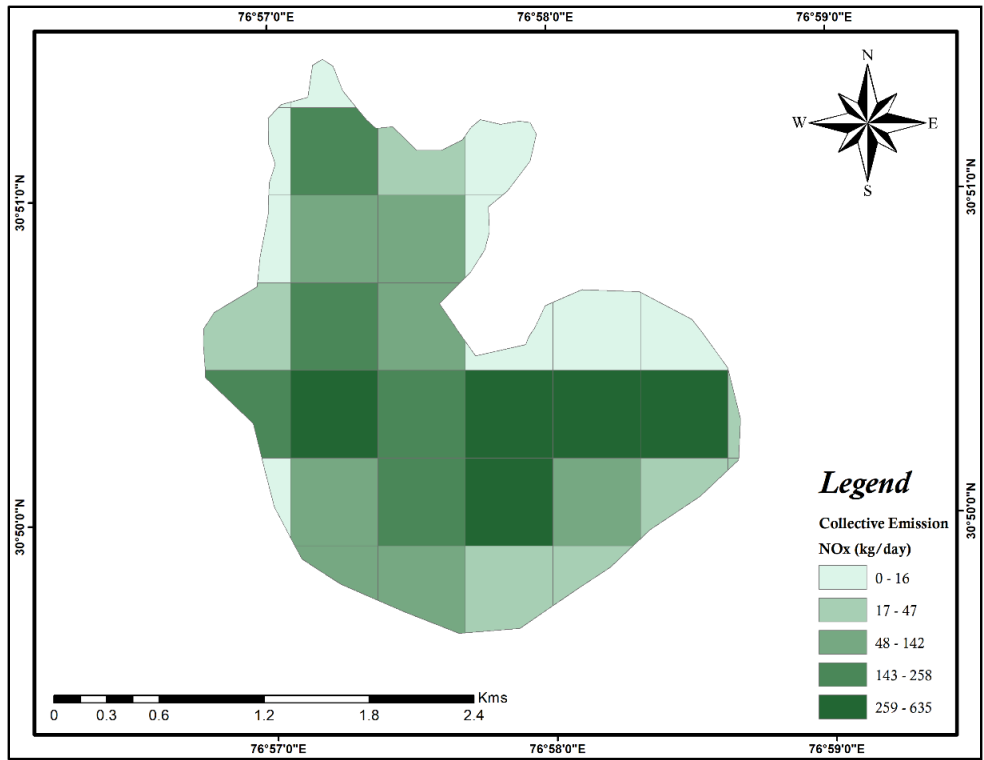


Figure 4.89: Spatial Distribution of NOx Emissions in the City of Parwanoo

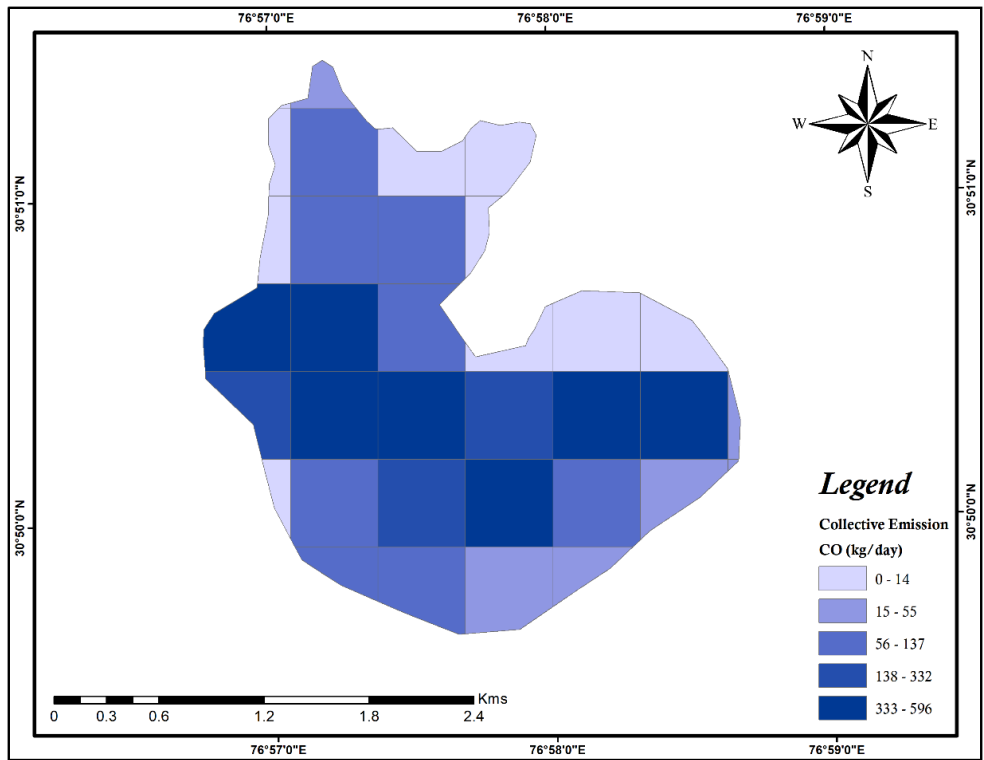


Figure 4.90: Spatial Distribution of CO Emissions in the City of Parwanoo

5 Receptor Modelling and Source Apportionment

5.1 Receptor Modeling

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

1. Dispersion Modeling and
2. Receptor source Modeling.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Ambient 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 December 14 – 23, 2019 in winter at three sites in Parwanoo.

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 Parwanoo are described in the next section.

5.3 PMF Modeling Results and interpretation (Parwanoo)

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 0.98 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 $PM_{2.5}$.

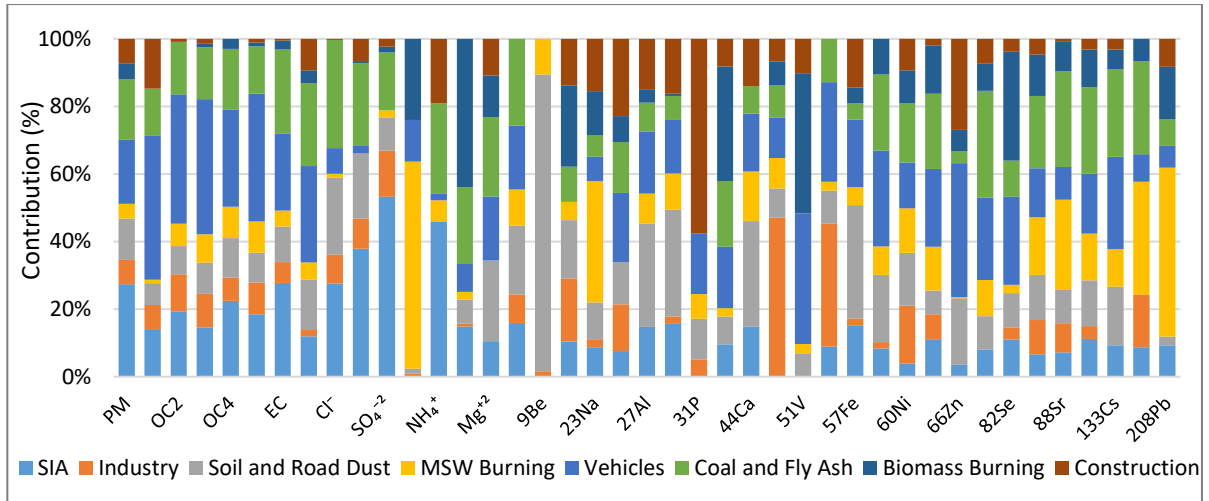


Figure 5.1: PMF-based Source profiles for PM_{10} and $PM_{2.5}$

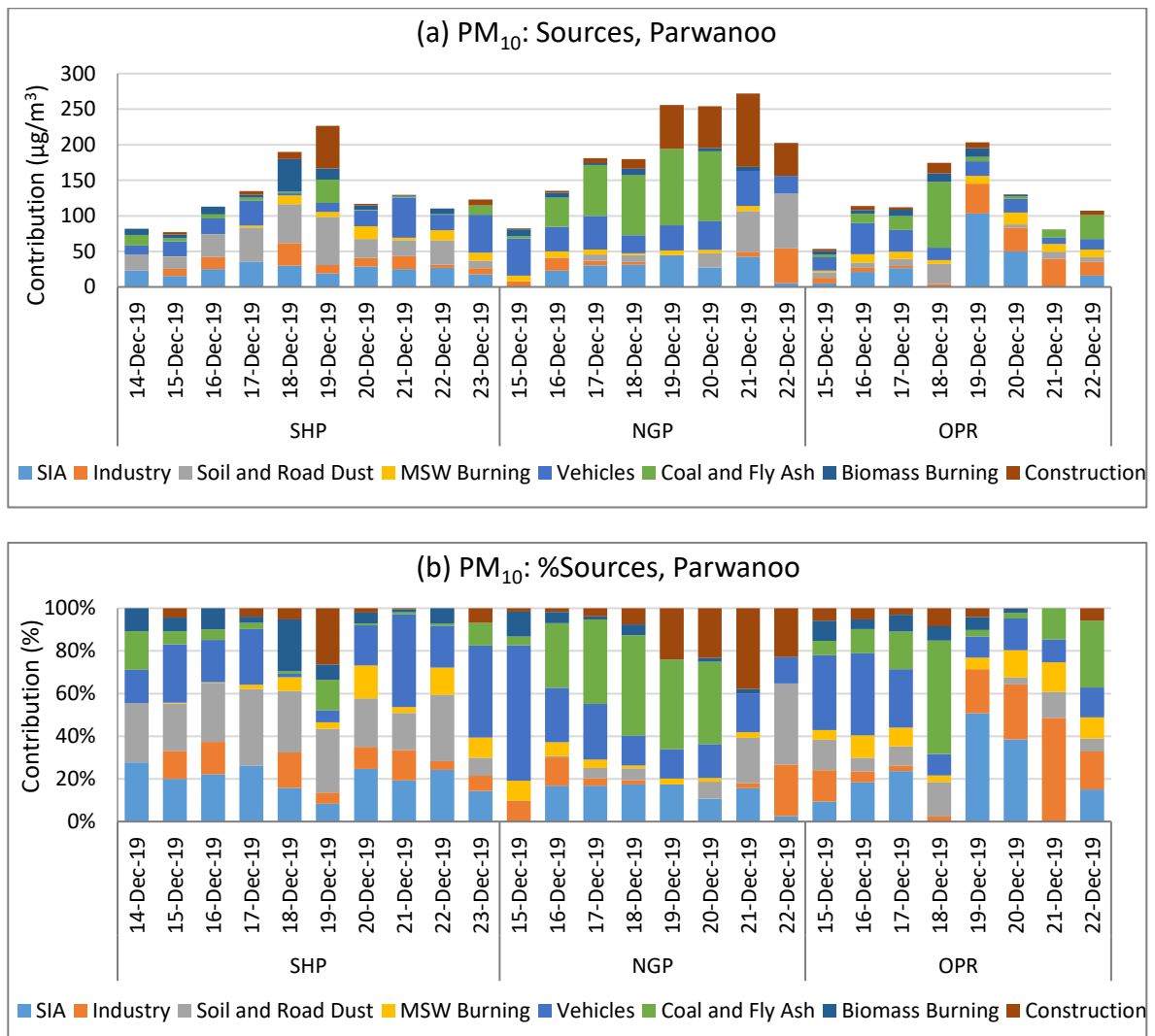


Figure 5.2: PMF modeling Results for PM_{10} at all sites

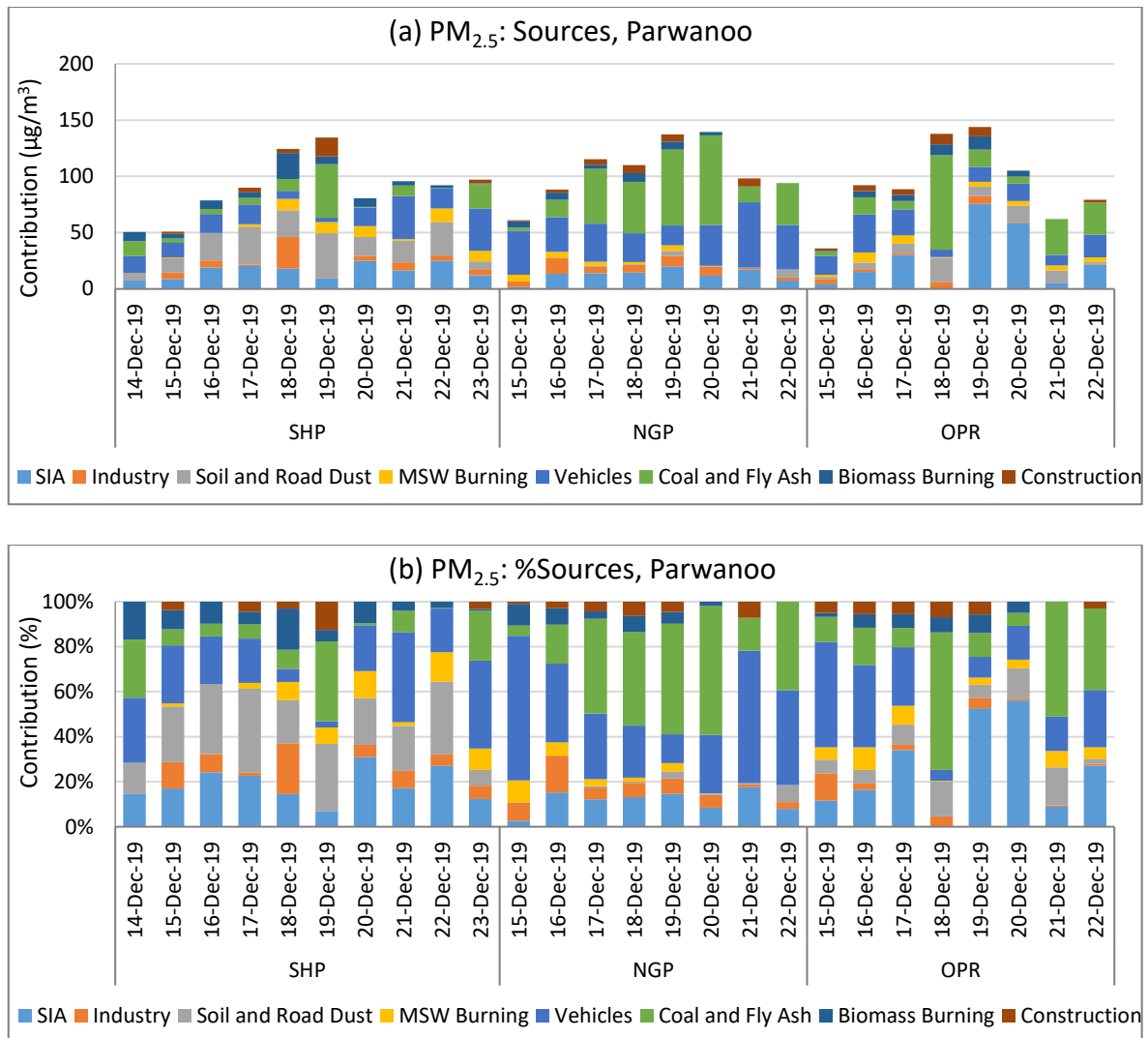


Figure 5.3: PMF modeling Results for PM_{2.5} at all sites

5.3.1 SHP

PM₁₀

The average PM₁₀ concentration was 107 µg/m³. Figure 5.2 represents PM₁₀ contribution of sources in terms of concentration, and percent contribution of sources at all sites (SHP represented in 1st part of the graphs). Figure 5.4(a) represents PM₁₀ overall contribution in terms of the percentage of sources. It is observed that the major source contributing to PM₁₀ was soil and road dust (26%) followed by vehicular emission (20%). The other sources are SIA (19%), industrial emission (10%), Biomass burning (8%), Construction (7%), Coal combustion (6%) and Municipal solid waste burning (6%).

PM_{2.5}

The average PM_{2.5} concentration was 72 µg/m³ (i.e., about 0.67 of PM₁₀). Figure 5.3 represents PM_{2.5} contribution of sources in terms of concentration, and percent contribution of sources at all sites (SHP 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 soil and road dust (24%) followed by vehicular emission (21%). The other sources are SIA (18%), coal combustion (13%), biomass burning (8%), industrial emission (7%), MSW burning (6%), and construction (3%).

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

Inferences

- Soil and road dust contribution is most significant in PM_{2.5} (24%) and PM₁₀ (26%). The high contribution in emissions during sampling period may be due to bad/unpaved roads.
- Vehicle contribution is consistent in PM_{2.5} (21%) and PM₁₀ (20%).
- The secondary particles contribute significantly to PM₁₀ (18%) and PM₁₀ (19%). These particles are expected to source from precursor gases (SO₂ and NO_x) emitted from far distances. However, the contribution of NO_x from local sources, especially vehicles and power plants can also contribute to nitrates. For sulfates, the major contribution can be attributed to large power plants and refineries from long distances.
- The biomass and MSW burning contribution have significant. It is clearly seen that MSW burning is a major source that contributes to PM₁₀ and PM_{2.5}. biomass and MSW burning emission are expected to be large from regions of economically lower strata of society that do not have proper infrastructure for collection and disposal of solid waste and use of biomass as a solid fuel for cooking.
- The contribution of coal combustion and flyash is high both in PM₁₀ (6%) and PM_{2.5} (13%).
- An industrial source has a significant contribution to PM other than coal combustion.

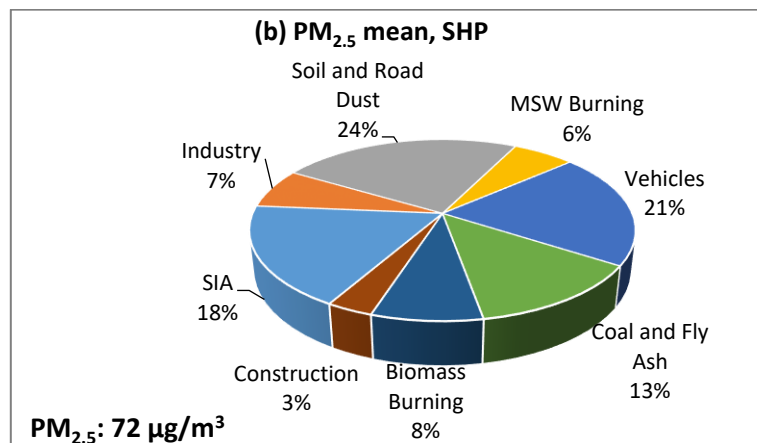
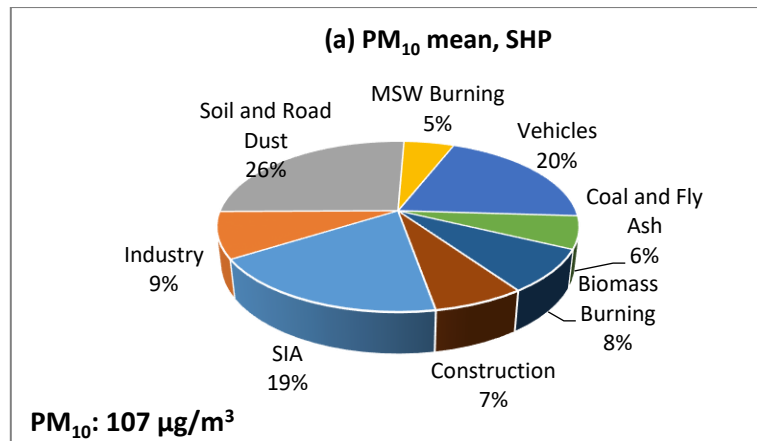


Figure 5.4: PMF modeling for (a) PM₁₀ and (b) PM_{2.5} at SHP

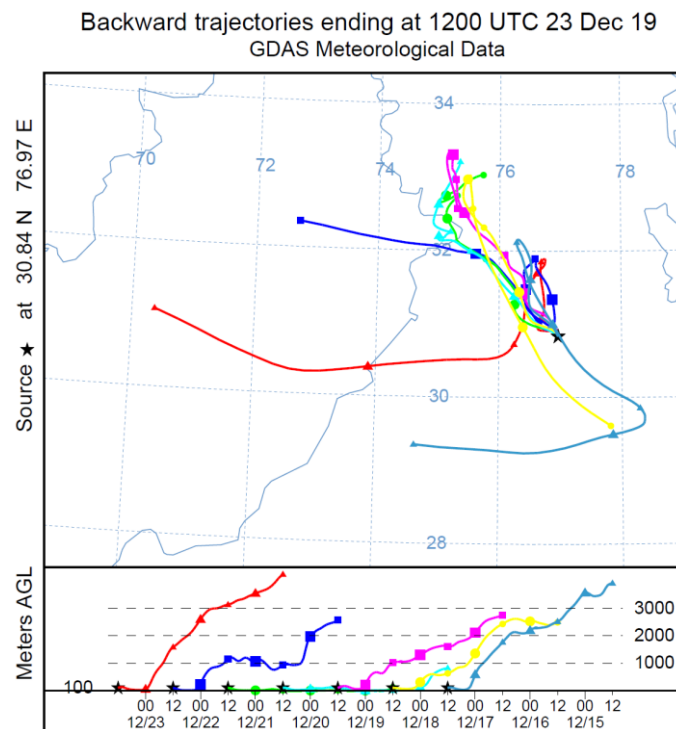


Figure 5.5: Backward trajectories at SHP

5.3.2 NGP

PM₁₀

The average PM₁₀ concentration was 188 µg/m³. Figure 5.2 represents PM₁₀ contribution of sources in terms of concentration, and percent contribution of sources at all sites (NGP represented in 2nd part of the graphs). Figure 5.6(a) represents PM₁₀ overall contribution in terms of the percentage of sources. It is observed that the major source contributing to PM₁₀ was coal and flyash (26%) followed by vehicular emission (20%). The other sources are construction (19%), SIA (13%), soil and road dust (11%), industrial emission (6%), Municipal solid waste (MSW) burning (3%) and Biomass burning (3%).

PM_{2.5}

The average PM_{2.5} concentration was 104 µg/m³ (i.e., about 0.55 of PM₁₀). Figure 5.3 represents PM_{2.5} contribution of sources in terms of concentration, and percent contribution of sources at all sites (NGP 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 coal and flyash (37%) followed by vehicular emission (33%). The other sources are SIA (12%), industrial emission (6%), biomass burning (4%), MSW burning (3%), construction (3%) and soil and road dust (2%).

HYSPLIT back trajectories (Figure 5.7) indicate that wind is flowing from NW and SE directions. Winds can pick up the pollutants on the way, especially from large sources (e.g., power plants, open burning) and tall emitting sources but these contributions have not been quantified.

Inferences

coal and flyash contribute about 37% in PM_{2.5} and 26% in PM₁₀. It indicates use of construction activities in nearby areas and coal combustion. Vehicles contribute about 33% in PM_{2.5} and 20% in PM₁₀. Soil and road dust contribution reduced to 2% in PM_{2.5} compared to 11% in PM₁₀. Industrial source contributes about 6% in PM₁₀ and PM_{2.5}. SIA contribution also significantly high at 13% in PM₁₀ and 12% in PM_{2.5}.

5.3.3 OPR

PM₁₀

The average PM₁₀ concentration was 116 µg/m³. Figure 5.2 represents PM₁₀ contribution of sources in terms of concentration, and percent contribution of sources at all sites (OPR represented in 3rd part of the graphs). Figure 5.8(a) represents PM₁₀ overall contribution in terms of the percentage of sources. It is observed that the major source contributing to PM₁₀ was SIA (23%) followed by coal combustion (19%). The other sources are vehicular emission (18%), industrial emission (16%), MSW (8%), soil and road dust (7%), biomass burning (5%) and construction (4%).

PM_{2.5}

The average PM_{2.5} concentration was 91 µg/m³ (i.e., about 0.78 of PM₁₀). Figure 5.3 represents PM_{2.5} contribution of sources in terms of concentration, and percent contribution of sources at all sites (OPR 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 SIA (28%) followed by coal combustion (26%). The other sources are vehicular emission (19%), soil and road dust (10%), biomass burning (5%), MSW burning (5%), construction (4%) and industrial emission (3%).

HYSPLIT back trajectories (Figure 5.9) indicate that wind is flowing from NW and SE directions. Winds can pick up the pollutants on the way, especially from large sources (e.g., power plants, open burning) and tall emitting sources but these contributions have not been quantified.

Inferences

Sources of SIA contribute about 23% in PM₁₀ and 28% in PM_{2.5}. Coal combustion (including flyash) contribution was very high at 19% in PM₁₀ and 26% in PM_{2.5}. It could be due to the use of coal in industries and cement in construction activities. vehicles contribution is also high in PM₁₀ and PM_{2.5}.

5.3.4 Overall

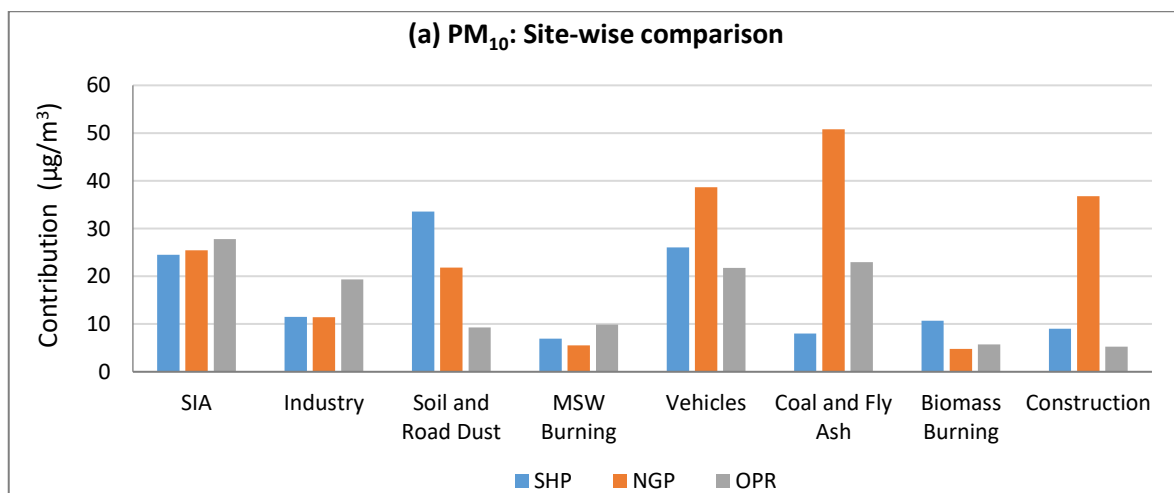
The overall summary of PMF modeling results is shown in Figures 5.10 – 5.11. Tables 5.1 – 5.2 provide a summary of overall statistics.

PM₁₀

The average PM₁₀ concentration was 135 µg/m³. Figure 5.10(a) represents a site-wise comparison of PM₁₀ contributing sources and Figure 5.11(a) represents the overall contribution in terms of concentration and percentage of sources for the Parwanoo city. It is observed that the major source contributing to PM₁₀ was vehicular emission (29 µg/m³ ~ 19%) followed by coal combustion (27 µg/m³ ~ 18%). The other major sources are SIA (26 µg/m³ ~ 17%), soil and road dust (22 µg/m³ ~ 15%), construction (17 µg/m³ ~ 11%), industrial emission (14 µg/m³ ~ 10%), biomass burning (7 µg/m³ ~ 5%), and MSW burning (7 µg/m³ ~ 5%).

PM_{2.5}

The average PM_{2.5} concentration was 88 µg/m³ (i.e., about 0.65 of PM₁₀). 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 coal combustion (25 µg/m³ ~ 26%) followed by vehicular emission (24 µg/m³ ~ 24%). The other major sources are SIA (18 µg/m³ ~ 19%), soil and road dust (11 µg/m³ ~ 11%), biomass burning (5 µg/m³ ~ 6%), industrial emission (5 µg/m³ ~ 6%), MSW burning (4 µg/m³ ~ 4%) and construction (4 µg/m³ ~ 4%).



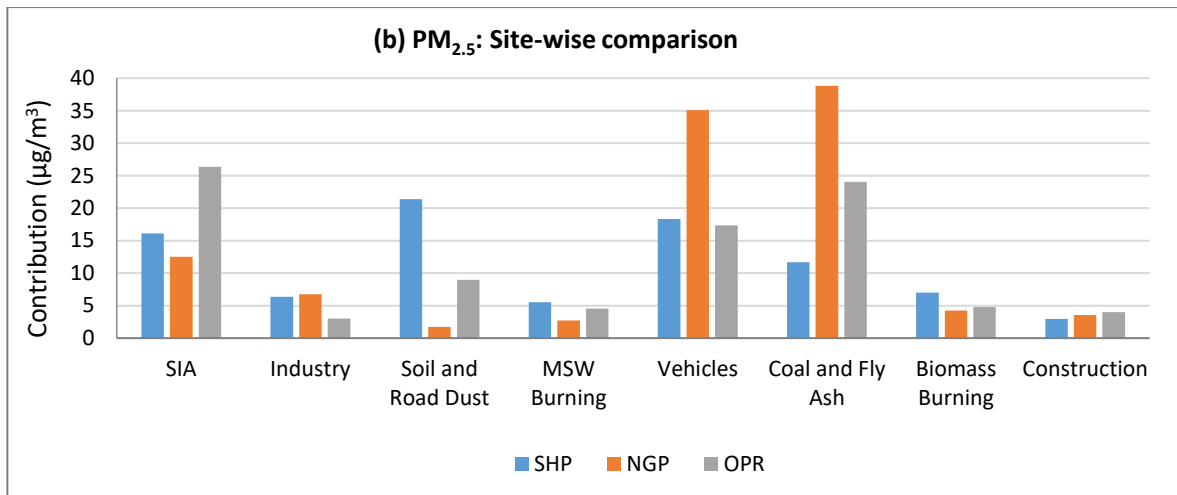


Figure 5.10: source concentration comparison at sites for (a) PM₁₀ and (b) PM_{2.5} at all sites

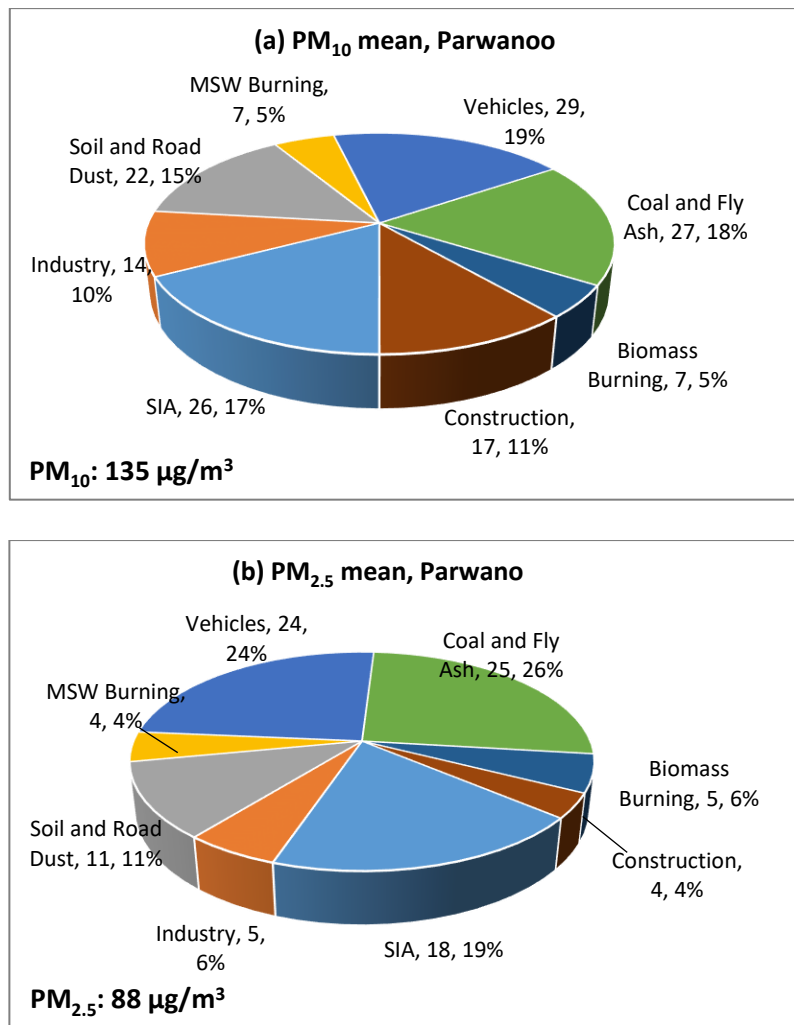


Figure 5.11: Overall contribution (Source, µg/m³, %) for (a) PM₁₀ and (b) PM_{2.5}

Table 5.1: Summary of source concentration of PM₁₀: Parwanoo

Site	Parameter	Measured PM ₁₀	Calculated PM ₁₀	% Mass	% Source Contribution							
					SIA	Industry	Soil + Road Dust	MSW Burning	Vehicles	Coal and Flyash	Biomass Burning	Construction
SHP	Mean	107.03	130.29	126.37	20.26	8.61	25.20	5.24	22.12	6.12	7.51	4.93
	SD	44.14	45.90	15.83	6.02	6.20	7.85	5.52	13.74	6.21	6.85	7.93
NGP	Mean	188.01	195.35	103.37	12.15	6.91	9.78	3.51	23.67	25.22	3.41	15.36
	SD	56.19	65.29	5.56	7.09	8.43	13.35	3.06	16.91	20.33	3.90	13.48
OPR	Mean	116.05	122.03	106.38	19.46	17.19	8.45	8.60	20.07	17.54	4.58	4.10
	SD	46.65	48.17	3.57	17.90	15.42	5.60	3.92	11.79	17.15	3.57	2.94
OVERALL	Mean	134.72	147.77	113.15	17.52	10.73	15.30	5.75	21.97	15.51	5.35	7.89
	SD	61.75	60.50	14.75	11.41	10.96	12.03	4.71	13.75	16.70	5.29	10.09
	CV	0.46	0.41	0.13	0.65	1.02	0.79	0.82	0.63	1.08	0.99	1.28
	MAX	259.53	271.90	158.45	50.79	48.61	37.97	15.41	63.47	53.18	24.35	37.86
	MIN	48.72	53.41	97.95	0.00	0.00	0.00	0.00	1.65	0.00	0.00	0.00

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

Site	Parameter	Measured PM _{2.5}	Calculated PM _{2.5}	% Mass	% Source Contribution							
					SIA	Industry	Soil + Road Dust	MSW Burning	Vehicles	Coal and Flyash	Biomass Burning	Construction
SHP	Mean	72.33	89.47	129.31	18.75	6.78	23.60	5.55	22.29	12.19	8.14	2.70
	SD	26.51	26.95	19.94	7.33	6.69	9.24	5.00	12.13	11.63	5.78	3.90
NGP	Mean	103.80	105.42	101.45	11.47	6.63	1.62	3.01	36.43	33.22	4.33	3.30
	SD	23.08	26.04	5.52	4.83	4.51	2.62	3.43	17.74	18.64	3.57	2.79
OPR	Mean	90.89	93.07	103.33	25.84	3.59	9.40	5.45	22.38	25.09	4.29	3.95
	SD	35.21	36.15	6.27	20.51	3.81	5.34	3.09	14.19	21.45	3.23	2.66
OVERALL	Mean	87.72	95.49	112.75	18.69	5.75	12.47	4.74	26.67	22.63	5.78	3.27
	SD	32.08	29.42	18.48	13.29	5.29	11.44	4.04	15.54	18.87	4.70	3.15
	CV	0.37	0.31	0.16	0.71	0.92	0.92	0.85	0.58	0.83	0.81	0.96
	MAX	147.80	143.78	173.23	56.06	22.57	37.29	13.05	64.20	61.03	18.41	12.50
	MIN	29.41	35.94	91.77	0.00	0.00	0.00	0.00	2.79	0.34	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 secondary inorganic aerosol (SIA) (18 – 19%), industrial and combustion (11 – 6%), soil and road dust (15 – 12%), MSW burning (6 – 5%), vehicles (22 – 27%), coal and flyash (16 – 23%), biomass burning (5 – 6%) and construction activities (8 – 3%).
- The most consistent sources for PM_{10} and $PM_{2.5}$ are vehicles, SIA and 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 and flyash and industrial emissions.
- Vehicles' contribution is most significant and consistent in PM_{10} (22%) and $PM_{2.5}$ (27%) in the city.
- Coal and flyash is the second most contributor in PM_{10} (16%) and $PM_{2.5}$ (23%). It could be due to uses in industries, hotels and restaurants and as a part of cement used for construction activities.
- Secondary inorganic aerosol is significantly high contribution in both PM_{10} (18%) and $PM_{2.5}$ (19%).
- Soil and road dust contribute 15% in PM_{10} and 12% in $PM_{2.5}$, showing high variability, which infers that the road condition in the city is not up to the mark. It indicates that most parts of roads and kerb-sides were poorly maintained.
- From the uncollected solid waste, the major part would be burned. It is seen that MSW burning is a major source that contributes to both PM_{10} (6%) and $PM_{2.5}$ (5%). 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.

- SHP site was in an industrial area having major polluting industries. Therefore, it has the movement of large trucks ferrying raw material and finished products. The dumping and burning of MSW and plastic waste along the roadsides were a routine practice. The MSW/plastic burning contribution is high both in PM₁₀ (5%) and PM_{2.5} (6%) that indicating improper management of waste generated in market.
- Industrial contribution in the city is moderate for both PM₁₀ (11%) and PM_{2.5} (6%) which are in conformance with the fact that the city has a large number of industries. Most of the industrial emissions are from combustion and process emissions. It may be noted that industrial emissions are 7% of PM₁₀ and 16% of PM_{2.5}, but their contribution is also significant at the breathing level.
- The contribution of biomass burning is reasonable and lowest among all sources at 5% (for PM₁₀) and 6% (for PM_{2.5}). Sizeable biomass is consistent in PM, indicating local sources present in Parwanoo city and nearby areas. Biomass burning is because of arboriculture activities, agricultural residue burning, high energy crop burning for fuel, etc.

Directions for PM control

- Industrial and combustion sources

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

- Construction, Soil and road dust

These sources contribute about 23% to PM₁₀. The silt load on some of the road is very high and silt can become airborne with the movement of vehicles. The estimated PM₁₀ emission from road dust is over 3 tons per day. Similarly, soil from the open fields gets airborne due to agricultural operations. The potential control options can be sweeping and watering roads, better construction and maintenance, growing plants, grass, etc. to prevent the resuspension of dust.

- Biomass burning

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

- MSW burning

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

- Coal combustion

Coal combustion (including flyash) contributes about 16% of PM₁₀ and unless sources contributing to flyash are controlled, one cannot expect improvement in air quality. It appears these sources are more of fugitive in nature than regular point sources. Flyash emission from hotels, restaurants and tandoors also cause large emissions and requires better housekeeping and flyash disposal.

- Secondary particles

These particles are expected to source from precursor gases (SO₂, and NO_x) which are chemically transformed into particles in the atmosphere. Mostly the precursor gases are emitted from far distances from large sources. For sulfates, the major contribution can be attributed to large power plants and refineries. However, contribution of NO_x from local sources, especially vehicles and power plants can also contribute to nitrates. Behera and Sharma (2010) for Kanpur have concluded that secondary inorganic aerosol accounted for significant mass of PM_{2.5} (about 19%) and any particulate control strategy should also include control of primary precursor gases.

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

6 Control options, Analyses and Prioritization for Actions

6.1 Air Pollution Scenario in the City of Parwanoo

The city of Parwanoo 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 secondary inorganic aerosol (SIA) (18 – 19%), industrial and combustion (11 – 6%), soil and road dust (15 – 12%), MSW burning (6 – 5%), vehicles (22 – 27%), coal and flyash (16 – 23%), biomass burning (5 – 6%) and construction activities (8 – 3%).

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

6.2 Controlling of sources within the city

6.2.1 Hotels/Restaurants/Banquet Halls

The total number of big hotels and restaurants was approximately 32, mainly situated in the central part of the city and along with the Kalka-Shimla and National Highway-5. 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 Parwanoo City.

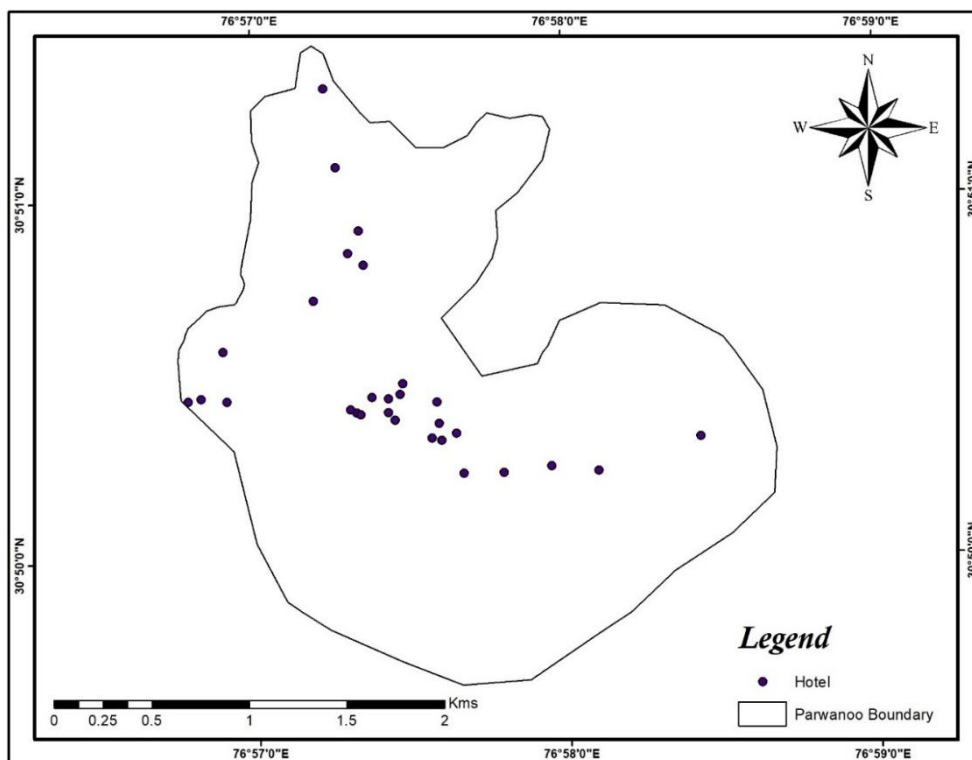


Figure 6.1: Location of Hotels, Restaurants, GHs and BHs in Parwanoo City

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 Committee, Parwanoo 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 Committee, Parwanoo, Department of Food, Civil Supplies and Consumer Affairs, and oil companies (Indian Oil, HP, etc.). A 70% reduction of PM_{10} (23 kg/d) and $PM_{2.5}$ (12 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 2 KVA and smaller (operating at ground level) should be banned and one can use an inverter or solar-based generators, and in the long-term, DG sets of 10 KVA and bigger should shift to PNG.

6.2.2 Municipal Solid Waste (MSW) Burning

MSW and other residue burning are rampant in Parwanoo (Figure 6.2). In winter, the overall source contribution from MSW burning is 6% in PM₁₀ and 5% in PM_{2.5} (Figure 5.15, Chapter 5) and stopping this burning is the simplest way to reduce PM₁₀ and PM_{2.5} levels. Any form of garbage burning should be strictly stopped and strictly monitored for its compliance. The Municipal Committee, Parwanoo 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 Parwanoo City

A mechanism should be developed to carry out a mass balance of MSW generation, collection and disposal on a weekly and monthly basis. Major commercial areas identified for this issue were Rehri Market, Kheri, Gol Market, and Sector 3, 4, 5, 6. Major residential areas (having high density) were sectors 1A, 4 and 6. Desilting and cleaning of municipal drains by Municipal Committee, Parwanoo should be undertaken on a regular interval, as the silt with biological activities can cause emission of air pollutants like H₂S, NH₃, VOCs, etc. In sector 5, the estimated solid waste volume was about 7-8 tonnes per day which is adjoining to Sukhna Nallah and solid waste being haphazardly managed.

In Parwanoo, ‘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 Committee, Parwanoo should prioritize the MSW collection mechanism starting systematically in each ward with an emphasis on

public awareness. Special attention is required for fruits and vegetable markets, commercial areas, mandis and high-rise residential buildings. Industrial waste burning is dealt with separately.

It is recommended to develop an Integrated TSDF along with provision of electricity connection and necessary water connection. The treatment and rightful disposal of fresh waste should not take more than 7 days i.e., as storage becomes a major source of VOCs.

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

The banning of MSW waste burning can reduce the emissions by 100% of PM₁₀ (13 kg/d) and PM_{2.5} (9 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 (Figure 6.3).

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 HP Urban Development Authority (HIMUDA), Himachal Pradesh Housing Board, Municipal Committee, Parwanoo, Urban Development Department, PWD, and HPSPCB.



Figure 6.3: Construction material and debris near construction sites

The suggested control measures will reduce the emission by 50% in PM₁₀ (7.5 kg/day) and 70% in PM_{2.5} (2.8 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 Parwanoo city for the year 2020 is approximately 12,000 and the emission from the domestic sector for the same is calculated. The total population including floating population for employment and non-permanent residents is more than 20,000 persons. The emission could be high due to significant floating population employed in industries. The fuel consumption pattern shows LPG (79%) consumption (PPAC, MoPNG, 2016), wood (12%), dung (2%), coal (2%), kerosene (4%) and crop residue (1%). The Department of Food, Civil Supplies and Consumer Affairs and oil companies (Indian Oil, HP, etc.) may formulate a time-bound plan for every household to have LPG.

The LPG should be made available to the remaining 21% of households to make the city 100% LPG-fueled. By 2030, planning should be done that as many households as a possible shift to electric cooking. For new societies, buildings should have a good infrastructure for PNG. A sizable floating population working in industries must also have an LPG supply.

This action is expected to reduce 82% of PM₁₀ (9.8 kg/day) and 81% of PM_{2.5} (7.3 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 PM₁₀ and PM_{2.5} emissions. The silt load, an important factor in PM emissions from the road varied from 3 to 6 g/m² which is high (typical load in developed countries is less than 1 g/m²). The industrial area, where heavy vehicle movement is seen, also shows the high road dust emission. It is suggested that high traffic density roads should be properly maintained, paved from one end to another, have sidewalks through interlocking blocks for the pedestrians, proper drainage from the road, shrubs should be planted on-road dividers. Out of the total road network, about 70% of surface quality is poor.

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

1. Convert all unpaved, partially paved roads to fully paved roads. PWD (Public Works Department) and city administration should act immediately to reduce the pollution load from road dust.
2. Municipal Council should carry out vacuum-assisted sweeping. The efficiency of vacuum-assisted sweeping should be 90% (Amato et al., 2010) and this should be part of the specification with no leakages of collected dust vacuum trucks. If the sweeping is done twice a month, the road dust emission will be reduced by 42% (PM₁₀ = 1302.8 kg/day and PM_{2.5} = 300 kg/day).
3. If the silt road is greater than 3 gm/m², the vacuum-assisted sweeping should be carried out along with washing by the municipal council and the HPSPCB should have the surveillance of this action.
4. NHAI should ensure that the silt load on highways maintained by them should have a silt load of less than 3 gm/m².

5. The condition of the roads must be maintained properly with no potholes and shoulders paved by interlocking concrete to have a proper sidewalk.
6. The truck carrying construction material, or any airborne material should be covered.
7. Vacuum sweeping of roads with high silt load locations (Kalka Highway, Parwanoo Bus Stop and Dharampur Solan 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.
8. Shrubs and perennial forages, or grass covers should be planted on the medians wherever possible.

The road dust deposition can be seen on the roads. It can be seen the roads are broken in patches causing higher road dust emissions (Figures 6.4).



Figure 6.4: Road Dust is prominent on various roads

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

For example, the quality of roads, silt load with less than 3.0 gm/m³ and interlocked concrete shoulder undertaken at Hyderabad can be seen and employed in Parwanoo (Figure 6.5).

❑ Construction of Foot Paths



❑ End to End Development of Roads



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

6.2.6 Vehicle Emission Control, Congestion and Traffic Management

The vehicle emission contribution is significant for CO, NO_x, PM₁₀, and PM_{2.5}. There is a relatively large contribution of diesel vehicles (trucks, buses, LCVs, cars, etc.) to PM₁₀, PM_{2.5} and NO_x. The source apportionment results show that NGP site have very large vehicle contributions (36% in PM_{2.5} and 24% in PM₁₀; Figure 5.11, Chapter 5) with an overall contribution of vehicles in the city is 24% in PM_{2.5} and 19% in PM₁₀ in winter months. Out of about 487 tonnes/d emission of PM_{2.5} from vehicles, about 70% is from diesel vehicles, especially trucks and buses. Therefore, control measures must focus on advanced technological intervention for diesel vehicles like Diesel Particulate Filter (DPF). The general recommendations for vehicular emission control are enumerated below (specific recommendations are discussed later).

1. Retro-fitment of DPF: These filters have a PM emission reduction efficiency of 60-90%. If the diesel vehicles entering and those in the city are equipped with DPF, there is a possible reduction of 40% of PM_{2.5} emissions. This option must be explored as Bharat stage VI fuel is available and this technology can be adopted.
2. Industries should encourage employing trucks and heavy-duty vehicles of Bharat stage-VI or IV with DPF for transportation of the raw and finished products at and from the industry.
3. By the end of 2024, a target of 50% of the total registration of vehicles in the city

should be EVs in the sector of 2Ws, 3Ws and passenger cars. A suitable subsidy or tax break may be considered for the individuals opting for EVs. Charging infrastructure should come up quickly at multiple places (As per Ministry of Petroleum guidelines, charging infrastructure for EV - Revised guidelines and standards, Oct 1, 2019, 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 Parwanoo are 5 (*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 Parwanoo 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 Parwanoo and other destinations) to quickly move towards electric buses.
9. The local public transport in the city should also move to electric buses. It is suggested that buses should be medium size of 30 seating capacity and provide better frequency for easy maneuvering in the city to avoid difficult turning and congestion.
10. Route rationalization: Improvement of availability by rationalizing routes and fleet enhancement with requisite modifications. Ensure integration of the existing metro

system with bus service.

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

Decongestion of Roads

Parwanoo is a municipal council in Solan district of Himachal Pradesh. It is an industrial town. It has Himachal's biggest wholesale market. It borders Panchkula district of Haryana and is before the towns of Pinjore and Kalka on the Chandigarh Shimla Highway. In fact, it is separated by a river bed from the town of Kalka and Pinjore to Parwanoo is almost a continuous urban belt.

The town is divided into 6 different sectors spread randomly across the Shivalik Range in a radius of about 4 km. While sectors 1A, 4 and 6 of Parwanoo are totally residential the other sectors 1, 2, 3 & 5 are Industrial with only a few residential areas. Parwanoo is essentially an industrial town with almost 80% of the local population engaged with the industries in one way or other.

It is the main centre of commercial and industrial activities in the state. A chaotic, undisciplined, and poorly managed traffic is normal on Kalka Highway, Parwanoo Bus Stop, and Dharampur Solan 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 Kalka-Shimla road, NH-5, Parwanoo-Kasauli Road, and Taksal road require specific attention including installation of DPF.

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

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

- Heavy encroachment by shopkeepers and street vendors is observed in the commercial area and residential areas, and vehicles are parked on the road. The parked vehicles take up to 40% of the road width, although one-third of the roads are more than 30 m wide. This reduces road utilization by about 50%.
- The unauthorized vehicle service centres located near the road make things worse as the vehicle is parked on-road while servicing and repairing and oil and grease spillage can be seen at Sector 2 near Central Bank of India, some of the areas where these unorganized shops can be seen at Sector1, Kheri and Rehri market.
- Heavy-duty vehicles and buses which are destined for other cities pass through major roads within Parwanoo city and create heavy congestion. The important points of congestions are Kalka Highway, Parwanoo Bus Stop, and Dharampur Solan Road. The city main roads are NH-5, Kalka-Shimla highway, Parwanoo-Kasauli, Taksal and Kamali Road; As a result, these routes within the city will also be congested.
- Areas that are adjacent to the market centers like Rehri Market, Kheri, Gol Market, and Sector 3, 4, 5, 6, and Nagar Nigam experience heavy traffic congestion due to the unregulated parking and encroachment by local shop owners. The on-street parking has to be removed and if required multistorey parking is developed (discussed later).

During the traffic recording and survey done by IIT Kanpur, the following major intersections are identified as traffic bottlenecks (Table 6.1 and Figure 6.6).

Table 6.1: Major Traffic Bottleneck at Parwanoo City

Kalka Highway	Parwanoo Bus Stop
Dharampur Solan Road	

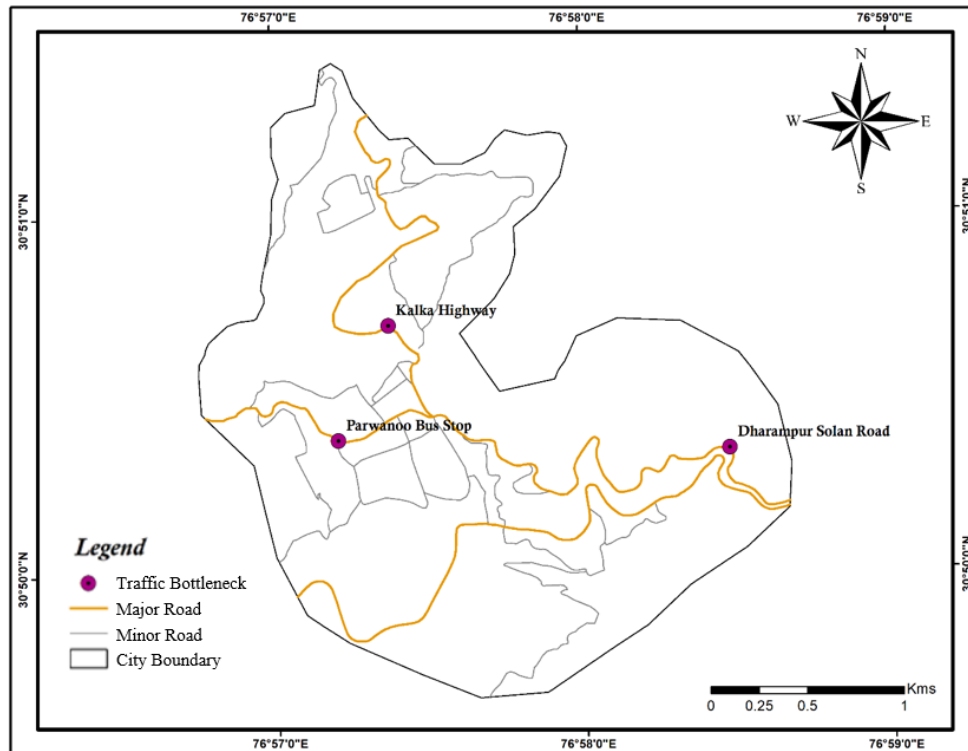


Figure 6.6: Location of traffic bottlenecks

Parking spaces

The off-street parking is inadequate in the city. There must be no parking zone (up to 50 m including auto, electric and hand-pulled rickshaw) near the intersections (Figure 6.7) it will help the smooth traffic flow. Certain parking policies in congestion areas (high parking costs, at city centers, only parking should be limited for physically challenged people.

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

- Near Intersections: the capacity of an intersection is greatly reduced if vehicles are allowed to park on the approaches. Visibility is also adversely affected & safety is reduced. It is the general practice to prohibit parking for a distance of about 50 m on the approaches to a major intersection.
- Narrow Streets: Narrow streets with heavy traffic require that all possible measures should be taken to remove obstacles to traffic flow. Prohibition of parking can have a salutary effect on traffic flow & congestion. In the busy street of the central area, it is generally desirable to prohibit parking on two-way streets with less than 5.75 m in width & one-way streets less than 4 m in width.

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

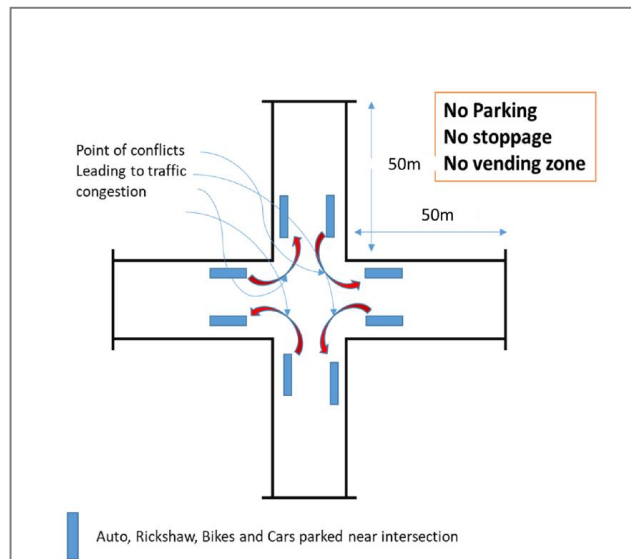


Figure 6.7: Conflicts due to on-street parking near intersections

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

Automated Multilevel Car Parking Systems

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

Dependent/Stack System: This allows two passenger cars to be parked one above the other (Figure 6.8). Its single post saves space and offers flexibility. Besides a platform (curved at the ends to allow the car to roll on/roll off conveniently) there is an operating control pendant that can be located anywhere in the garage, basement, and outdoor structure for operation from a safe distance.

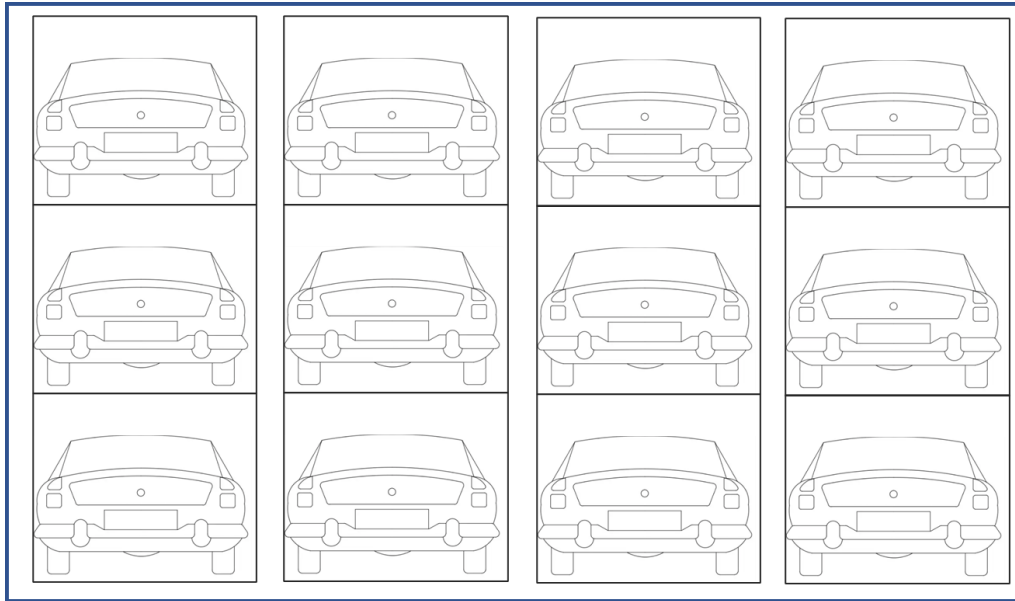


Figure 6.8: Multi-level car parking (example)

Parking prices

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

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

Promoting Public Transport Travel

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

6.2.7 Industries

Besides PM pollution (discussed later), ambient air samples collected in the industrial area during the winter months show high levels of PM₁₀ and PM_{2.5}; these levels are not acceptable. There are more than 17 polluting units that are claimed to have control devices installed. The devices are inadequate or poorly operated with very low collection efficiency. It is suggested that these industries must control PM with highly efficient capture devices and suitable disposal of collected particles.

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

A coordinated effort under the supervision of HPSPCB and Industries Departments (i.e., HIMUDA) 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 Parwanoo. It is recommended that no industrial waste should be mixed with MSW rather disposed of at TSDF for hazardous waste disposal.
- There are industries with induction furnaces, which is a very pollution process, with almost no pollution control devices. The maximum emissions occur when the furnace

lids and doors are opened during charging, back charging, alloying, oxygen lancing (if done), poking, slag removal, and tapping operations. These emissions escape from the sides and top of the building.

- To address the pollution caused by fugitive emissions using induction furnaces a fume gas capturing device has been developed and is commercially available. A side-based suction (Figures 6.9 – 6.11) is far more effective than top suction, which interferes with the movement of the crane.

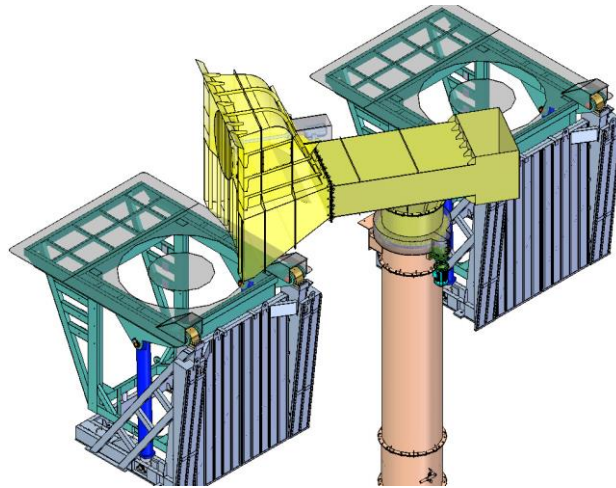


Figure 6.9: Proposed Suction Hood (Pic courtesy: Electrotherm)

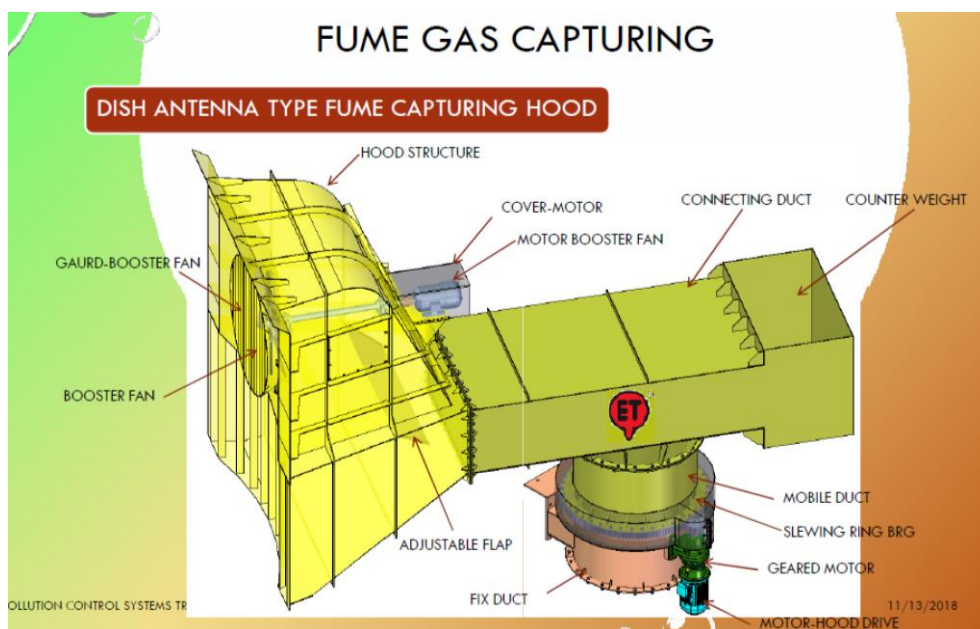


Figure 6.10: Side-based Suction Hood (Pic courtesy: Electrotherm)



Figure 6.11: Working on side-based Suction Hood (Sharma, 2020)

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

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

Assume a capacity of 8 tons per batch

Running time = 8 hrs.

Capital Cost of Suction Hood= Rs. 40 lakhs

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

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

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

Turnover of the company per year = Rs. 3 crore

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

It is seen that waste is burnt in industrial areas (Sector 1, 2, 3, and 5). Hazardous waste (oil, grease, and paint, packaging material) is dumped and burned on the roads in the areas like Sector 2 near Central Bank of India, where the trucks are being parked/repared. 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 Committee, Parwanoo and HPSPCB.

6.3 Summary of Actions and Control Options

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

6.4 Strengthening of HPSPCB Parwanoo, 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 Parwanoo (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 Committee, Parwanoo	1 year
	Link Commercial license to clean fuel	Municipal Committee, Parwanoo, 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 Committee, Parwanoo	1 year
Domestic Sector	LPG to all. Slums and about 21% of the population are still using wood, biomass and dung as cooking fuel.	Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian Oil/HP, etc.)	1 year
	No new building complex or society be allowed without a PNG supply distribution network	Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian Oil/HP, etc.)	1 year
	By 2030, the city may plan to shift to electric cooking (common in western countries) or PNG at the	Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian	10 years

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

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

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
		HPSPCB, and NGO	
Road Dust	The silt load in Parwanoo varies from 3 to 6 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 .	HIMUDA, Municipal Committee, Parwanoo, National Highway Authority, PWD, HPSPCB (for silt load compliance)	Immediate
	Convert unpaved roads to paved roads. Maintain pothole-free roads.	HIMUDA, Municipal Committee, Parwanoo, 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.	HIMUDA, Municipal Committee, Parwanoo, National Highway Authority, PWD	
	Increase green cover and plantation. Undertake the green of open areas, community places, schools, and housing societies.	HIMUDA, Municipal Committee, Parwanoo, National Highway Authority, State Forest Department, PWD	
	vacuum-assisted sweeping is carried out four times a month on major roads with road washing.	HIMUDA, Municipal Committee, Parwanoo, 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 Parwanoo.	Transport Department, Traffic Police, Parwanoo, 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 Parwanoo	1 year
	Bus stop and their parking should be rationalized to	Transport Department, RTO Parwanoo	1 year

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

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
	Disposal Facilities (TSDFs) for hazardous waste.	Industries Department, 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	Industrial Associations, HPSIDC, HPSPCB	Immediate
	Area and road in front of the industry should be the responsibility of the industry	Industrial Associations, HPSIDC, HPSPCB	
	Category A Industries (using coal and other dirty fuels)		
	About 17 boilers, Heater and furnaces in Parwanoo are running over coal, wood, and other dirty solid fuels which should be shifted to natural gas and electricity	Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian Oil/HP, etc.), Industrial Associations, HPSPCB	2 years
	Almost all rotary furnaces having significant emissions are running on coal that needs to be shifted to natural gas and electricity.	Industrial Associations, HPSPCB	2 years
	Multi-cyclones should be replaced by baghouses.	Industrial Associations, HPSPCB	2 years

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
	Ensure installation and operation of air pollution control devices in industries.		
	Category B Industries (Induction Furnace)		
	Recommended Fume gas capturing hood followed by Baghouse should be used to control air pollution.	Industrial Associations, HPSPCB	2 years
	Diesel Generator Sets		
	Strengthening of grid power supply, uninterrupted power supply to the industries.	State Energy Department, HPSEBL	2 years
	Renewable energy should be used to cater to the need of office requirements in the absence of power failure to stop the use of DG Set.	Industrial Associations	2 years
Decongestion of Roads in high traffic areas	Strict action on roadside encroachment. Disciplined movement of tempos to stop only at designated spots. Action on driving in the wrong lane.	HIMUDA, Municipal Committee, Parwanoo, RTO Parwanoo, Traffic Police, Parwanoo	6 months
	Disciplined Public transport (designate one lane stop).	RTO Parwanoo., Traffic Police, Parwanoo	
	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.	HIMUDA, Municipal Committee, Parwanoo, RTO Parwanoo, Traffic Police, Parwanoo	

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
	Examine the existing framework for removing broken vehicles from roads and create a system for speedy removal and ensure minimal disruption to traffic.	HIMUDA, RTO Parwanoo, NHAI, Traffic Police, Parwanoo	
	Synchronize traffic movements or introduce intelligent traffic systems for lane-driving.	HIMUDA, RTO Parwanoo, NHAI, Traffic Police, Parwanoo	
	Mechanized multi-story parking at bus stands, and big commercial areas. Remove at least 50 percent of on-street parking in the city.	HIMUDA, RTO Parwanoo, Municipal Committee, Parwanoo, NHAI, Traffic Police, Parwanoo	
	Identify traffic bottleneck intersections and develop a smooth traffic plan. For example, Kalka Highway, Parwanoo Bus Stop and Dharampur Solan Road are the main bottlenecks for traffic.	HIMUDA, RTO Parwanoo, Municipal Committee, Parwanoo, Traffic Police, Parwanoo	
	Parking policy in congestion areas (high parking cost, at city centers, only parking is limited for physically challenged people, etc).	HIMUDA, RTO Parwanoo, Municipal Committee, Parwanoo, NHAI, Traffic Police, Parwanoo	
	The important point of congestion is Kalka Highway, Parwanoo Bus Stop, Nagar Nigam Market, and	RTO Parwanoo, Traffic Police	2 years

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
	Himuda complex chauraha parking should be strictly prohibited.		
*The above steps should not only be implemented in Parwanoo municipal limits rather these should be extended up to at least 10 km beyond the boundary. This will need support from the central government.			

References

- Anchal Sharma, Ashok Kumar Gupta, Rajiv Ganguly. "Impact of open dumping of municipal solid waste on soil properties in mountainous region." *Journal of Rock Mechanics and Geotechnical Engineering*, 2018: 725-739.
- CPCB, (2011), Air quality monitoring, emission inventory and source apportionment study for Indian cities. National Summary Report, Central Pollution Control Board, Government of India, New Delhi, India.
- PPAC, MoPNG (2016) "Assessment Report: Primary survey on household cooking fuel usage and willingness to convert to LPG", *Petroleum Planning & Analysis Cell, Ministry of Petroleum and Natural Gas, Government of India*. (<https://www.ppac.gov.in/WriteReadData/Reports/201710310449342512219PrimarySurveyReportPPAC.pdf>).
- NGT CELL and Waste Management Division, HPSPCB.
- Census-India, (2012). Census of India, 2011. *The Government of India*, New Delhi, India. (<http://censusindia.gov.in/>)
- ARAI, (2009), Air Quality Monitoring Project-Indian Clean Air Programme (ICAP): 'SOURCE PROFILING FOR VEHICULAR EMISSIONS' as a part of Ambient Air Quality Monitoring and Emission Source Apportionment Studies. *Central Pollution Control Board*, Government of India, Delhi, India, Report No. ARAI/VSP-III/SP/RD/08-09/60
- ARAI, (2011), Indian Emissions Regulations: Limits, Regulations and Measurement of Exhaust Emissions and Calculation of Fuel Consumption. *The Automotive Research Association of India*, Pune, India
- Cooper, J.A. and Watson J.G., (1980), Receptor oriented methods of air particulate source apportionment. *JAPCA*, 30(10): 1116-1125.
- Javitz, H.S., Watson, J.G. and Robinson, N.F., (1988). Performance of the chemical mass balance model with simulated local-scale aerosols. *Atmos. Environ.*, 22(10): 2309-2322.

- NOAA, (2013), Real-time Environmental Applications and Display sYstem: Providing a Unique Web-based System for Displaying Meteorological Data. National Oceanic and Atmospheric Administration, *Air Resources Laboratory*, College Park, MD 20740.
- Sharma M, (2020), Air Quality Assessment, Trend Analysis, Emission Inventory and Source Apportionment Study in Jaipur City, (Final Report), IIT Kanpur submitted to Rajasthan State Pollution Control Board, Jaipur.
- USEPA (2014), EPA Positive Matrix Factorization (PMF) 5.0 Fundamentals and User Guide Air Quality Modeling Group. *U.S. Environmental Protection Agency*, NC., EPA/600/R-14/108
- USEPA, (1991), Receptor model technical series, Vol. 1: Overview of receptor model application to particulate source apportionment. *Office of Air Quality Planning and Standards Research Triangle Park*, North Carolina, EPA- 450/4-81-061
- USEPA, (1999a), Compendium of Methods for the determination of Inorganic Compounds in Ambient Air, Compendium Method IO-4.2: Determination of Reactive Acidic and Basic Gases and Strong Acidity of Atmospheric Fine Particles (<2.5 μ m) in Ambient Air. Center for Environmental Research Information Office of Research and Development, *U.S. Environmental Protection Agency*, Cincinnati, OH 45268, EPA/625/R-96/010a1999.
- USEPA, (1999b), Compendium of Methods for the determination of Inorganic Compounds in Ambient Air, Compendium Method IO – 3.1: Selection, Preparation and Extraction of filter material. Center for Environmental Research Information Office of Research and Development, *U.S. Environmental Protection Agency*, Cincinnati, OH 45268, EPA/625/R-96/010a.
- USEPA, (1999c), Compendium of Methods for the determination of Inorganic Compounds in Ambient Air, Compendium Method IO-3.4: Determination of Metals in Ambient Particulate Matter using Inductively Coupled Plasma (ICP) Spectroscopy. Center for Environmental Research Information Office of Research and Development, *U.S. Environmental Protection Agency*, Cincinnati, OH 45268, EPA/625/R-96/010a.
- USEPA, (1999d), Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air, Compendium Method TO-13A: Determination of Polycyclic Aromatic Hydrocarbons (PAHs) in Ambient Air Using Gas Chromatographic/Mass Spectrometry (GC/MS). Center for Environmental Research

- Information Office of Research and Development, *U.S. Environmental Protection Agency*, Cincinnati, OH 45268, EPA/625/R-96/010b.
- USEPA, (2000), AP 42, Fifth Edition, Compilation of Air Pollutant Emission Factors. <http://www3.epa.gov/ttnchie1/ap42/> <last retrieved on November 05, 2015>
- USEPA, (2006), SPECIATE-4.0-Speciation Database Development Documentation, U.S. *Environmental Protection Agency*, NC, EPA/ 600/ R-06/161
- USEPA, (2015), AERMOD View, Gaussian Plume Air Dispersion Model – AERMOD, Version 9.0 *Lakes Environmental Software*
- USEPA, 2000. AP 42, fifth edition, Compilation of Air Pollutant Emission Factors, USEPA
- Varshney, C.K., Aggarwal, M. (1992), Ozone pollution in the urban atmosphere of Delhi. *Atmospheric Environment*, 26B(3), 291 – 294.
- Watson, J.G. (1984), Overview of receptor model principles. *JAPCA*, 34: 619-623.
- Watson, J.G., Chow, J.C., Lu, Z., Fujita, E.M., Lowenthal, D.H., Lawson, D.R., and Ashbaugh L.L., (1994), Chemical Mass Balance Source Apportionment of PM₁₀ during the Southern California Air Quality Study. *Aerosol Sci. Technol.*, 21(1): 1-36.

Annexure 1

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

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

* Average kilometre run per litre of diesel is taken as: 10 km (for 3W); 15km (for 4W); 7 km (for LCV and 5 km (for Buses/Trucks). Sulfur content in diesel is taken as =500 ppm (wt/wt).

Annexure 2

Gridded Emissions (kg/day) for Parwanoo city are represented below.

GRID ID	PM₁₀	PM_{2.5}	SO₂	NO_x	CO
P1	0.00	0.00	0.00	0.00	0.00
P2	27.63	18.88	0.27	131.91	136.20
P3	17.20	11.56	0.28	80.77	83.39
P4	7.92	6.23	0.28	38.38	55.21
P5	5.67	4.56	0.23	31.64	41.66
P6	0.00	0.00	0.00	0.00	0.00
P7	0.00	0.00	0.00	0.00	0.00
P8	0.00	0.00	0.00	0.00	0.00
P9	19.82	13.02	0.25	88.42	92.28
P10	39.17	27.06	0.57	184.08	198.62
P11	82.37	62.29	1.00	430.66	524.77
P12	25.86	17.61	0.78	122.83	127.90
P13	7.31	4.96	0.74	34.64	35.77
P14	3.89	2.67	0.67	18.67	19.28
P15	46.90	29.80	3.54	209.92	210.38
P16	121.16	85.91	354.54	635.24	595.61
P17	73.38	51.55	59.02	257.78	475.75
P18	87.34	65.53	92.64	338.14	331.90
P19	89.28	57.78	2.01	382.18	401.94
P20	87.83	60.06	1.13	415.71	430.85
P21	3.96	2.72	0.43	17.88	19.61
P22	35.63	29.85	1.47	46.86	430.74
P23	201.46	172.07	235.18	220.78	552.53
P24	31.28	18.98	1.32	120.56	114.97
P25	0.00	0.00	0.00	0.00	0.00
P26	0.10	0.07	0.01	0.04	0.48

GRID ID	PM₁₀	PM_{2.5}	SO₂	NO_x	CO
P27	0.00	0.00	0.00	0.00	0.00
P28	0.00	0.00	0.00	0.00	0.00
P29	2.49	1.78	0.29	12.38	14.14
P30	29.34	21.56	235.79	101.82	114.28
P31	35.93	22.17	1.91	142.14	137.36
P32	0.52	0.23	0.03	0.09	1.10
P33	0.00	0.00	0.00	0.00	0.00
P34	0.00	0.00	0.00	0.00	0.00
P35	0.00	0.00	0.00	0.00	0.00
P36	1.53	1.14	0.50	6.96	8.87
P37	34.88	26.13	285.15	171.68	113.94
P38	3.22	2.63	51.80	21.38	5.23
P39	0.86	0.49	0.10	0.26	3.37
P40	0.00	0.00	0.00	0.00	0.00
P41	0.00	0.00	0.00	0.00	0.00
P42	0.00	0.00	0.00	0.00	0.00
P43	0.00	0.00	0.00	0.00	0.02
P44	3.48	2.48	0.36	15.66	18.44
P45	0.00	0.00	0.00	0.00	0.00
P46	0.00	0.00	0.00	0.00	0.00
P47	0.00	0.00	0.00	0.00	0.00
P48	0.00	0.00	0.00	0.00	0.00
P49	0.00	0.00	0.00	0.00	0.00