Report
(June, 2021)

Source Apportionment Study for the city of Surat, Gujarat

Prepared for
BLOOMBERG PHILANTHROPIES

By
THE ENERGY & RESOURCES INSTITUTE

THE ENERGY AND RESOURCES INSTITUTE
Creating Innovative Solutions for a Sustainable Future

ENERGY AGRICULTURE ENVIRONMENT HABITAT RESOURCE SECURITY CLIMATE HEALTH & NUTRITION

Suggested format for citation:

T E R I 2021
Source Apportionment Study & Preparation of Air Quality Action Plan for Surat City, The Energy and Resources Institute (TERI), New Delhi

TERI Team:

Principal Investigator: Dr. Sumit Sharma

Co-principal Investigator: Dr. Anju Goel

Team Members: Mr. Suresh Ramasubramanya Iyer, Dr. Arindam Datta, Mr. Mrinal Alexander Emmanuel, Mr. Nimish Singh, Md. Hafizur Rahman, Mr. Ved Prakash Sharma, Mr. Shivang Agarwal, Ms. Shivani Sharma, Mr. Justin Jacob, Mr. Prabhat Sharma, Ms. Varsha Gupta, Ms. Seema Kundu, Mr. Dheeraj Mehra

Field Team: Mr. Surinder Singh Negi, Mr. Kulwant Singh, Mr. Mahesh Kumar

Secretarial Assistance: Mr. Ritesh Kumar Jha, Ms. Valsa Charles

Submitted to
Bloomberg Philanthropies

Table of Contents

List of Figures

List of Tables

EXECUTIVE SUMMARY

Rapidly expanding economy and uncontrolled emissions from various sectors plays a very important role in deteriorating air quality in most of the Indian cities. More than 70% of cities where air quality monitoring is carried out, violate the national ambient air quality standards. In order to combat the challenge of improving the urban air quality, the government of India has taken several measures to tackle the air pollution problems which includes formulation of nationla clean air program (NCAP), expansion of air quality monitoring network, stringent vehicular emission standards, penetration of LPG in rural households etc.These measures aim to limit the problem to some extent but due to increasing population and rapid growth in economic sectors, the air qualoty remains deteriorated.

National clean air programme (NCAP) identifies 122 non-attainment cities which have consistantly violated the national ambient air quality standards. Surat city is identified as one of the non-attainment cities of Gujarat besides being known as a major industrial hub of the state. The major objectives of this study were to undertake source apportionment of ambient particulate matter (both $PM_{2.5}$and PM_{10}) using two different modelling based approaches, and develop an air quality management plan based on future projections of source emissions levels to reduce pollutant concentrations in future.

The major sources of ambient air pollution in Surat were assessed through two different modelling approaches; where one approach depends upon monitoring and chemical characterization of collected PM samples and estimates contributions of different sources at a particular site using the chemical markers of a particular source (receptor model), and the other uses the sector specific emissions inventory along with the meteorological parameters, trans-boundary pollutant inflows, terrain and landuse parameters, etc. to simulate the ambient concentration of the air pollutants in the city of Surat (dispersion model). The simulated ambient concentrations of different air pollutants were validated with the actual on-ground measurement of air pollutants before undertaking source sensitivity analysis. The source contributions of air pollutants from both approaches were compared and found to be converging. The dispersion modelling approach has been used for projection of future ambient air quality by taking into account the growth in different sectors and emissions control options adopted or planned in various sectors. Finally, based on the present and future assessment of air quality, city specific policy interventions were suggested to achieve the standards in Surat city.

Some of the major findings of air quality monitoring, chemical characterization, receptor modelling, emission inventory, dispersion modelling, and future projections are summarized in subsequent sections.

Ambient Air Quality Status of Surat

A comprehensive air quality monitoring exercise was carried out at six locations within the city along with a background location in the upwind direction of the city covering two seasons of the year (summer and winter). The six locations included industrial, residential, kerbside, and commercial locations representing different land use pattern and sources of activity. Different locations were selected based on land use pattern, predominant wind direction and in consultation with officials from Surat Municipal Corporation (SMC) and

Gujarat Pollution Control Board (GPCB). Key highlights of the monitoring results are:

- Ambient PM_{10} and $PM_{2.5}$ concentrations are of concern as they exceed the NAAQS at all monitored locations in Surat in winter season. Summers show lesser $PM_{2.5}$ concentrations than the prescribed standards; however PM_{10} still remains above the standards.
- Average PM_{10} concentration levels varied between 56 μg/m^3 to 151 μg/m^3 (mean – 103 μg/m^3) in summer, while during winter it ranged between 122 μg/m^3 to 205 μg/m^3 (mean – 163.5 μg/m^3).
- Average $PM_{2.5}$ concentration varied between 25 to 62 μg/m^3 (mean – 43.5μg/m^3) and 61 μg/m^3 to 110 μg/m^3 (mean – 85.5μg/m^3) during summer and winter season respectively.
- Average ratio of $PM_{2.5}$ to PM_{10} was found to be 0.5 and 0.6 in summer and winter season, respectively, indicating influence of more combustion based activities in winters.
- Highest levels of PM are observed at industrial and commercial locations, possibly due to industrial coal use, road dust, construction activities, coal usage in the nearby restaurant, frequent vehicular movements.

Chemical characterization

The samples collected on different filter media were further analysed for its three most common chemical constituent categories: elements, ions and carbon.

- Primary particles are attributable more to the local and nearby (urban scale) sources, while secondary pollutants generally take time to form and hence are more attributable to long range transport.
- Elements were identified as the most abundant chemical constituents in ambient PM_{10} concentration across all the monitoring locations during summer season. While ions were the most abundant chemical constituents in ambient PM_{10} at different monitoring locations during winter season.
- Irrespective of monitoring locations, elements: Si, Al, Fe, Ca, Na and S were identified as the most dominating species in ambient PM_{10} during summer and winter season, hence depicting significant contributions from dust and industrial sources.
- NH_4^+, Ca^{2+}, Na^+, Cl^-, SO_4^{2-} and NO_3^- were identified as the most dominant ionic species in ambient PM_{10} and $PM_{2.5}$ across different monitoring locations during summer and winter seasons, depicting significant contributions from chemically formed inorganic secondary particles from long range transport and sea salts.
- Ions were most dominating chemical constituents in ambient $PM_{2.5}$ samples across all the monitoring locations during both summer and winter seasons. Elements were the second most dominating chemical species in ambient $PM_{2.5}$ among different monitoring locations during the summer season, while carbon was the second most dominating chemical species in ambient $PM_{2.5}$ during the winter season. Winter season shows higher share of carbon depicting dominance of combustion based sources.
- The proportion of EC ranged between 12% to 47% and 25% to 35% of total carbon in PM_{10} amongst different monitoring locations during summer and winter seasons respectively. The proportion of EC ranged between 10 to 18% and 28 to 36% of total carbon in $PM_{2.5}$ amongst different monitoring locations during summer and winter seasons respectively. Higher shares of EC in winters show dominance of diesel and biomass based combustion, which are the rich sources of elemental carbon emissions.

Source apportionment using Receptor modelling

The chemical constituents of the collected PM samples along with source profiles were fed into a CMB model to identify and apportion sources of airborne particulate matter in the atmosphere.

- Summers : Dust generated from road dust, soil and construction is identified as the major sources of ambient $PM_{2.5}$ (27-38%) and PM_{10} (33-59%) at different monitoring locations in the city followed by industries during summer season.
- 1-13% PM_{10} and 2-9% $PM_{2.5}$ were contributed from sea salt emissions during summer season due to close proximity to the sea.
- The contribution from transport (3-6%) and residential (4-24%) sectors to the $PM_{2.5}$ levels in summer season was found to be higher than their corresponding contribution to PM_{10} (1-3% PM_{10} and 2-7% PM_{10} respectively).
- Winters: 34% PM_{10} is contributed by industries during winters followed by 28% from secondary particulates. However, 32% $PM_{2.5}$ was contributed from secondary particulates and 27% from the industries in winters. High contributions of secondary particulates in in winters are attributable to higher formation rates of nitrates in low temperatures.
- Contribution of transport sector was found to be higher in winter than in summers for both PM_{10} and $PM_{2.5}$, as the source is local and calmer conditions in winters do not allow far fast dispersal.

Emission inventory of air pollutants

Source specific multi pollutants emissions inventories have been prepared for the year 2019 at a high resolution of about 2 X 2 km^2 . Inventories were developed for PM and also for other pollutants such as SO_2, NOx, CO and NMVOCs, which account for secondary particulates formation. Major sectors covered are industries (including brick kilns), power plants, residential, transport, road dust, construction, DG sets, restaurants, refuse burning, landfill, crematoria, Hazira port, aviation, etc. The contributions of different sectors in emission inventories are summarized below.

At Surat district level

- Major sources of PM_{10} emissions are road dust (47%), industry (27%), transport (11%) and thermal power plants (5%), while industry (35%) is the major contributor to the total $PM_{2.5}$ emissions followed by road dust (25%), and transport (24%) in Surat district
- In case of SO_2, industry (49%) and thermal power plants (47%) are the major contributor to the total emissions (due to use of sulphur rich fuels), while NOx is majorly contributed by high temperature combustion in transport sector (50%) followed by industry (36%) and power plants (12%).

At Surat city level

- In the city, major sources of PM_{10} emissions are road dust (55%), industry (25%) and transport (12%). For $PM_{2.5}$ emissions, road dust (33%), transport (30%) and industry (27%) are the major contributors. Share of combustion sources is higher in $PM_{2.5}$ as they emit higher shares of fine particulates in comparison to dusty sources like road dust and construction.

- Sources of SO_2 emissions are primarily from industry (85%) followed by residential sector (12%). 85% of NOx emissions are contributed by transport sector followed by industries (12%). These gaseous emissions are also responsible to form inorganic secondary particulates after reacting with ammonia.
  This is to be noted that emission contributions are only reflective of source emissions at the tail-pipe before interacting with meteorology and the source contributions in ambient concentrations will change due to meteorological and terrain influences and also due to trans-boundary movement of pollution from outside of Surat district.

Source apportionment using dispersion modelling

Ambient PM concentrations were simulated using WRF-CMAQ models. Emissions inventory along with 3-dimensional meteorological fields over the study domain (Surat district) were taken as input to run the CMAQ model. The simulated concentrations were compared with the actual observations at specific locations. Thereafter, the share of different constituents of PM and source contributions were also derived using CMAQ model.

- Dispersion modelling results reveal that industrial sources are the major contributor in both the seasons with contributions ranging from 20% to 28% for $PM_{2.5}$ while 14% to 28% for PM_{10}. It is followed by transport sector with contribution of $PM_{2.5}$ ranging from 10% to 16% and in PM_{10} ranging from 5% to 15%.
- In case of ambient PM_{10} concentration, major contributors is industrial sector which contributes around upto 25% of the total PM_{10} concentration followed by road dust and construction sector with 14% contribution.
- The ambient $PM_{2.5}$ contribution from international sources varies from 55% in summers and drops down as low as 9% in winters while PM_{10} concentration varies from 9% to 70%. This is due to the westerly wind direction during summers, which brings trans-boundary pollution towards India and Surat. In winters the wind direction is opposite and hence does not carry the pollution load from international boundaries.

Comparative analysis of Receptor Modelling and Dispersion modeling

A comparative analysis of the sectoral contributions at each location of air quality monitoring obtained from both receptor and dispersion model was carried out. The results are shown in table below

PM_{10} concentrations of Surat city: The results of source apportionment from the two approaches seem to be congruent for most sectors. In summer season, dust (soil, road & construction) is major contributing source with share of 48% and 46% PM_{10} for receptor and dispersion modelling approaches respectively. Second major contributing source is industrial sector with contribution of 37% and 33% PM_{10} for receptor and dispersion modeling respectively. In winter season, industry is major contributing source with PM_{10} contribution of 51% and 40% from receptor and dispersion modelling approaches respectively, followed by 16% and 19% contribution from dust (dust soil & construction), 17% and 13% PM_{10} contribution from transport sector.

$PM_{2.5}$ concentrations of Surat city: Industry/power plants sector is the major contributor to the ambient $PM_{2.5}$ concentrations in both the seasons as apportioned from both the receptor and dispersion modelling approaches with 46% and 42% contribution in winters and 39% and 35% contribution of $PM_{2.5}$ in summer from receptor and dispersion approaches respectively. The contributions estimated for other sectors to the winter $PM_{2.5}$ concentrations in Surat city are also found to be close proximity for the two approaches- 23% and 15% contribution from transport sector, 12% and 17% contribution from residential sector, 9% and 11% contribution from dust(road, soil & construction).

PM_{10}	**Summers**		**Winters**	
Source	**Receptor**	**Dispersion**	**Receptor**	**Dispersion**
Transport	3%	1%	17%	13%
Soil, Road & Construction	48%	46%	16%	19%
Residential	3%	15%	7%	15%
Industry/Power Plants	37%	33%	51%	40%
Sea Salt	7%	-	-	-
Refuse	-	-	2%	1%
Agricultural Residue Burning	-	-	2%	2%
Others	2%	5%	5%	10%
$PM_{2.5}$	**Summers**		**Winters**	
Source	**Receptor**	**Dispersion**	**Receptor**	**Dispersion**
Transport	6%	6%	23%	15%
Soil, Road & Construction	33%	40%	9%	11%
Residential	15%	13%	12%	17%
Industry/Power Plants	39%	35%	46%	42%
Sea Salt	5%	-	-	-
Refuse	-	-	2%	3%
Agricultural Residue Burning	-	-	3%	3%
Others	2%	6%	5%	9%

Future projections

Future scenario analysis (for 2025 and 2030) was carried out to understand the growth in different sectors contributing to air pollution in Surat. A business as usual (BAU) scenario has been developed which takes into account the prevailing growth trajectories in various sectors and also the policies and interventions which have already been notified for control of pollution. With an objective of meeting the prescribed ambient air quality standards, different alternative scenario (strategies which could provide significant air quality benefits) have also been developed and corresponding air quality benefits in terms of PM concentrations have been quantified.

- In the BAU scenario, the winter season PM_{10} and $PM_{2.5}$ concentrations are expected to further increase by 23% and 15%, respectively in 2030, w.r.t BAU 2019.
- More stringent controls will be required to control emissions in the entire Surat district and the rest of the airshed to bring winter season PM_{10} and $PM_{2.5}$ levels down considerably.

- Based on the intervention analysis, the major strategies suggested for control of pollution in Surat are :
  a) Complete ban on burning of agricultural residues.
  b) Buses on Electric modes
  c) Reduced real-world emissions through congestion management
  d) 100% fuel switch from solid and liquid to gaseous fuels in industries
  e) 100% enforcement of Zig-Zag brick kiln technology
  f) Vacuum cleaning of arterial, sub-arterial and local roads.
  g) 100% control of dust from construction activities- barriers and fogging based controls.
  h) Control on hotel & restaurant; landfill and port emissions
- Two alternative scenarios – controls at Surat district and controls at Surat airshed (whole region contributing to pollution in Surat city) were formulated to estimate the concentration of PM_{10} and $PM_{2.5}$ in future years in Surat city. We found that district level controls can reduce winter season PM_{10} and $PM_{2.5}$ concentrations by 36% and 28% by the year 2030 w.r.t BAU. While, air shed level controls can reduce winter season PM_{10} and $PM_{2.5}$ concentrations by 64% and 62% by the year 2030 w.r.t BAU.
- Effect of regional scale pollution is pronounced in Surat's particulate matter concentrations and hence, regional level air quality planning and implementation is recommended for effective control of pollution in the entire region. Therefore, for effective controls to meet the ambient air quality standards, airshed level controls will be required. A regional scale plan for the whole state of Gujarat needs to be prepared to contribute in air quality improvement at city level including Surat. Based on the intervention analysis, the major strategies suggested for control of pollution in Surat are (prioritisation to be done based on reduction potential of these strategies given in Table 8.5 and other local considerations):

  - Fuel switch from solid and liquid to gaseous fuels in Surat district and other important industrial regions in the upwind regions of Gujarat.
  - Public and para-transit transport on electric modes
  - Reduced real-world emissions through congestion management and strengthened I&M system
  - Fleet modernization of vehicles
  - Enforcement of Zig-Zag brick kiln technology in 2025 and 2030
  - Landscaping and vacuum cleaning of arterial, sub-arterial and local roads.
  - Faster penetration of LPG in Surat district and upwind regions of Gujarat
  - Control of dust from construction activities- barriers and fogging based controls
  - Complete ban on burning of agricultural residues.
  - Control on hotel & restaurant; landfill and port emission

INTRODUCTION

1

1.1 Background

Constituents of the atmosphere are changing as a consequence of continuous emissions due to human activities resulting into critical environmental issues like air pollution. Atmospheric concentration of pollutants are found to be much above its natural background concentration which has resulted in undesirable effects on humans and environment in last few decades. In India also, air pollution has now become an issue of serious concern with more than 70% of cities violating the prescribed standards of PM_{10} concentrations.

Consumption of fossil fuels, increasing transportation needs, congestion, and seasonal agricultural crop residues burning are the primary source of air pollution. Increase in population coupled with rapid growth of industries and urbanization have acted as the primary drivers leading to severity of the issue. The levels of $PM_{2.5}$ and PM_{10} are found to be extremely higher than the WHO guidelines in most cities in India. Surat is one of the non-attainment city identified in the National Clean Air Program of India as the levels of PM especially during winters have been found to violate the prescribed standards.

In order to better understand the atmospheric chemistry, air quality, and its impact on human health, more accurate data of spatially and temporally distributed emissions is required. It is essential to estimate the impacts created by such the pollution sources, and hence apportionment of different sources towards prevailing pollution levels becomes essential. This is especially important for the policy makers to formulate effective emission control strategies and air quality management plans. Emission inventory is an important tool for identifying the source of pollutants and quantitatively expressing their pollution load in a defined area at a particular time. Furthermore, the estimation of shares of contributing source to ambient pollution concentrations at any receptor location is referred to as source apportionment, and is one of the most powerful technique to strengthen the process of air quality management planning. Emission of pollutants from sources and their effects on ambient pollutant concentrations can be related using receptor and dispersion modeling techniques.

TERI in collaboration with Gujarat Pollution Control Board, and Surat Municipal Corporation, has conducted this study on Source apportionment of particulate matter pollution in Surat city. This is supported by Bloomberg Philanthropies in order assist the Government of India in order to accomplish some of the important objectives of NCAP.

This report is aimed to provide essential knowledge about contributions of sources of air pollution in the city of Surat using established scientific methodologies. This report provides information on prevailing PM_{10} and $PM_{2.5}$ levels and their chemical characteristics in Surat. In addition, it presents the emissions inventory of different sources in the Surat district and results of receptor and dispersion models showing contributions of various sources towards prevailing ambient PM concentrations. Finally, using models future projections of emissions and air quality have been made and key recommendations to improve air quality have been made.

1.2. Objectives

The major objectives of this study are:

- To monitor PM_{10} and $PM_{2.5}$ concentrations at different area categories in Surat
- To carry out chemical characterisation of PM samples
- To conduct grid-wise emissions study for various sources in the Surat district and city.
- To conduct source apportionment study of particulate matter (both PM_{10} and $PM_{2.5}$) using receptor and dispersion models
- To project emissions levels in future under different control options and identify interventions for control
- To suggest strategies for strengthening the air quality action plan for Surat city

1.3 Approach

The study has focused on air quality monitoring, development of emission inventory, dispersion and receptor modelling and strengthening of air quality management plan for the city of Surat.

Seven locations were identified for carrying out monitoring of ambient PM_{10} and $PM_{2.5}$ concentrations in the city. Monitoring was carried out on specific filters papers in two seasons and the samples were chemically analyzed for their constituents. The data of chemically characterized samples was fed into a receptor model to carry out source apportionment. Using a parallel approach, emissions inventory has been prepared for both city and district of Surat. In total 14 sectors have been considered for the purpose of emission inventorisation both in Surat district and city based on both primary and secondary datasets. The primary data includes sector specific surveys for transport (traffic count and parking lot surveys), hotels and restaurants, refuse burning, diesel generator (D.G.) sets etc. Detailed approach and methodology adopted for the study has been defined in the subsequent sections. Overall approach of the study is shown in Figure –1.1

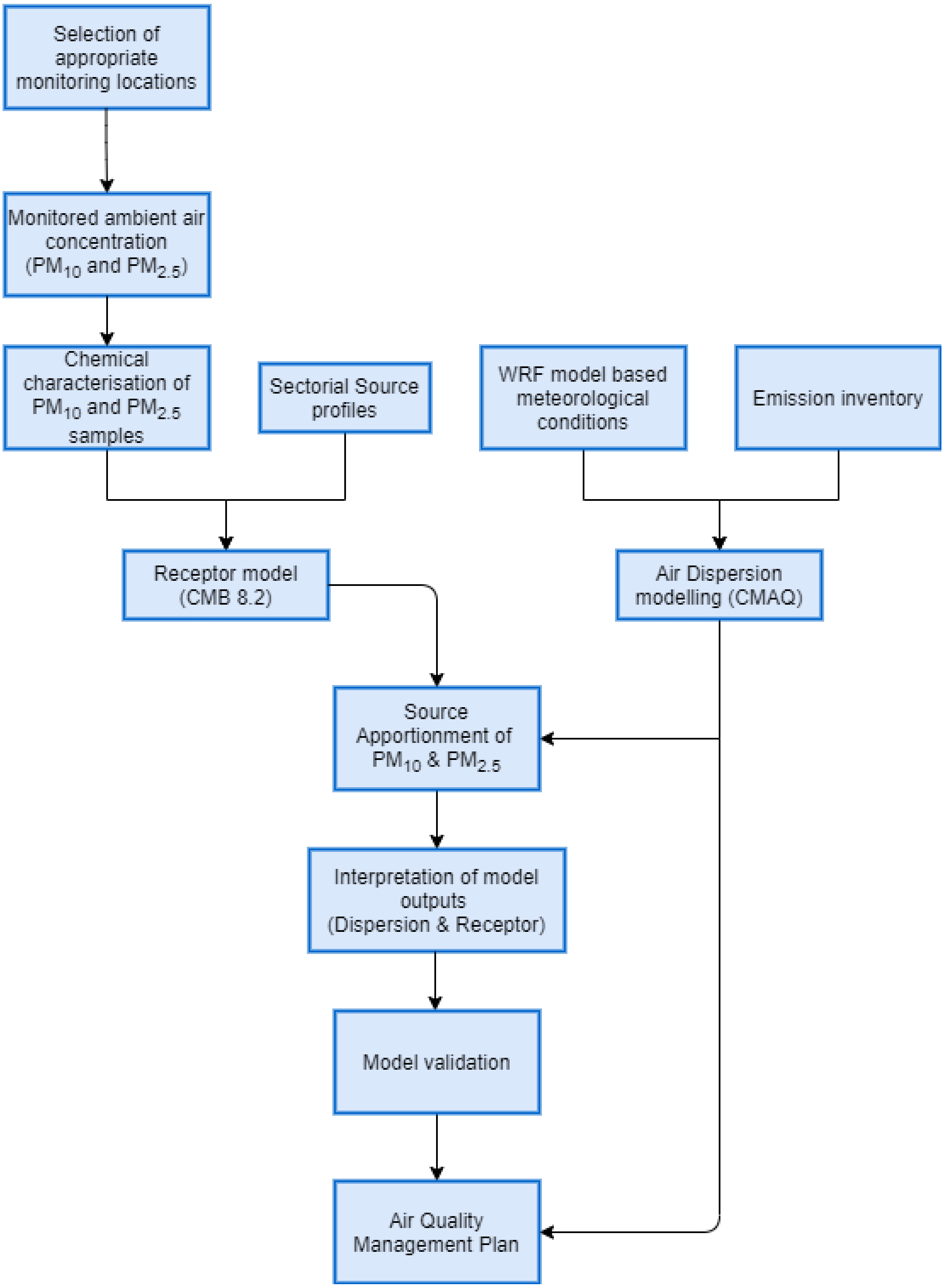


Figure 1.1: Overall approach for the source apportionment study in Surat City

1.3.1 Sector Specific emission inventory approach

Information/data such as vehicular data (registered vehicle types, vehicle kilometer travelled etc. traffic patterns, road conditions, DG sets and restaurants were obtained using primary survey, whereas industrial statistics on fuel consumption, APCD's etc were collected from regional office of GPCB.

The secondary data e.g. census based information, meteorological datasets, industrial fuel consumption, registered vehicles, growth trends of vehicles in the city, land use and land cover, crop production, information of municipal and landfill waste etc, was collected from various departments and agencies in Surat. Emission inventories are prepared both for district and city levels in Surat. The data collected from primary and secondary sources has been used for dispersion modelling to carry out apportionment of various air polluting sources contributing to PM_{10} and $PM_{2.5}$. Emission inventory of various sectors along with meteorological datasets (generated through WRF model using ERA5 datasets) were fed into the CMAQ air quality model to assess pollution concentrations and contribution of different sources at both urban and regional scales. Based on the results of receptor and dispersion models, the action plan for improvement of air quality of the city is strengthened.

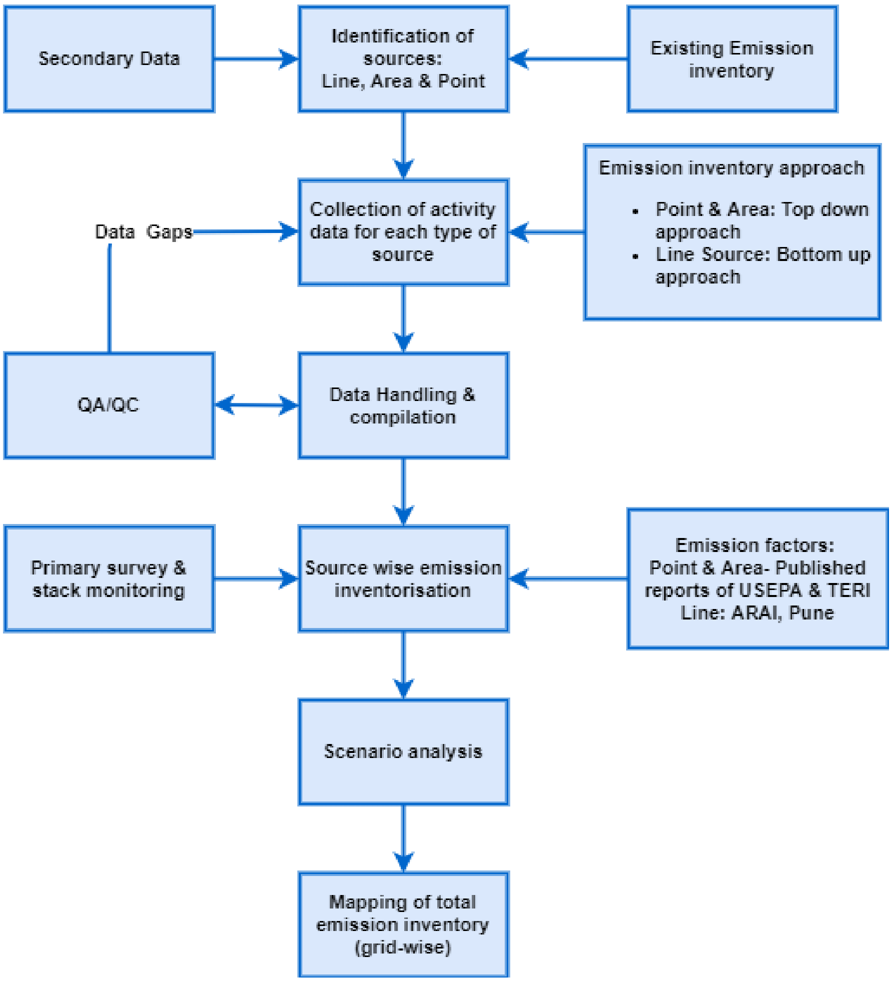


Figure 1.2: Overall approach for emission inventorisation of Surat city

The overall approach to emissions inventory is presented in Figure 1.2. In order to facilitate the preparation of emissions inventory, the study area and surroundings has been divided into grids of 2x2 km with due consideration to prominent activities in that grid. An appropriate methodology has been adopted for the development of emissions inventory (both existing and future under different scenarios). Main focus has been kept on the impact zones around the identified air quality monitoring sites. Traffic count and parking lot surveys have been carried out to estimate emissions from transport sector. Based on land use pattern in the study domain, locations for traffic count survey have been selected for different categories of roads namely arterial, sub-arterial and local roads. Moreover, emphasis has been given to quality assurance and quality control of data and documentation. A literature review has been carried out to select appropriate emissions factors (preferably Indian) and a database of emissions from all the existing sources has been prepared.

Emission factors for transport sector have been adopted from Automotive Research Association of India (ARAI) report, while for most of the other sectors indigenous factors have been used from various reports and papers. Emission inventory has been prepared for the study area as whole as well as grid-wise emissions for 2 X 2 km grids. For all sectors, emission estimates has been prepared for pollutants - PM_{10} $PM_{2.5}$, SO_2, NO_2, CO, NMVOCs (non-methane volatile organic compounds).

1.3.2 Dispersion modelling

Emissions estimated in pervious step were then fed into an air quality dispersion model - CMAQ for assessing the air quality concentrations under different scenarios. Meteorological data has been generated using the WRF model simulations, validated with actual observations.

Based on the emissions inventory developed in the current study and the 3-d meteorological data, ambient concentrations have been predicted for the pollutants PM_{10} and $PM_{2.5}$ (Figure 1. 3). These simulated concentrations values are compared against the measured ambient air quality values to validate the model. The model is first run at national level (India scale) using the national level emission inventory of TERI. The output of India-scale simulations has been fed into the CMAQ model to account for long range transport of pollution from outside of Surat district.

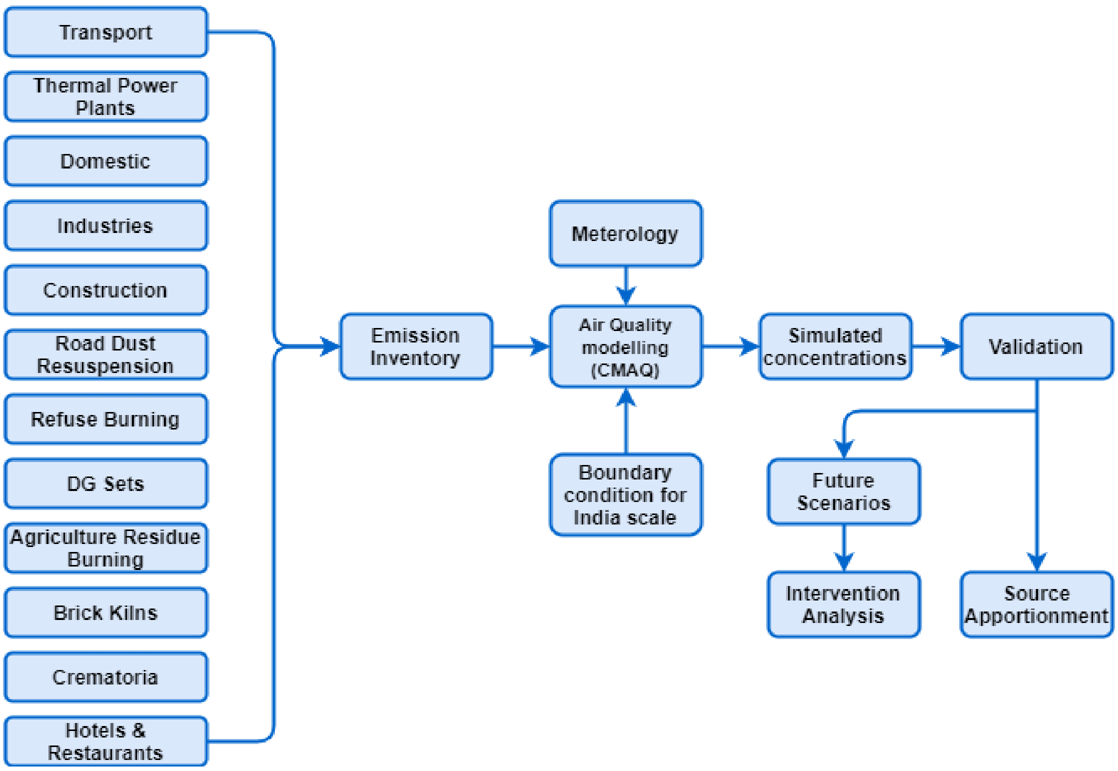


Figure 1.3: Approach for dispersion modelling in Surat city

1.3.3 Receptor Modelling and Source Apportionment

Receptor models rely on the principle of mass conservation which is used to identify and apportion sources of airborne particulate matter in the atmosphere. Chemical mass balance (CMB) model is one of several receptor models that have been used to identify air pollution sources in a specific region. The model is based on an effective-variance least squares method (EVLS) as it uses the chemical and physical characteristics of gases and particles measured at source and receptor to both identify and quantity source contributions to pollutants measured at the receptor location.

Overall approach to conduct source apportionment of PM_{10} and $PM_{2.5}$ is presented in Figure 1.4. Ambient samples for PM_{10} and $PM_{2.5}$ were taken using samplers equipped with Teflon and quartz filters. The samples collected on the filter paper were analysed for different ions, elements, carbon content for characterization of the PM_{10} and $PM_{2.5}$ samples. Characterized sample data and uncertainty estimates have been used as inputs to the receptor model CMB 8.2. Source profile characteristics (already available and developed in various other studies) have been another input to the model. Sample-wise CMB model runs have been performed to arrive at the source apportionment of PM_{10} and $PM_{2.5}$ for various area categories in the city.

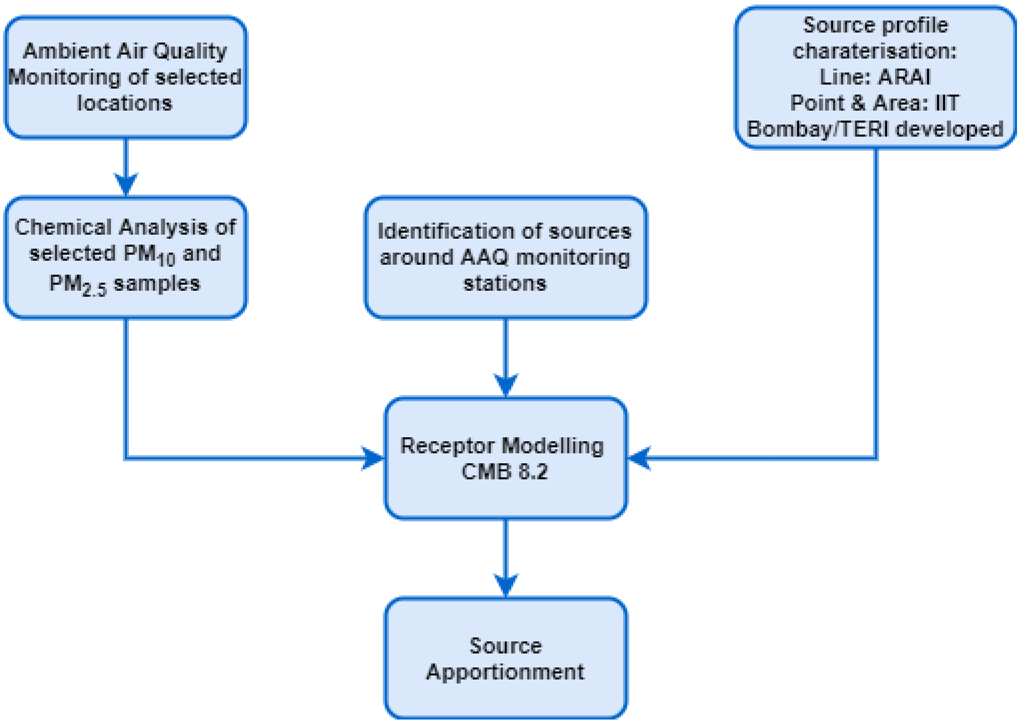


Figure 1.4: Approach to source apportionment using receptor model in Surat city

1.4 Study Domain – Surat City

Surat is one of the most dynamic cities of India with rapid growth rates. The city also attracts a large number of immigrants from various part of the country. This city is also popularly known as the diamond city and has seen an unprecedented growth in last four decades (which is one of the highest growth rates observed in the country). With growth, the city area has expanded with time and presently covers 319 sq.km (SUDA). Figure 1.5 shows the location of Surat district and Surat city in India. Surat is India's eighth and Gujarat's second most populous city with a population of about 4.5 million in 2011 (Census, 2011).

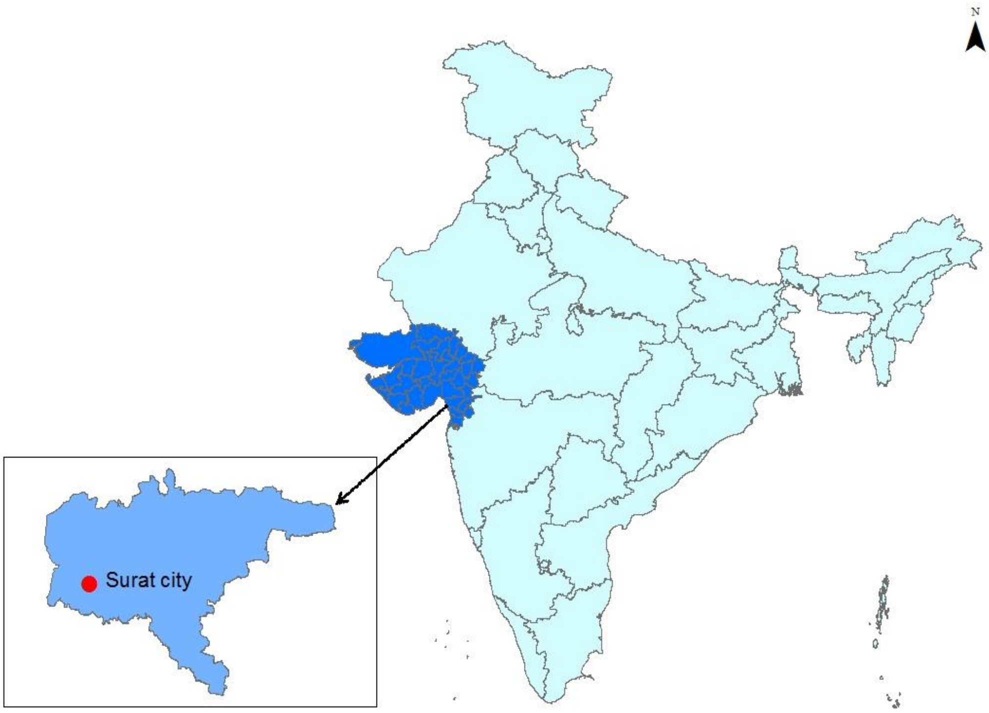


Figure 1.5: Location of Surat district and Surat city in India

The foundations for the growth in the city was laid in the 60's with the expansion of diamond trade, gradual shift in the economic base into zari and textiles (power looms), and the intensification of oil and gas exploration activities. District of Surat is an industrial hub for textile manufacturing, trade, diamond cutting and polishing industries, intricate Zari works, chemical industries and the petrochemical and natural gas based industries at Hazira established by leading industry houses such as ONGC, Reliance, ESSAR, and Shell. Textile manufacturing accounts for country's 40% of manmade fabric production and diamond cutting, polishing industries accounts for 70% of country's total diamond cutting and 40% of diamond exports, (SMC[1]). Surat has 92 brick kilns in the vicinity of the city (author's compilation using google earth). Surat being a major textile center in India with over 40,000 power loom units which produces around 9 million meters of fabric. About 60 % of total polyester cloth in India is made in Surat (urban emissions[2]).

[1] Surat Municipal Corporation (https://www.suratmunicipal.gov.in/TheCity/Contribution)

[2] https://urbanemissions.info/india-apna/surat-India/#:~:text=Surat%20is%20a%20major%20textile,port%20city%2C%2025km%20from%20Surat.

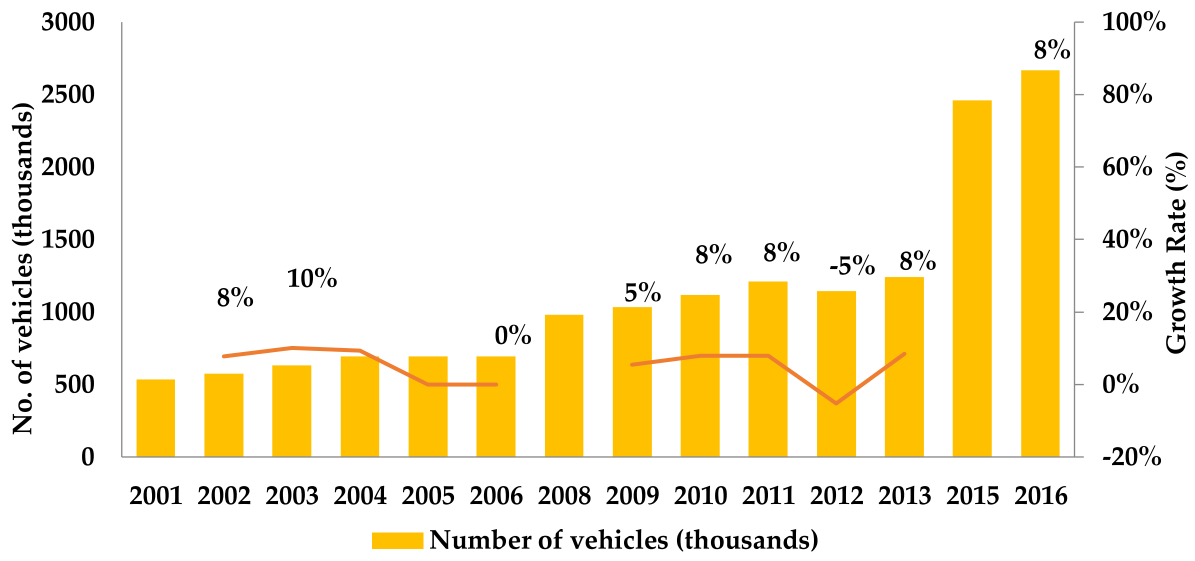


Figure 1.6: Number of registered vehicles in Surat city from 2001-2016

*2007, 2014 data not available
Source – MoRTH, 2018

With the growth in population, income level and ever increasing industrial and commercial activities, the transportation sector has also grown at a substantial rate in the city. The growth has been observed in terms of number of commercial, passenger and heavy motor vehicles. Juned & Hemangi (2015[3]) states that the compounded 5 yearly growth rate of vehicles added in the Surat city is estimated to be 34.14 % (Solar Master Plan for Surat[4]). Figure 1.6 shows the increase in total no. of vehicles in Surat between 2000- 2016.

1.5 Demographics

As per Census 2011, Surat's population is 44,66,826 with a population density of 13680 Persons/sq.km, which is second largest city in Gujarat. It is the eighth largest city and ninth largest metropolitan area of India. The overall decadal growth rate is 55.6% whereas annual growth rate is reported as 4.5% for year 2001-2011. Table 1.1 shows the decadal growth in the population of Surat city. As per Surat Municipal Corporation (SMC), assuming the growth trend remain the same for next few years would result in population 69,36,534 persons by year 2021 with population density of 21,079 people/km^2. Other demographic information related demographics of Surat city is presented in Table 1.1.

[3] Juned S. Miyajan and Hemangi H. Desai (2015), *Diurnal Concentration of Carbon Monoxide (CO) as an Indicator of Vehicular Pollution in Urban Area of Surat City*, Gujarat, India, Journal of Energy Research and Environmental Technology, Vol.2, 278-280

[4] Solar Master Plan for Surat.2014. Ministry of New Renewable Energy

Table 1.1: Demographics Features of Surat

Surat Demographics	
Oldest Municipality	1852 AD
Area	326.515 Sq. Km.
Population	44,66,826 (as per Census -2011)
Density	13680 Persons/Km² (as per Census -2011)
No. Of Slum Pockets	334 (as per Census -2011)
Zones	7
No. Of Election Wards	29
Crude Birth Rate	14.67%
Crude Death Rate	4.14%
Literacy Rate	87.89%
Male	91.22%
Female	83.44%
Decadal Growth Rate	55.29% (as per Census -2011)

Table 1.2: Population trend in Surat Municipal Area

Year	1951	1961	1971	1981	1991	2001	2011	2021 (P)
SMC area (km²)	8.18	8.18	33.85	55.56	111.2	111.3	326.5	326.52
Population (Lakh Persons)	2.23	2.88	4.72	7.77	14.99	24.34	44.5	68.825
Decadal Growth Rate (%)	_	29.05	63.75	64.65	93	62.38	82.84	54.66 (Avg. Decadal Growth Rate
Population Density (persons/ km²)	27284	35211	13934	13977	13483	21873	13629	21079

***P – Projected for 2021**
Source - *City Development Plan (2008-13) and SMC*

Rapid increase in population, rapid industrialization and high growth in vehicle population puts extraneous pressures on environmental resources like air and has worsened the problem of air pollution in Surat city. Table 2 depicts the population growth trends in Surat Municipal Area since 1951-2021

1.6 Topography

Geography - Surat is a port city (with Hazira port nearby) situated on the banks of the river Tapi. The city is located at 21.1702° N, 72.8311° E. It is surrounded by the Bharuch and Bhavnagar in the North, Navsari and Vapi in the south, Dhule in the East and Gulf of Cambay to the west. According to 2011 census, district of Surat covers an area of 4,549 km².

Climatic Conditions – Surat has a Tropical Savanna Climate i.e. Tropical dry and wet climate. Summer season begins from March to June with April and May as the hottest months. Winter season remains from December to February. Maximum and minimum temperature recorded for Surat is 42 °C and 12°C respectively. The average wind speed reported is 8 km/hr in the south west direction and has reached a maximum of 74 km/hr. The wind rose pattern for Surat City indicated that the predominant wind direction during summer season was south-west and during winters it was north –east (Fig 2.2). Average rainfall for the area is 87.37 mm annually

1.7 Land Use and Land Cover

Surat is primarily an agricultural district with sugarcane and paddy as the predominant crops (PLP, 2016-2017). The other major crops cultivated are jowar, wheat, groundnut, banana, vegetables etc. About 65 % of land holdings are with small and marginal farmers and the average size of the holdings is 2.02 ha. (PLP 2016-17[5]).The district covers an area of 4,148 sq. km and is bordered by the districts of Bharuch and Narmada in the North, Navsari and Dangs in the South and the Gulf of Khambat in the West. In Surat district, agriculture land covers the maximum area of 4207.44 Sq. Km (census, 2011). The major area of the Surat city is occupied by constructed and built up area followed by agriculture land and river bodies. The land-use distribution of Surat is shown in Figure 1.7

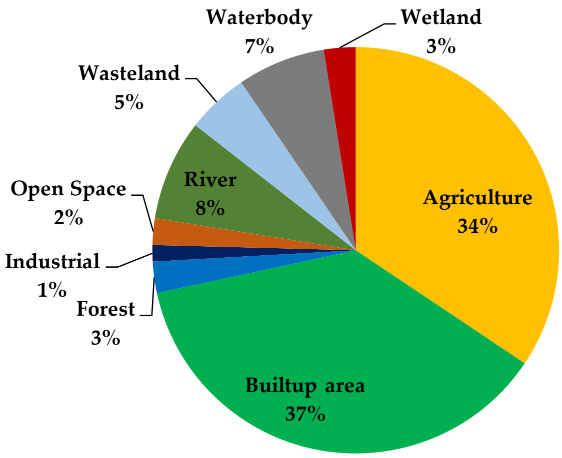


Figure 1.7: Land-use pattern of Surat city

Source: Patel (2019)[6]

1.8 Road Network of Surat

Surat has an extensive network of roads. City is located in the State of Gujarat along the principal rail corridor, midway between Bombay and Ahmedabad, the capital cities of the two most industrialized states in India and one of the India's busiest trunk routes (National Highway - 8). The city is well connected with two National Highways (NH-8 and NH-53) and six state highways (SH-6, SH-167, SH-168, SH-169, SH-170 and SH-602). Among all these, NH-8 is the busiest highway which passes towards the eastern periphery of the city

[5] https://www.nabard.org/demo/auth/writereaddata/tender/2110160649PLP%202016-2017%20Surat.split-and-merged.pdf

[6] z

and provides connectivity from Delhi to Mumbai. The length of road network within the SMC is 3,859Km[7]. The road network in Surat City has grown manifolds from 372 kms in 1976 to 644 kms in 1990, showing an average increase of 18 kms per annum. As per 2016 Business as usual scenario (BAU) estimates for 2046, there will be 2.1 times increase in population which would result in 2.9 times increase in vehicular population. This is expected to result in 4 times increase in congestion on roads, which would increase the passenger travel time by 2.3 times and increase the greenhouse gas emission by 2 times (*M.* Thennarasan, (2018[8]).

1.9 Municipal Solid Waste Management in Surat

With growing volumes of waste in Surat, proper and systematic waste management becomes a priority. Waste Management in Surat is primarily done by Surat municipality which is responsible for collecting, transporting, sorting, processing and disposing of municipal solid waste (MSW). Approximately, 2,200 metric tons of solid waste is generated per day in the Surat municipality, with approx. 4.5 million inhabitants.

In recent years waste management in Surat has evolved significantly. The SMC has adopted a number of measures to transform the waste management systems in the city with efforts like introduction of daily monitoring system for better waste collection efficiency, engaging private contractors for collection and transportation of waste to the disposal site, as well as sweeping and scraping all major streets during the night; slum improvement operations and policy decisions to create a responsive waste management system to address complaints.

1.10 Brief review of the air quality status of Surat city

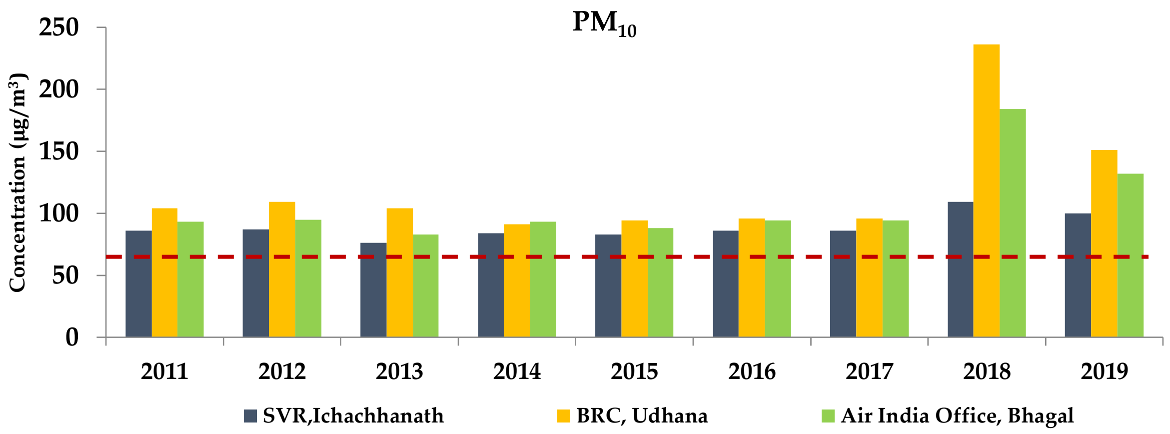
Under the National Air Quality Monitoring Programme (NAMP- CPCB) air quality is regularly monitored at few locations in Surat. Three manual ambient air quality monitoring stations are operating under national air quality monitoring programme (NAMP) in Surat city- SVR College, Ichachhanath, BRC, Udhana, and Air-India Office building, Bhagal. Figure 1.8 shows the trend of PM_{10} and $PM_{2.5}$ levels in Surat city from year 2011-12 to 2017-19. At all the three locations, PM_{10} has always been high and remained well above the nationally prescribed standards during most parts of the year. However, gaseous pollutants like SO_2 and NO_2 are generally found within the standards. Though $PM_{2.5}$ was not observed as a major issue till 2016-17, but the levels have been found to cross the limits in 2017-19 at all the three monitoring locations possibly due to increased construction activities industrial activity and vehicular congestion[9]. Figure 1.8 shows the trend in the pollutant concentration from 2011-2019.

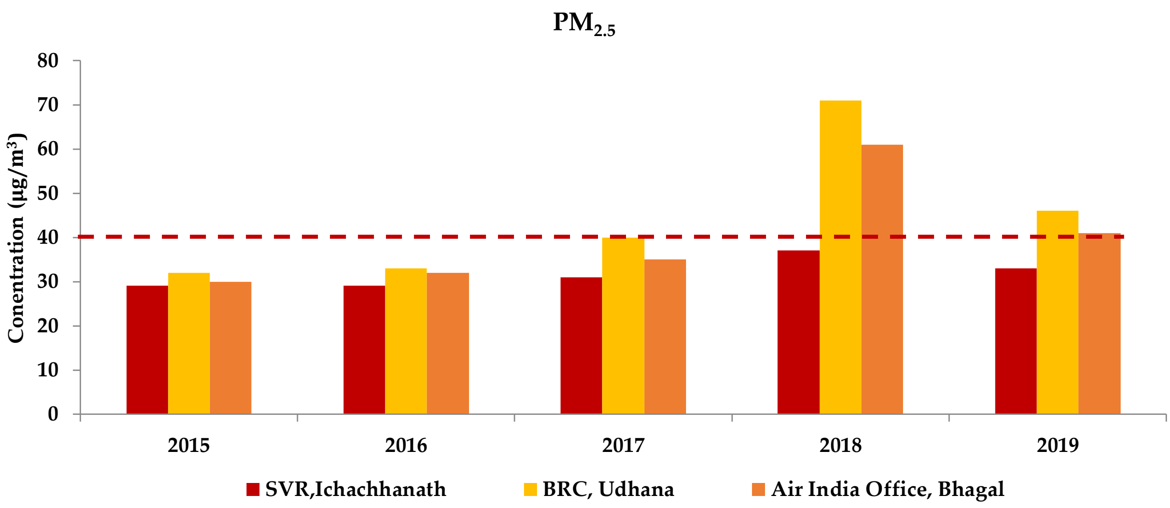
---

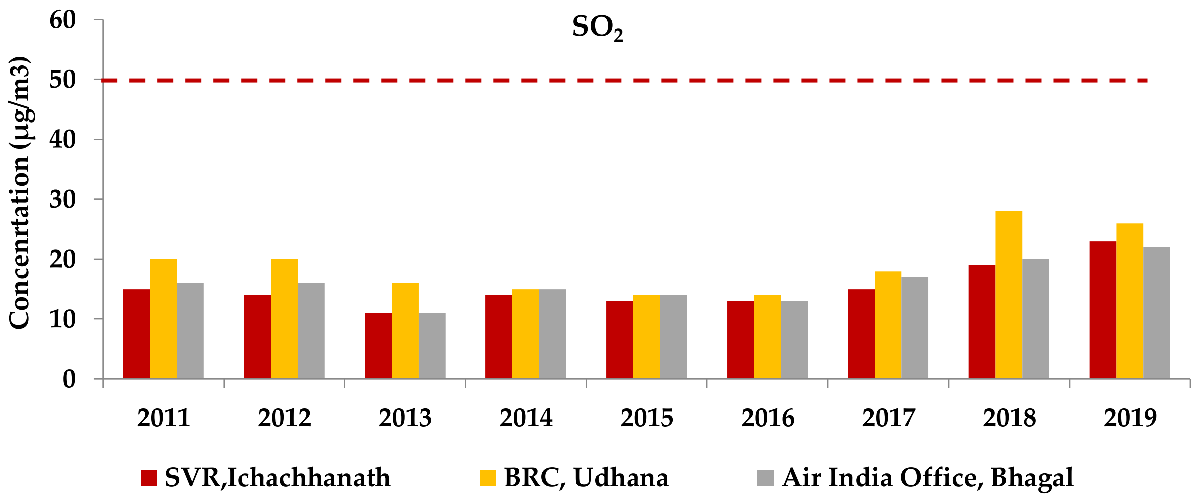
[7] SMC,2018, Sustainable Urban Trasnport Index, https://www.unescap.org/sites/default/d8files/knowledge-products/SUTI%20Mobility%20Assessment%20Report%20%20-%20Surat.pdf

[8] M. Thennarasan, 2018, Sustainable Urban Design and Development, Surat Municipal Corporation, Surat

[9] Mukherjee, F., & Singh, D. (2020). Assessing land use–land cover change and its impact on land surface temperature using LANDSAT data: A comparison of two urban areas in India. *Earth Systems and Environment*, *4*(2), 385-407.


PM10
Concentration (µg/m3)
250
200
150
100
50
0
2011
2012
2013
2014
2015
2016
2017
2018
2019
SVR,Ichachhanath
BRC, Udhana
Air India Office, Bhagal


PM2.5
Conentration (µg/m3)
80
70
60
50
40
30
20
10
0
2015
2016
2017
2018
2019
SVR,Ichachhanath
BRC, Udhana
Air India Office, Bhagal


SO2
Concenrtation (µg/m3)
60
50
40
30
20
10
0
2011
2012
2013
2014
2015
2016
2017
2018
2019
SVR,Ichachhanath
BRC, Udhana
Air India Office, Bhagal

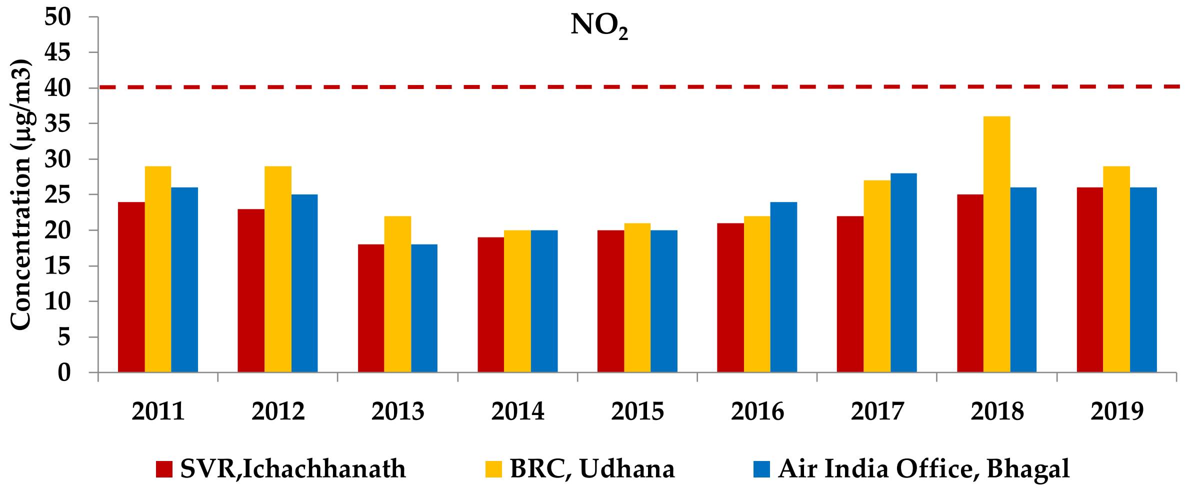


Figure 1.8: Annual average pollutant concentration trend during 2011-19 at different stations in Surat city

The possible sources of air pollution in Surat include vehicular exhaust, re-suspension of road dust, domestic and industrial fuel combustion, in-situ diesel generators, construction and waste burning (Guttikunda and Jawahar, 2012). Also, previously conducted studies show that especially during early hours of morning, the concentration of RSPM, SPM, NO_x and CO exceeds beyond the permissible limits indicating the vehicular movement and congestion in the area (Juned, 2014[10]). This study showed an AQI of 140 and above, which is highest according to EPA guidelines and unhealthy for sensitive groups. Nema & Goyal (2010[11]) stated that Surat recorded 1900 premature deaths in 2001 and 1250 premature deaths due to PM_{10} in 2010.

Multi pollutant emission inventory of Surat city conducted under APnA program showed that industrial sector has the highest emissions followed by emissions of vehicles and road dust re-suspension (APnA, 2018[12]).

These studies show deteriorated air quality of Surat which requires attention, and hence has been included as one of the non-attainment city in the NCAP. There is clearly a need for development of a scientific air quality management for the city to mitigate emissions from different sectors with specific solutions in a time bound planned manner.

The subsequent chapters in this report provide information on methodologies used, results of air quality monitoring carried out at 7 locations, chemical characteristics of PM_{10} and $PM_{2.5}$ samples, emission inventory of Surat city and district, results of source apportionment based on receptor and dispersion modelling, and future projections. The report can be used for strengthening of air quality management plan for the city.

[10] Juned, M. S., & Hemangi, D. (2014). Assessment of ambient air quality index of Surat city during early morning hours. *Journal of Environmental Research And Development*, *8*(3), 384.

[11] Nema, P., Goyal, S.K., 2010.*Estimation of health impacts due to PM10 in major Indian cities* (Chapter 11). Air Pollution: Health and Environmental Impacts. CRC Press e Taylor & Francis Group, pp. 297e310

[12] https://shaktifoundation.in/report/air-pollution-knowledge-assessment-surat/?psec=NQ==#ODY5OQ==

Report Structure

The report is divided into nine chapters:

Chapter 1: Introduction and background of study domain - Surat city and district

Chapter 2: Deals with the ambient air quality status of the seven monitoring locations in Surat during two seasons namely summers and winters

Chapter 3: Deals with the chemical characterization of PM_{10} and $PM_{2.5}$ into ions, elements & elemental and organic carbon

Chapter 4: Deals with receptor modelling results (CMB 8.2) and results interpretation

Chapter 5: Deals with the emission inventory development of various sources in Surat city and district

Chapter 6: Deals with the source apportionment of Surat w.r.t dispersion modeling

Chapter 7: Shows a comparative analysis of receptor modeling and dispersion modeling results of this study

Chapter 8: Future projections

Chapter 9: Conclusions

2

AMBIENT PARTICULATE MATTER MONITORING IN SURAT

Key observations

- The results show that ambient PM_{10} and $PM_{2.5}$ concentrations are of concern and exceeds the NAAQS at all locations in Surat in winter season. Summers show much lesser concentrations, however PM_{10} still remain above the standards.
- Wind flows dominantly from North-East direction in winters which ensures contributions due to atmospheric transport from upwind regions in Gujarat and rest of India to the city of Surat. In summers, the wind direction reverses and flows from sea-side (South-West), resulting in less contributions from anthropogenic activities.
- Average PM_{10} levels varied between 56 to 151 µg/m^3 (mean – 99 µg/m^3) in summer, while during winter it ranged between 122 to 205 µg/m^3 (mean – 157 µg/m^3).
- The average $PM_{2.5}$ varied between 25 to 62 µg/m^3 (mean – 43 µg/m^3) and 61 to 110 µg/m^3 (mean – 87 µg/m^3) during summer and winter season respectively.
- The average ratio of $PM_{2.5}$ to PM_{10} was found to be 0.5 and 0.6 in summer and winter season, respectively, indicating influence of more combustion based activities in winters.
- Highest levels of PM are observed at industrial and commercial locations, possibly due to industrial coal use, road dust, construction activities, coal usage in the nearby restaurant, frequent vehicular movements.
- Being close to the sea coast and wind blowing from the same direction in summers, contributions from long range transport from international boundaries are expected. However, during winters, other than Surat district, contributions are expected from other unwind regions of Gujarat and rest of India in the north-east direction

2.1 Introduction

Ambient air quality monitoring is an integral part of an effective air quality management system. This would help in generating baseline data of ambient PM levels, designing adequate policy goals and standards, evaluation of emission control strategies and analyzing air quality trends in a region. In this study, ambient monitoring of particulate matter concentrations has been carried out to ascertain the level of particulate pollution against the prescribed standards and also to collect samples for detailed chemical characterization analysis.

2.2 Methodology

In Surat, seven locations representing different land use categories were selected to carry out ambient monitoring of particulate matter (both PM_{10}, and $PM_{2.5}$) concentrations (Table 2.1). The wind trajectory of the Surat city suggests that the dominant wind direction over the city is from South-West in summer season and North-East in winter season. Two monitoring locations each were established in typically industrial and residential areas; one each was chosen to represent kerbside and commercial areas. A reference sampling location was selected outside of the city limits at Dumas in the South-West side of the Surat Municipal Corporation. All the locations were selected on the basis of land use land cover (LULC) pattern, population density, and meteorology of the city to represent the whole city and the sectors contributing to pollution of ambient air. The seven representative locations were selected in consultation with officials from regional office Gujarat Pollution Control Board (GPCB), Surat and Surat Municipal Corporation (SMC). In order to capture seasonal variation in pollutant concentrations, 24-hourly sampling was carried out at each of the selected locations for a period of 15 continuous days covering both summer and winter seasons of the year. At the background station, the monitoring was carried out for 30 continuous days during each season. Details of the seven locations selected for carrying out ambient air quality monitoring in Surat city are given in Table 2.1 and Figure 2.1.

Summer season monitoring was carried out in the month of May-June 2019 and winter season monitoring was carried out in the month of December 2019 – January 2020 for all seven locations. Envirotech make APM 550 samplers were used to monitor PM_{10} and $PM_{2.5}$ during the monitoring period to measure concentrations of both PM_{10} and $PM_{2.5}$ in ambient air at different locations. The equipment collects the sample of air at a flow rate of 16.7 liters per minute (LPM). Gravimetric method was followed to carry out the analysis of collected samples. PM samples were collected on different filter media such as quartz and Teflon for further chemical analysis and the filter papers were conditioned before and after the sample collection. The methods followed were strictly in accordance with the guidelines laid down by the Central Pollution Control Board (CPCB) and Bureau of Indian Standards (BIS). The results of the ambient air quality monitoring at each location were compared with the National Ambient Air Quality Standards (NAAQS) prescribed by CPCB.

Table 2.1: Locations of ambient air quality monitoring stations and their co-ordinates in Surat city

S. No	Land-use category	Location	Activities around the site	GPS co-ordinate
1	Background	Dumas	Low income group, Dumas beach, tourist destination, traffic, small eateries	21^{0}04.854′N; 72^{0}42.900′E
2	Industrial 1	Sachin (Colortex) GIDC	Industries, High way traffic, dusty roads, DG sets	21^{0}06.283′N; 72^{0}51.130′E
3	Industrial 2	Hoziwala (Power house) GIDC	Industries, Highway traffic, dusty roads, construction, D G sets, Small eateries	21^{0}04.837′N; 72^{0}54.315′E
4	Residential 1	Ram Nagar School	Densely populated, traffic, construction, Restaurants and dhabas	21^{0}12.991′N; 72^{0}47.419′E
5	Residential 2	SMC South Zone office	Medium density population, refuse burning, DG sets, traffic and restaurant, dhabas, etc.	21^{0}10.343′N; 72^{0}50.164′E
6	Commercial	SMC Hospital	Heavy traffic, Industries, dusty roads, open burning, restaurants, dhabas and small eateries	21^{0}11.025′N; 72^{0}51.182′E
7	Kerbside	Kargil Chowk	Heavy traffic, hotels and restaurants, small eateries, DG sets	21^{0}09.905′N; 72^{0}46.805′E

Figure 2.1: Selected seven ambient air quality monitoring locations in Surat city

The geographical locations of all the 7 locations are depicted on the map of Surat in Figure 2.2. In addition, the predominant wind directions are also depicted for the two season.

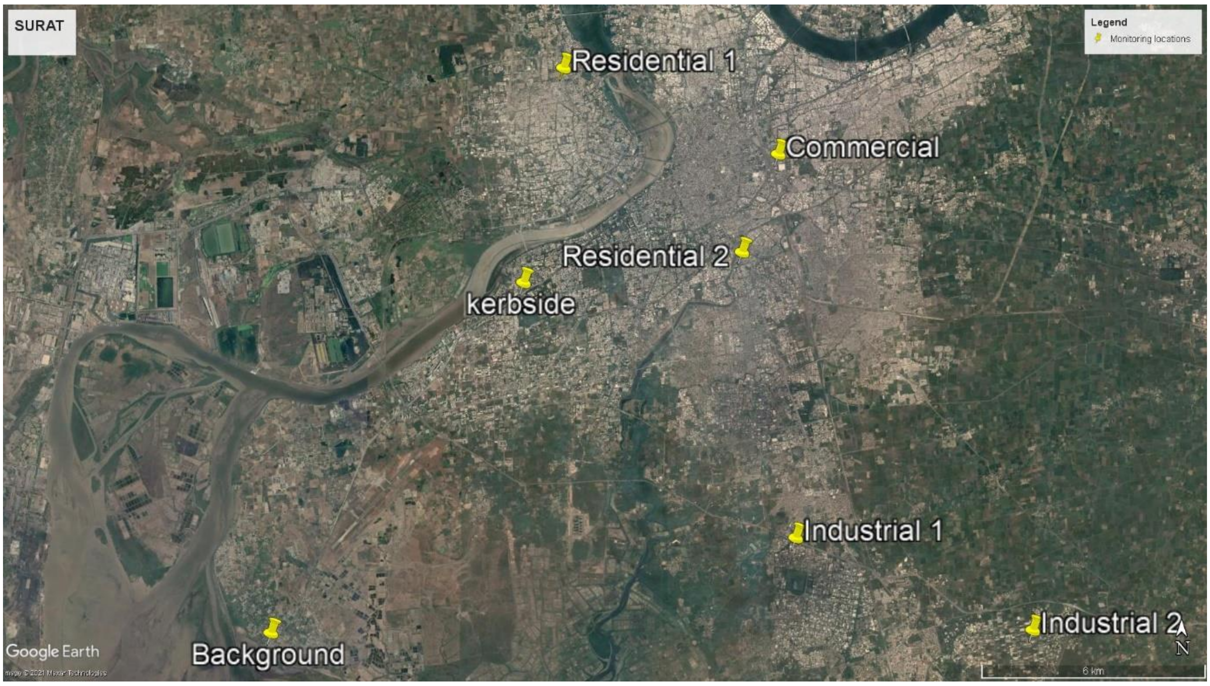


Figure 2.2: (a) Geographical locations of all the 7 monitoring locations in Surat city

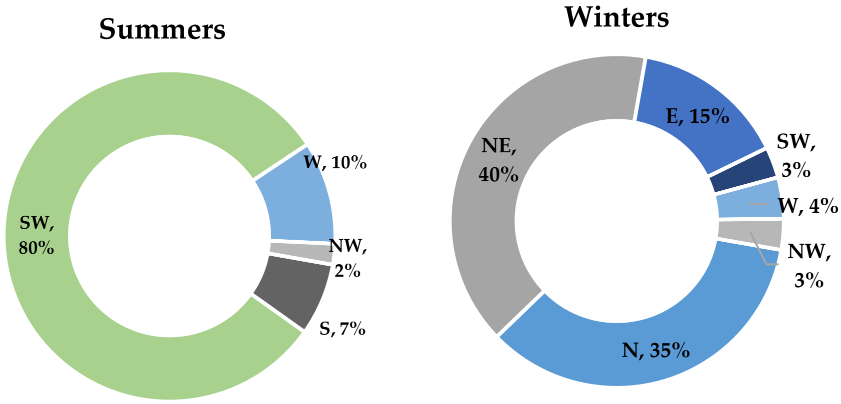


Figure 2.2 (b) Wind direction distribution at Surat in both summers & winters season

2.3 Results of ambient PM monitoring at seven locations in Surat

This section provides the monitored concentrations of PM at the selected sites. It is to be noted that observed concentrations at the 7 monitoring stations in Surat can be influenced by local as well as far off sources at the urban and regional scale. With atmospheric transport of winds, pollutants can travel long distances can pollute downwind regions quite significantly.

TERI & ARAI (2018)[13] has showed that about 60-70% of Delhi's pollution was attributed to sources outside of city limits. Location wise description of air quality is given in subsequent sections.

2.3.1 Background location

Results of ambient air quality monitoring carried out at background location are illustrated in Figure 2.3. The results revealed that the levels of PM_{10} and $PM_{2.5}$ at this location during the winter period were higher than (except for a few observations of $PM_{2.5}$ in winter) the 24-hr respective NAAQS (100 µg/m³ and 60 µg/m³ for PM_{10} and $PM_{2.5}$ respectively). However, levels of PM_{10} and $PM_{2.5}$ during the entire summer period were observed to remain within the prescribed limit.

PM_{10} concentrations during summer and winter seasons ranged between 17 to 130 µg/m3 (Mean 55 µg/m3) and 90 to 225 µg/m3 (Mean 138 µg/m3) respectively. While, the $PM_{2.5}$ concentrations during summer and winter seasons ranged between 11 to 52 µg/m3 (Mean 27 µg/m3) and 22 to 112 µg/m3 (Mean 80 µg/m3) respectively. Since this location is close to the Dumas beach, the impact of windblown dust and soil on ambient PM levels are expected at this location.

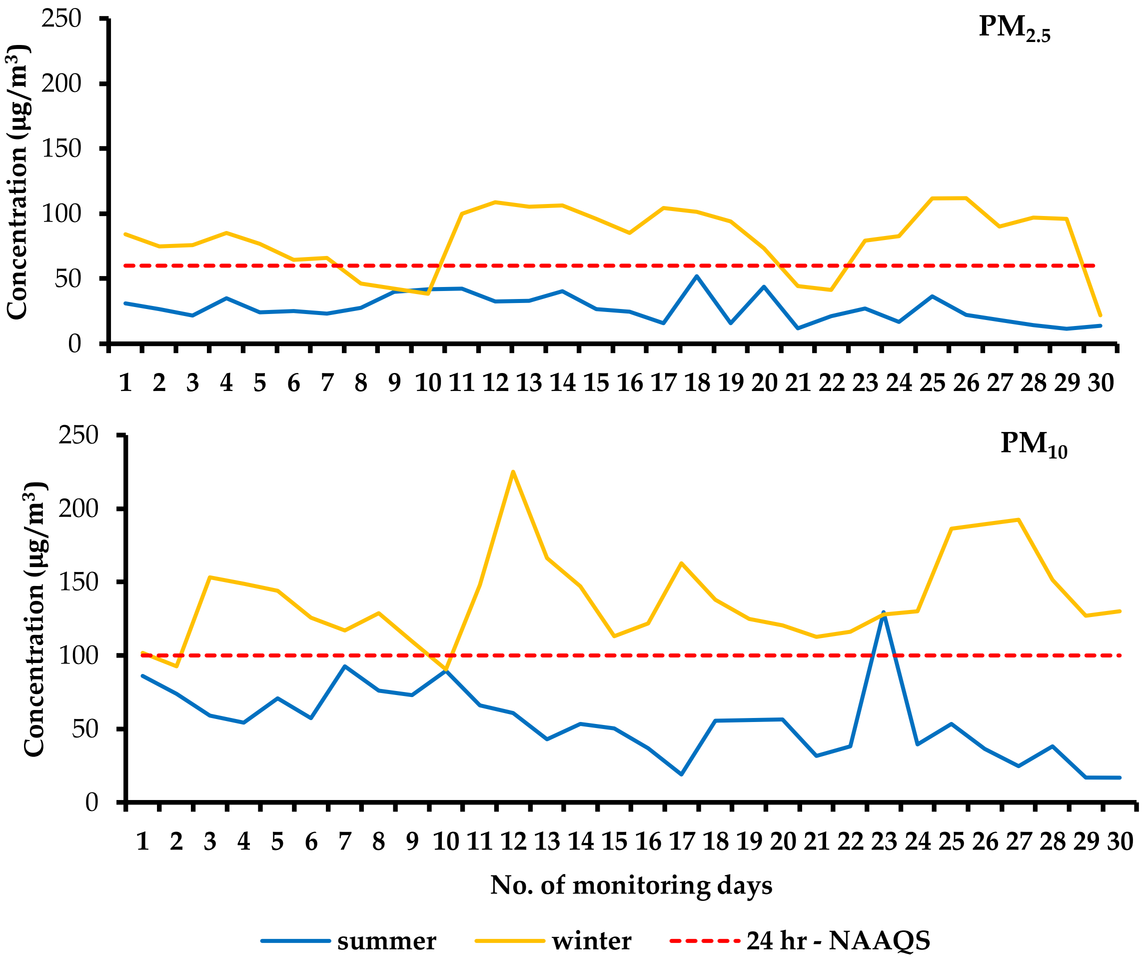


Figure 2.3: Trend of PM_{10} and $PM_{2.5}$ levels for different seasons at Background location

[13] ARAI, TERI, (2018), Source apportionment of $PM_{2.5}$ and PM_{10} concentrations of Delhi & NCR for identification of major sources, Department of Heavy Industry, Ministry of Heavy Industry and Public Enterprises, New Delhi

2.3.2 Commercial location

The results of ambient air quality monitoring at the commercial location is illustrated in Figure 2.4. The results have revealed that ambient PM_{10} concentrations at this location were exceeding the NAAQS limit throughout the monitoring period. Similarly, ambient $PM_{2.5}$ concentration at this location during winter season was also violating the prescribed limit. However, levels of $PM_{2.5}$ during summer period were within the prescribed limit for most of the monitoring days.

The PM_{10} concentrations during summer and winter seasons ranged between 98 to 174 µg/m3 (Mean 140 µg/m3) and 112 to 287 µg/m3 (Mean 207 µg/m3) respectively. While, the $PM_{2.5}$ concentrations during summer and winter seasons ranged between 35 to 87 µg/m3 (Mean 57 µg/m3) and 49 to 182 µg/m3 (Mean 106 µg/m3) respectively. Other than regional scale pollution which influences the whole city of Surat, relatively higher PM levels at this location could be attributed to the pollution emitted from local sources such as transport, road dust generated due to movement of vehicles on dusty roads. Also, since this location is commercial, a lot of small eateries and dhabas surrounding this location could also contribute to the ambient PM levels. The high PM levels at this location can also be attributed to the impact of industrial (wood/coal) and small construction activities in the nearby area.

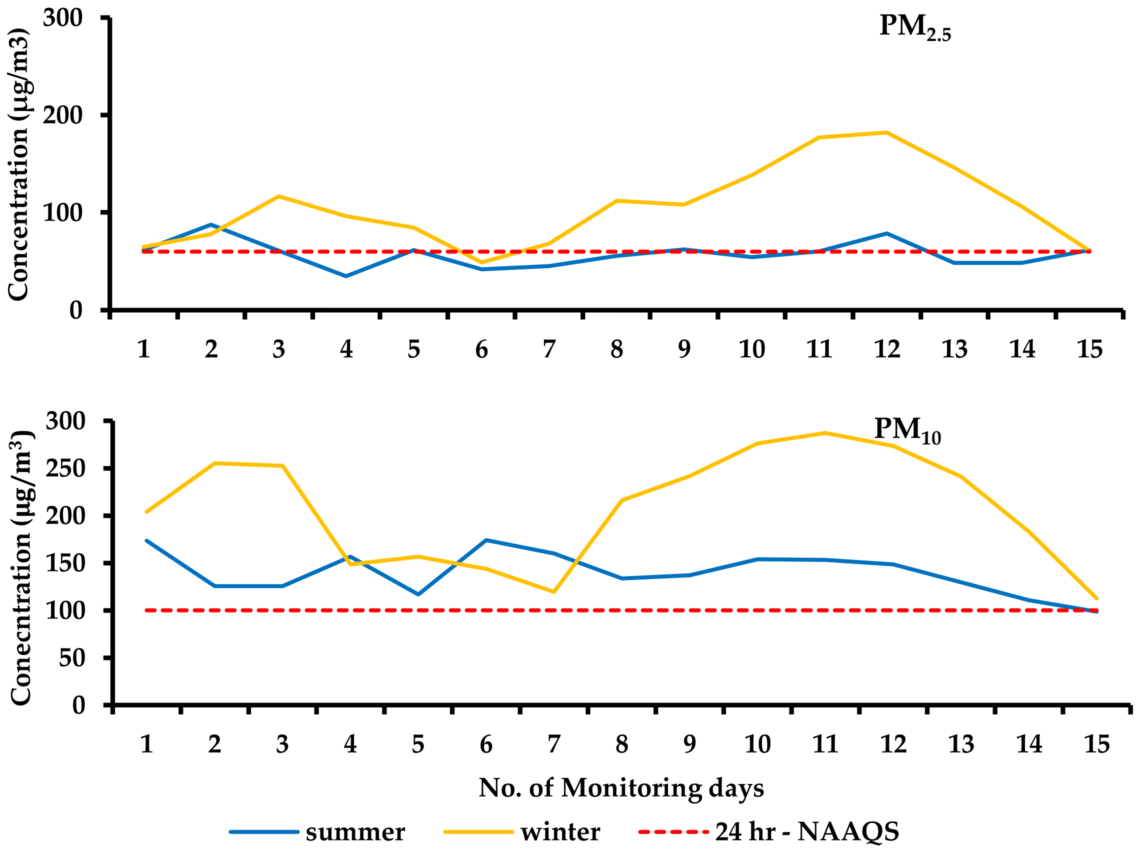


Figure 2.4: Trend of PM_{10} and $PM_{2.5}$ levels for different seasons at commercial location

2.3.3 Residential location - 1

Daily variations in PM_{10} and $PM_{2.5}$ concentrations at residential location-1 is shown in Figure 2.5. It is evident that PM_{10} concentrations at this location have exceeded the precirebed limits throughout monitoring periods. However, the level of $PM_{2.5}$ during summer period was found within the prescribed standard of 60µg/m³ for most of the monitoring days. PM_{10} concentration varied between 74 to 210 µg/m³ (Mean 129 µg/m³) during summer and 62 to 358 µg/m³ (Mean 139 µg/m³) during winter season. While, $PM_{2.5}$ concentration ranged between 30 to 84 µg/m³ (Mean 49 µg/m³) during summer and 53 to 136 µg/m³ (Mean 85 µg/m³) during winter season. Since this loaction is close to the busy traffic road, impact of vehicular movements and road dust generated due to movement of vehicles could be the local sources of ambient PM levels at this location, other than the regional scale influence of upwind sources. Also there are a lot of resturants/dhabas and small eateries in the nearby vicinity of this location where combustion of wood and charcoal takes place. This can also be the reasons for high PM levels at this location.

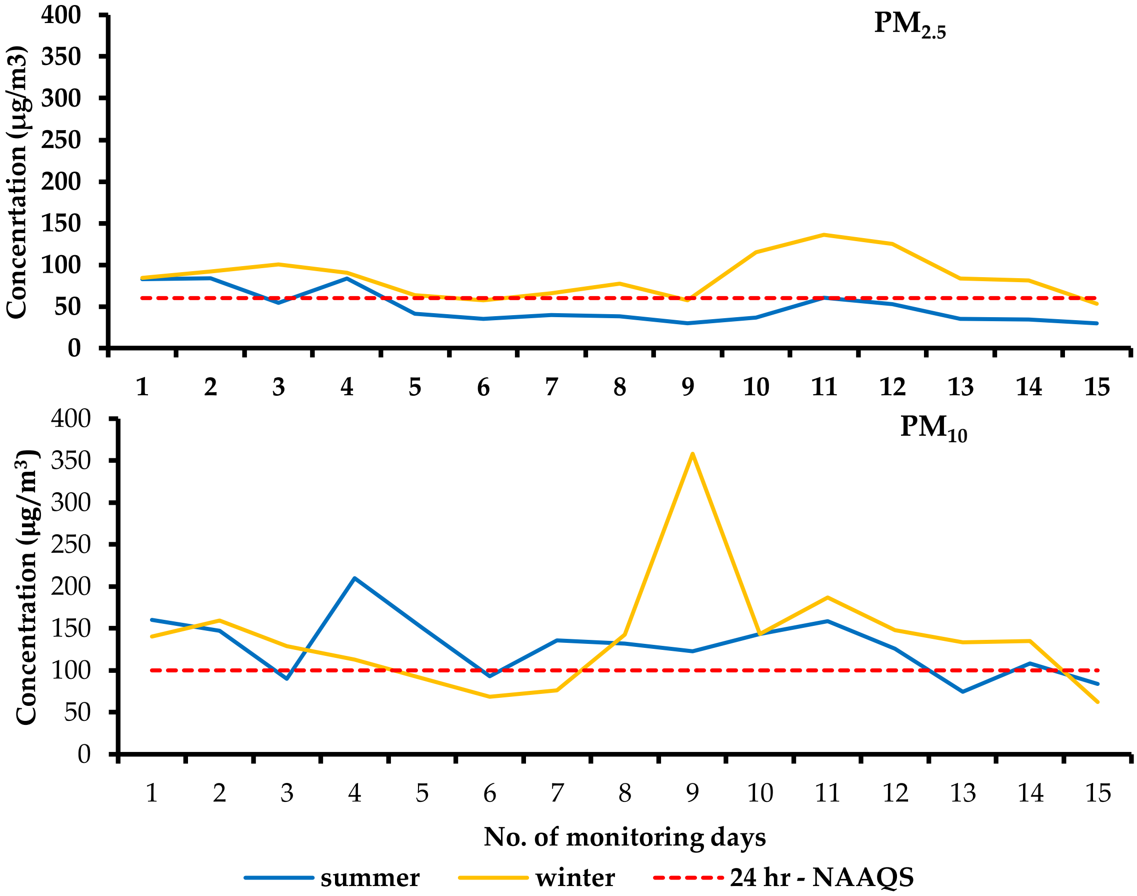


Figure 2.5: Variations of PM_{10} and $PM_{2.5}$ concentrations for different seasons at residential location 1

2.3.4 Residential location - 2

Daily variations in PM_{10} and $PM_{2.5}$ concentrations at residential location 2 is represented in Figure 2.6. It is evident that levels of PM_{10} and $PM_{2.5}$ at this location throughout summer season were observed within the prescribed standard. While, the ambient PM_{10} and $PM_{2.5}$ concentration during winter season were exceeding the prescribed limit. PM_{10} concentration varied between 56 to 112 µg/m³ (Mean 71 µg/m³) during summer and 100 to 236 µg/m³ (Mean 148 µg/m³) during winter season. While, $PM_{2.5}$ concentration ranged between 24 to 66 µg/m³ (Mean 42 µg/m³) during summer and 42 to 150 µg/m³ (Mean 86 µg/m³) during winter season. Other than regional sources, and residential sector influneces, there is a road close to this location with frequent vehicular movements, which could be the major source of ambient PM at this location.

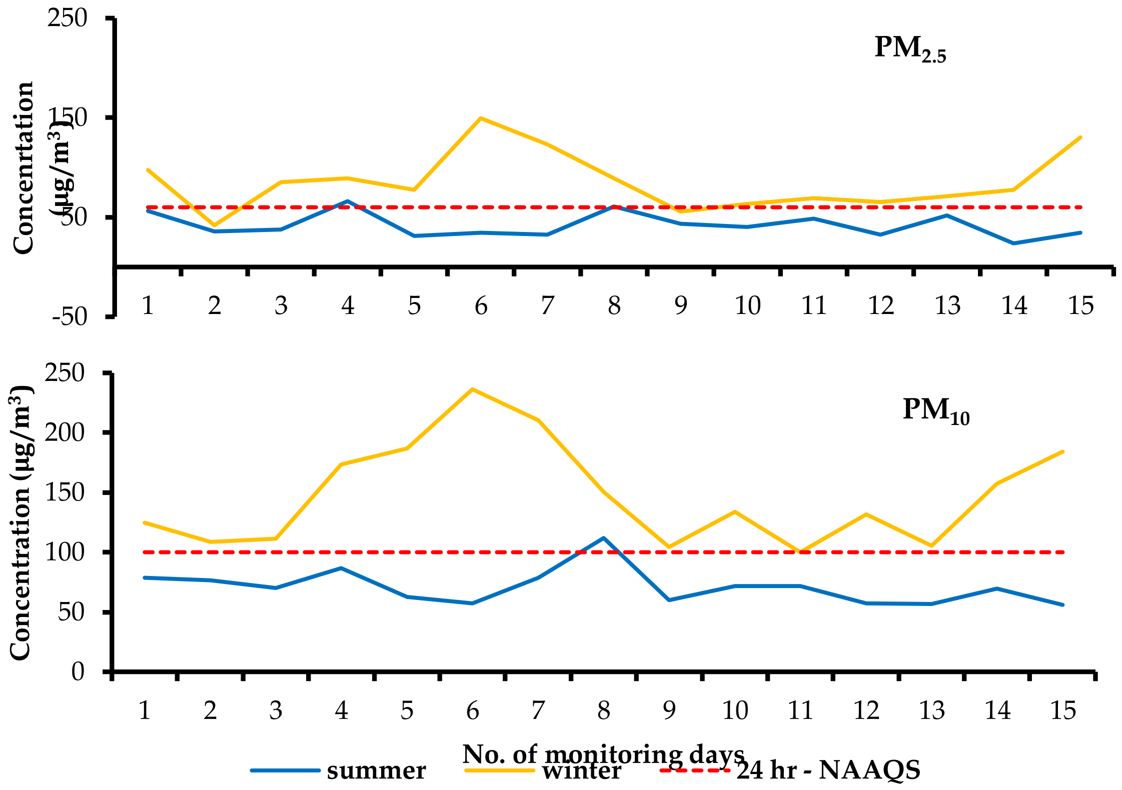


Figure 2.6: Variations of PM_{10} and $PM_{2.5}$ concentrations for both seasons at residential location 2

2.3.5 Kerbside location

Daily variations in PM_{10} and $PM_{2.5}$ concentrations at Kerbside location is illustrated in Figure 2.7. It is evident that levels of PM_{10} and $PM_{2.5}$ at this location were observed within the prescribed standard throughout the summer season. However, ambient PM_{10} and $PM_{2.5}$ concentration during winter season have exceeded the precirebed limit. The PM_{10} concentration varied between 42 to 132 µg/m^3 (Mean 87 µg/m^3) during summer and 99 to 229 µg/m^3 (Mean 158 µg/m^3) during winter season. While, $PM_{2.5}$ concentration ranged between 30 to 66 µg/m^3 (Mean 47 µg/m^3) during summer and 54 to 172 µg/m^3 (Mean 107 µg/m^3) during winter season. Other than the regional influneces from outside of Surat city, the major local sources of PM levels at this location is traffic and road dust generated due to movements of vehicles. The higher levels of $PM_{2.5}$ during winter season could also be attributed to the secondary particulate (nitrate) formation of NOx emitted from tailpipe of vehicles.

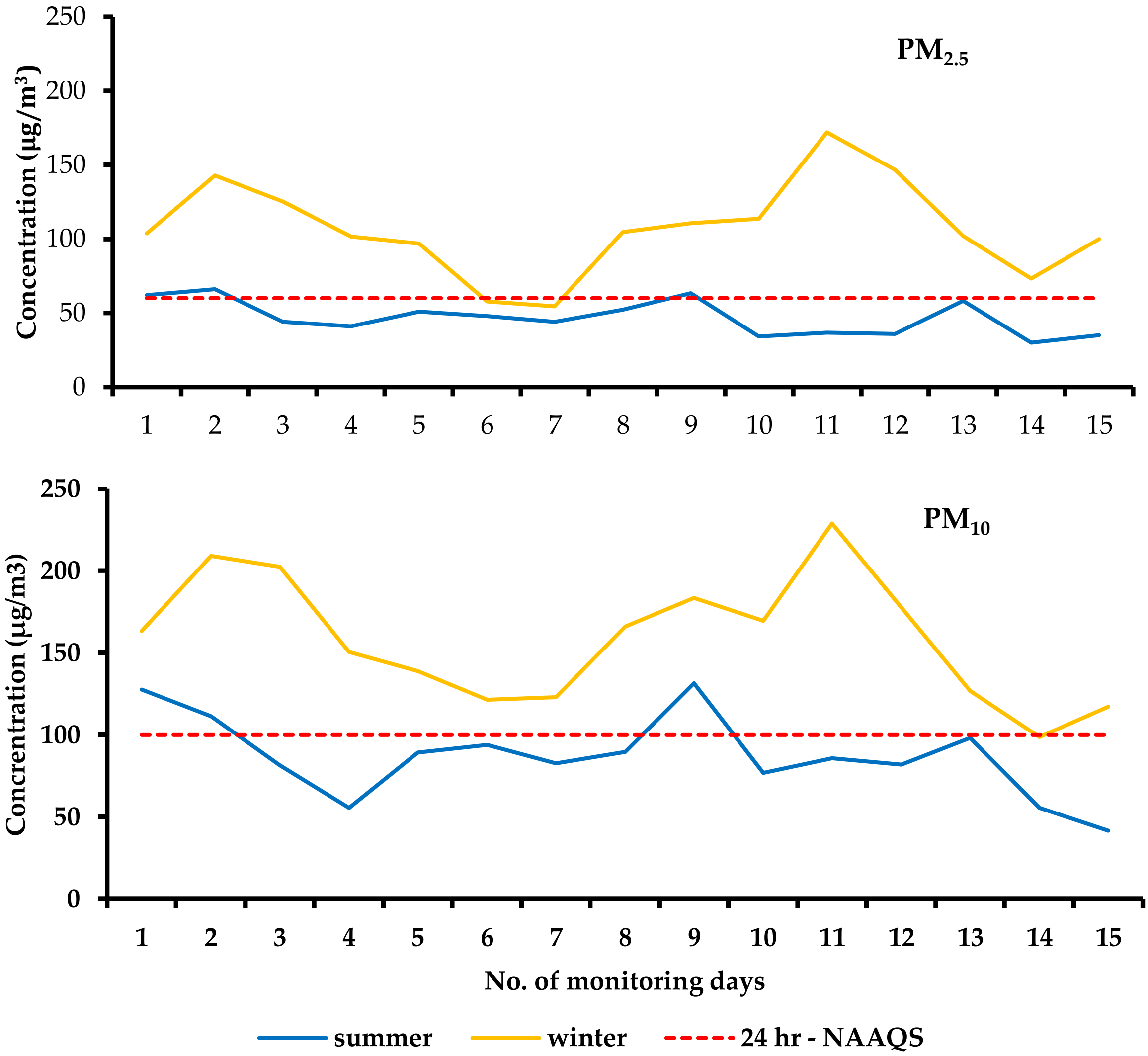


Figure 2.7: Variations of PM_{10} and $PM_{2.5}$ concentrations for different seasons at Kerbside location

2.3.6 Industrial location - 1

The trend of ambient PM_{10} and $PM_{2.5}$ concentrations at industrial location 1 throughout the monitoring season is shown in Figure 2.8. It is evident that both PM_{10} and $PM_{2.5}$ levels throughout the monitoring seasons have exceeded the NAAQS limit.

PM_{10} concentrations during summer and winter seasons varied between 103 to 194 µg/m3 (Mean 151 µg/m3) and 77 to 178 µg/m3 (Mean 122 µg/m3) respectively whereas $PM_{2.5}$ concentrations during summer and winter seasons ranged between 42 to 81 µg/m3 (Mean 62 $\mu g/m^3$) and 51 to 148 $\mu g/m^3$ (Mean 88 $\mu g/m^3$) respectively. Other than regional contributions from outside of Surat city, the major local sources of PM levels at this location are the combustion of coal and other fuels in industries. SO_2 emitted from industries due to combustion of coal in upwind region is converted into sulphates, which in turn contribute to the ambient PM levels as secondary particulates. Also there is a highway close to this location with frequent vehicular movements, which also contributes to the PM levels at this location. High PM levels during winter at this location could also be attributed to the secondary nitrate formation of the NOx emitted from the tailpipe of vehicles in the upwind regions.

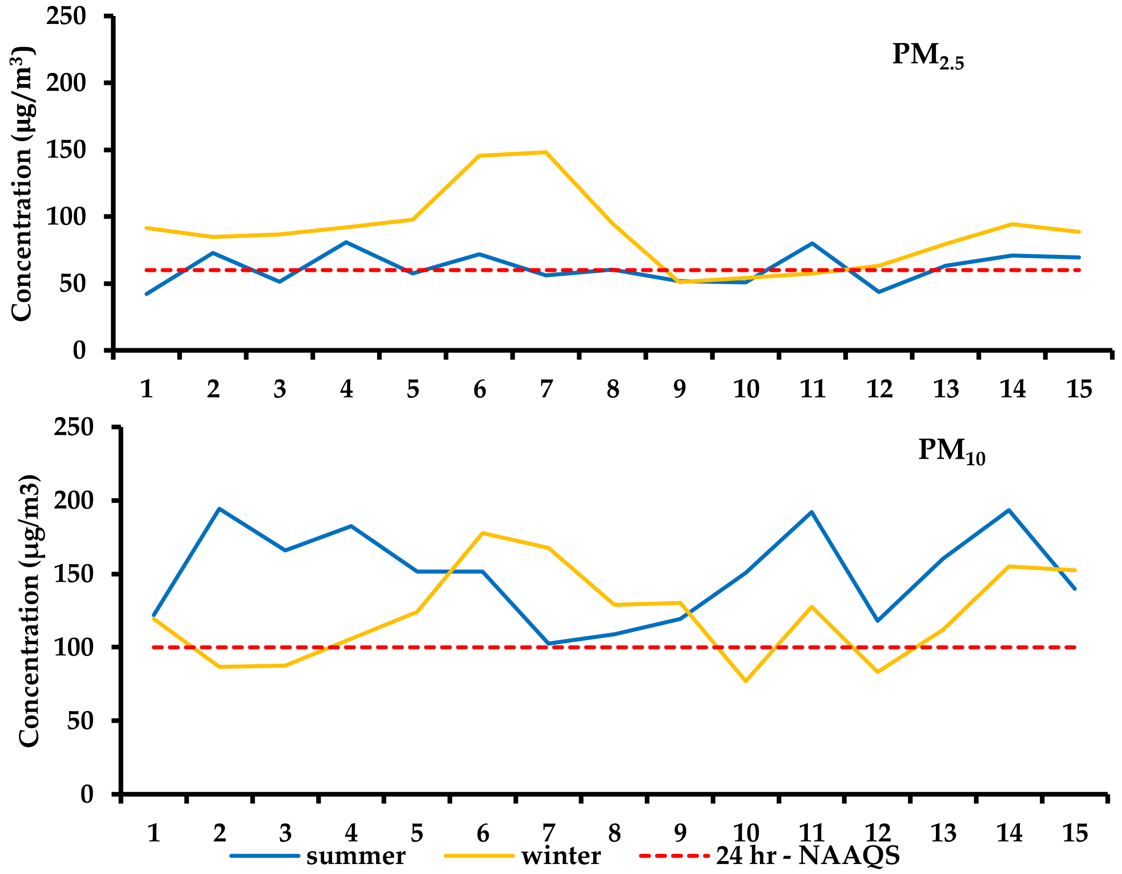


Figure 2.8: Variations of PM_{10} and $PM_{2.5}$ concentrations for different seasons at industrial location 1

2.3.7 Industrial location - 2

The trend of ambient PM_{10} and $PM_{2.5}$ concentrations at industrial location 2 is presented in Figure 2.9. It is evident that both PM_{10} and $PM_{2.5}$ levels during summer season were recorded within NAAQS limit. However, in contrast to summer season monitoring, ambient PM_{10} and $PM_{2.5}$ concentrations during winter season have remained above the NAAQS limit.

The recorded PM_{10} concentration ranged between 43 to 98 µg/m^3 (Mean 62nµg/m^3) and 123 to 295 µg/m^3 (Mean 192 µg/m^3) during the summer and winter period respectively. While, the recorded $PM_{2.5}$ concentration ranged between 23 to 44 µg/m^3 (Mean 33 µg/m^3) and 83 to 161 µg/m^3 (Mean 110µg/m^3) during summer and winter season respectively.

Regional sources from outside of city limits influence all locations in the city. Over and above these, high PM levels at this location can be attributed to vehicular movements, road dust generated due to movements of vehicle on dusty and industrial fuel combustion.

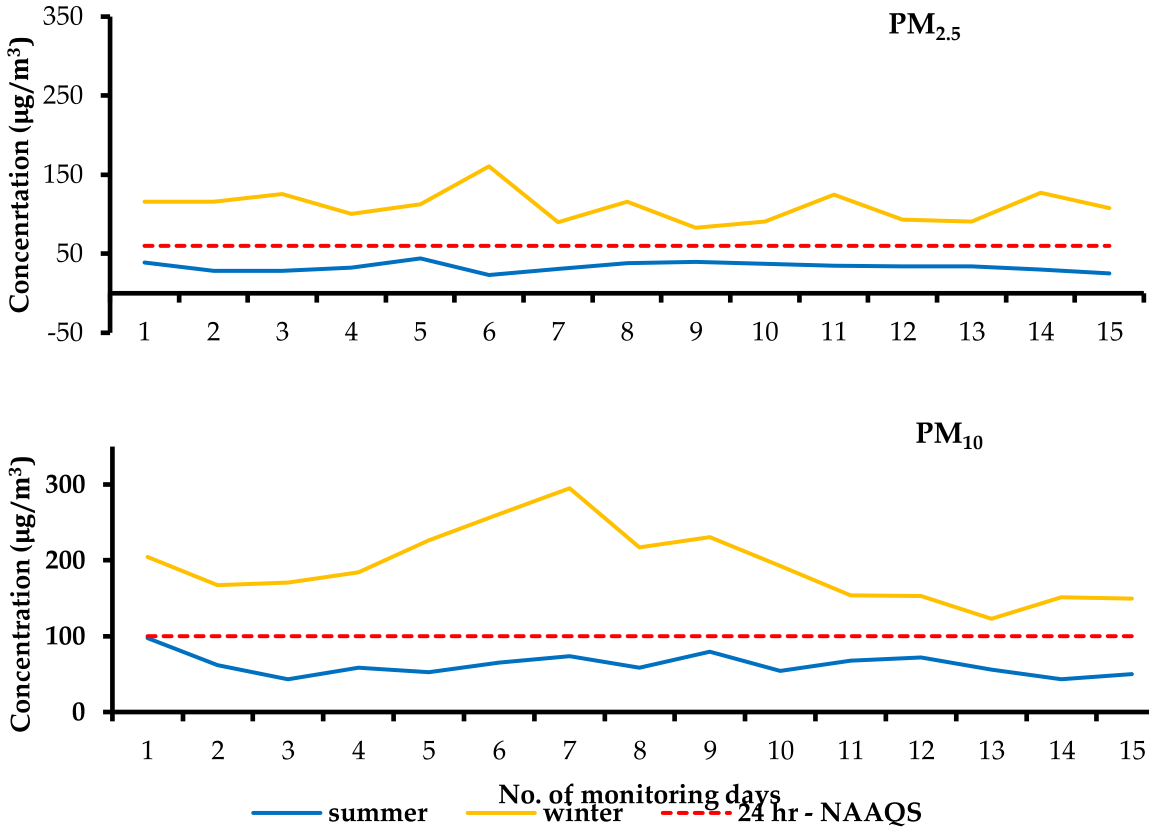


Figure 2.9: Variations of PM_{10} and $PM_{2.5}$ concentrations for both seasons at industrial location - 2

2.4 Overview of ambient air quality in Surat in winter and summer seasons

The average ambient concentration of PM_{10} across different locations varied between 55 to 150 µg/m³ and 122 to 207 µg/m³ during summer and winter season, respectively. Similarly, the average ambient concentration of $PM_{2.5}$ across different locations varied between 27 to 62 µg/m³ and 80 to 110 µg/m³ during summer and winter season, respectively. Irrespective of monitoring locations and seasons, the ambient concentration of PM_{10} and $PM_{2.5}$ during winter period were higher than 24-hr average National Ambient Air Quality Standards for PM_{10} and $PM_{2.5}$, respectively. However, during summer season the average ambient concentration of $PM_{2.5}$ across different locations were recorded below the prescribed limit. PM_{10} levels at four out of seven monitoring sites during summer period were also recorded within prescribed standard. This can be attributed the wind flows which vary significantly during summer and winter seasons. The wind direction during winters is from North-East direction which ensures comntributions from upwind regions from the high population density landmass of India. However, in summers the wind-direction reverses and the wind blows from South-West (from the sea-side) direction. This ensures lesser contributions form anthropogenic combustion based activities, and hence, low $PM_{2.5}$ concentrations are observed in summer, while PM_{10} remains high due to dusty sources

During summer season, the average ambient concentration of PM_{10} across different monitoring sites was approximately 0.56 to 1.51 times the NAAQS level. The average ambient concentration of $PM_{2.5}$ across different monitoring sites were found to be approximately 0.45 to 1.03 times the NAAQS limit. During winter period, the average ambient PM_{10} levels across different monitoring locations were approximately 1.22 to 2.07 times the NAAQS limit, whereas the average ambient $PM_{2.5}$ levels were approximately 1.33 to 1.83 times the NAAQS limit.

The ratio of $PM_{2.5}/PM_{10}$ varied between 0.4 to 0.6 at all monitoring sites during summer season and 0.5 to 0.7 during winter period. Higher ratio of $PM_{2.5}/PM_{10}$ during winter period indicated larger presence of combustion based sources from different activities. Moreover, lower ratio of $PM_{2.5}/PM_{10}$ during summer period could be attributed to enhanced contributions of dusty sources in the study region, which increase the coarser fraction of particulates ($PM_{2.5}$ and above) in the ambient air during this period.

Average ambient concentration of PM_{10} and $PM_{2.5}$ recorded across different monitoring sites during winter season were significantly higher compared to summer period. This could be attributed to relatively adverse meteorological conditions: lower wind speed, low temperature and low mixing heights; which does not allows the particles to disperse effectively. Additionally, the dominant wind direction during winters was observed to be from North-East which ensures atmospheric transport of pollution from distant upwind sources in the Indian landmass. Lower average ambient concentration of PM_{10} and $PM_{2.5}$ at all sampling sites during summer period could be attributed to higher wind speed, and enhanced vertical diffusion which causes faster dispersion and removal of pollutants (mostly fine particulates) emitted from polluting sources. Also, the wind direction during summers was dominantly from the seas side resulting in less contributions from combustive sources from the landmass. Table 2.2 shows the seasonal average $PM_{2.5}$ and PM_{10} concentrations at different locations in Surat.

Table 2.2: Seasonal average $PM_{2.5}$ and PM_{10} concentrations at different locations in Surat

Location	PM_{10} (µg/m³)		$PM_{2.5}$ (µg/m³)		Ratio ($PM_{2.5}/PM_{10}$)	
	Summer	Winter	Summer	Winter	Summer	Winter
Background (Dumas)	55	138	27	80	0.5	0.6
Commercial (SMC –Hospital)	140	207	58	106	0.4	0.5
Residential - 1 (Ram Nagar School)	129	139	49	85	0.4	0.6
Residential - 2 (SMC south zone office)	71	148	42	86	0.6	0.5
Kerbside (Kargil chowk)	87	158	47	107	0.5	0.7
Industrial - 1 (Colour test Ind. Pvt. Ltd.)	151	122	62	89	0.4	0.7
Industrial - 2 (Hoziwala industrial Association office)	62	192	33	110	0.5	0.6

Figure 2.10 shows the variation of PM_{10} concentrations at different locations in the two seasons. It is evident that commercial and industrial locations show highest concentrations of PM_{10}. In case of $PM_{2.5}$, kerbside location also show relatively higher values than other stations (Figure 2.11). This shows higher contributions of $PM_{2.5}$ fractions by vehicles at the location. The ratio of $PM_{2.5}/PM_{10}$ was also found to be highest for kerbside in winters depicting enhanced contribution of fine particulates from vehicles.

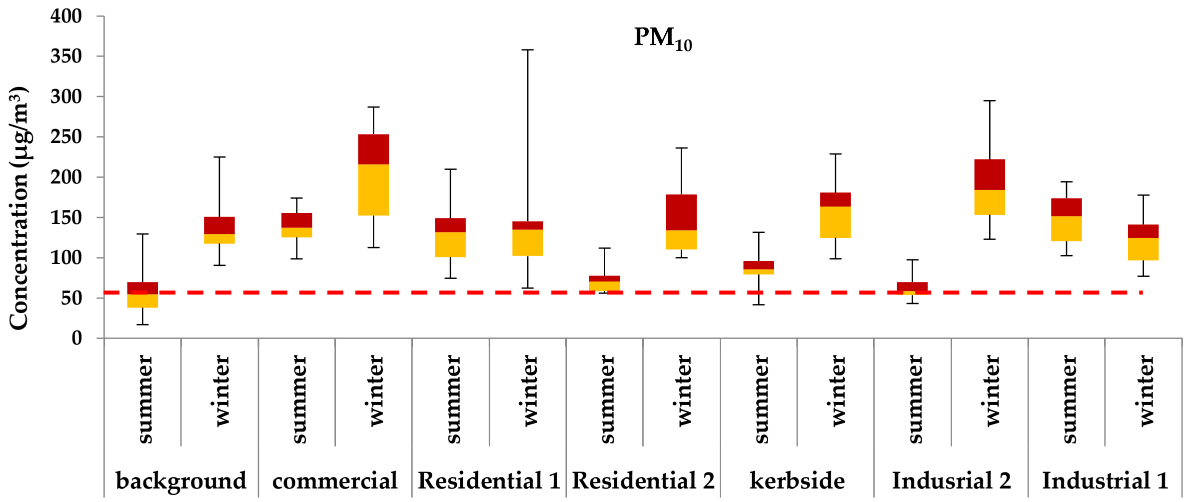


Figure 2.10: PM_{10} concentration at different monitoring locations in Surat during winter and summer season

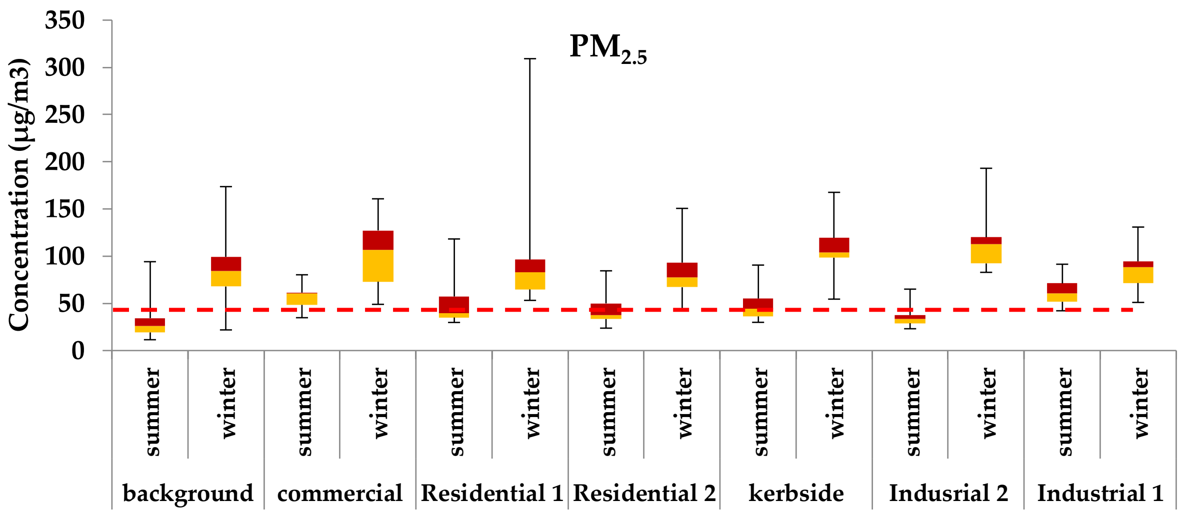


Figure 2.11: $PM_{2.5}$ concentration at different monitoring locations in Surat during winter and summer season

**Graphical representation of PM data set in the form of box-whisker plot is presented in Figure 2.10. Box-whisker plot consists of a "box" which goes from the first quartile (Q1) to the third quartile (Q3). The middle line within the box represents the median of dataset. The first quartile is the median of the lower half of the data set represents 25% of the numbers in the data set lie below Q1 and about 75% lie above Q1 whereas the third quartile, denoted by Q3, is the median of the upper half of the data set represents 75% of the numbers in the data set lie below Q3 and about 25% lie above Q3. The top whisker of the box goes from Q3 to the maximum value in the data set, and the bottom whisker goes from Q1 to the minimum value within dataset.*

CHEMICAL CHARACTERISATION OF PARTICULATE MATTER

3

Key Observations

- Primary particles are more attributable to local and nearby (urban scale) sources, while secondary particles generally take time to form and hence are attributed to long range transport.
- Elements were identified as the most abundant chemical constituents in ambient PM_{10} across all the monitoring locations during summer season. On the other side, ions were the most abundant chemical constituents in winter season.
- Irrespective of monitoring locations, Si, Al, Fe, Ca, Na and S were identified as the most dominating element species in ambient PM_{10} during summer and winter season, depicting significant contributions from dust and industrial sources.
- NH_4^+, Ca^{2+}, Na^+, Cl^-, SO_4^{2-} and NO_3^- were identified as the most dominating ionic species in ambient PM_{10} across different monitoring locations during summer and winter seasons, depicting significant contributions from chemically formed inorganic secondary particles from long range transport and sea salt.
- Ions were most dominating chemical constituents in ambient $PM_{2.5}$ samples across the monitoring locations during both summer and winter seasons. Elements were the second most dominating chemical species in ambient $PM_{2.5}$ among different monitoring locations during the summer season, while carbon was the second most dominating chemical species in ambient $PM_{2.5}$ during the winter season. Winter season shows higher shares of carbon depicting dominance of combustion based sources.
- Across all the monitoring locations Si, Al, Fe, Ca, Na, Cl and S were identified as the most dominating element species in ambient $PM_{2.5}$ during summer and winter season, depicting significant contributions from dust and industrial sources.
- The proportion of EC ranged between 12 to 47% and 25 to 35% of total carbon in PM_{10} amongst different monitoring locations during summer and winter seasons respectively. The proportion of EC ranged between 10 to 18% and 28 to 37% of total carbon in $PM_{2.5}$ amongst different monitoring locations during summer and winter seasons respectively. Higher shares of EC in winters show dominance of diesel and biomass based combustion, which is a rich source of elemental carbon emissions.

Chemical characteristics of ambient particulate matters depend on the size fractions, fuel compositions, technology of polluting sources and meteorological conditions including temperature, humidity, rainfall and wind speed. (*Police et al., 2016*). Chemical composition of particulate matter could provide useful information about the formation, ageing, reaction mechanism and the source they originate from. The ambient particulate matter collected on different filter media at seven different locations in Surat during both the seasons were analysed for their chemical characteristics. Composition of different ions, elements and carbon in ambient PM_{10} and $PM_{2.5}$ samples collected at different locations was analyzed following the methods described in Table 3.1. Detailed methodology of chemical characterization of ions, elements and carbon is provided in Annexure I.

Table 3.1: Details of chemical characterization processes followed to analyse concentrations of different elements, ions and carbon content in ambient samples of PM_{10} and $PM_{2.5}$

Component	Filter media	Analytical method
Elements Na, Mg, Al, Si, P, S, Cl, Ca, Br, V, Mn, Fe, Co, Ni, Cu, Zn, As, Ti, Ga, Rb, Y, Zr, Pd, Ag, In, Sn, La Se, Sr, Mo, Cr, Cd, Sb, Ba, Hg,	Teflon filter	Energy Dispersive X-Ray Fluorescence (ED-XRF) spectrometry (EDX 7000, Shimadzu, Japan)
Ions F^-, Cl^-, Br^-, NO_2^-, NO_3^-, SO_4^{-2}, K^+, NH_4^+, Na^+, Ca^{++}, Mg^{++}	Teflon filter	Ion chromatography (IC) system (ICSAquion, ThermoFischer Scientific)
Carbon Analysis (OC, EC & Total Carbon)	Quartz filter	Thermal/Optical Carbon Analyzer (DRI Model 2001A; Desert Research Institute, USA)

3.1 Chemical characterization of ambient PM_{10}

Chemical characterization of PM samples was done based on methodology presented in Annexure I. Analysis of data of chemical characteristics of PM_{10} samples collected from 7 different locations in Surat reveals several aspects of possible contributing sources.

The analysis shows that among the three broad components (carbon, ions and elements), elements were the most abundant chemical constituents in ambient PM_{10} across all the monitoring locations during summer season. Proportion of elements in the ambient PM_{10} at different monitoring locations during summer season followed this order: Residential – 1 (60%) > Residential – 2 (55%) > Kerbside (51%) > Industrial 2 (45%) = Industrial 2 (45%) > Background (36%) > Commercial (35%) (Figure 3.1). High elemental proportion among other chemical constituents at these locations could be attributed to presence of sea salt, industries, road dust and ongoing construction activities near the vicinity of monitoring sites. In addition, due to westerly wind direction in summers, trans-boundary movement of dust also expected to contribute to elemental mass of PM_{10} observed in Surat. However, in winters ions were found to be the most abundant chemical constituents in ambient PM_{10} at different monitoring locations. The proportion of ions in ambient PM_{10} samples was followed this order - Residential – 1 (50%) > Industrial 1 (44%) = Kerbside (44%) > Industrial

2 (41%) > Residential 2 (37%) > Background (36%) > Commercial (34%) in the Surat city during winter season (Figure 3.1). Higher ion proportion during the winter period could be attributed to long range contributions from secondary aerosol formation, sea salts and secondary contributions from local sources such as industries and vehicles. The proportion of carbon varied between 7 and 31% at different locations during summer season, with the highest fraction (31%) observed at commercial location. This can be attributed combustion based sources such as vehicles, DG sets in the commercial area, and refuse burning, biomass use, and industries in the upwind. During winter season, the proportion of carbon varied between 23 and 34%, with highest fraction observed at Background location, because of coal combustion in upwind industries, burning of biomass based fuels in households and also due to tandoors (restaurants and dhabas) and small eateries surrounding the location,. However, this is to be noted that total concentrations of PM_{10} and carbon were low at background site in absolute terms. A total chemical mass of 6 to 13% and 7 to 17% remained unidentified during summer and winter season respectively across the monitoring locations.

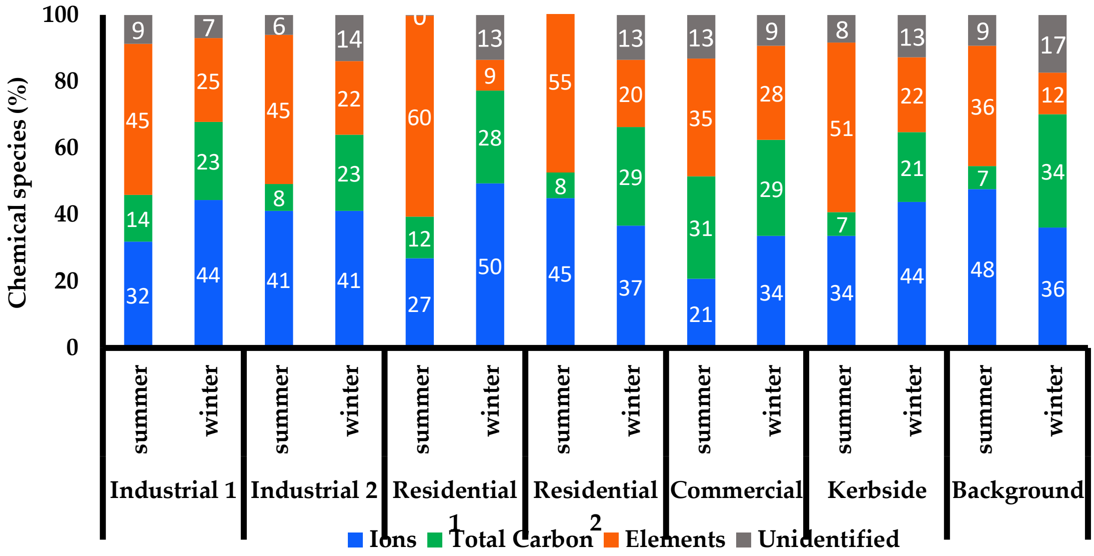


Figure 3.1: Seasonal variation in chemical characterization of ambient PM_{10} at seven monitoring locations

**The unidentified portion (reconstructed mass under estimated gravimetric mass showed as less than 100%), which includes organic matter associated with organic carbon, oxygen associated with the oxides of metals and other unidentified species which are not analysed. This discrepancy could also be attributed to some loss of organic compounds due to volatilization. On the other hand, the unidentified (reconstructed mass over estimated gravimetric mass showed as exceeding 100%) may be attributed to measurement errors, missing sources, and/or particle bound water.*

3.1.1 Elements

Si, Al, Fe, Ca, Na and S were identified as the most dominating element species in ambient PM_{10} across different monitoring locations during summer and winter seasons (Figure 3.2). Presence of several other elemental species was detected in trace amounts during both seasons. Irrespective of monitoring locations, Al, Si and Ca were identified as the most abundant elemental component in ambient PM_{10} during both summer and winter seasons. This could be attributed to dust generated from wind-blown soil, sea salt, road dust along with on-going construction activities. The proportion of Si in ambient PM_{10} at different sampling locations followed this order: Commercial (44%) > Background (38%) > Industrial 1 (33%) > Industrial 2 (31%) > Residential – 1 (30%) > Kerbside (24%) > Residential – 2 (18%), during the summer season. Other than dusty sources, coal contains free crystalline silica in the form of quartz (SiO_2), which when burnt in power plant and industries, becomes the part of fly ash. While high levels of Si were observed across the city, even higher Si levels at the commercial location may be attributed to local dust generated by wind-blown soil and vehicles moving on road, on-going construction activities, and combustion of coal in tandoors (restaurants and dhabas). The proportion of Al as an element among all others varied between 10 and 21% during summer season, with highest fraction (21%) was recorded at Residential-1 location. High Al concentrations can be again be attributed to dust generated from wind blow soil, construction, and road dust re-suspension. In addition, Alumina is a dominant part of flyash generated by coal combustion possibly in industries, power plants, tandoors (restaurants and dhabas) , small eateries surrounding the monitoring locations, and also from long range atmospheric transport. Further, Ca and Fe elements were identified as the second most abundant elemental components in ambient PM_{10} during both summer and winter seasons. These can be attributed to presence of dust generated from wind-blown soil, road, and construction activities near to this location. The proportion of Ca varied between 10- 21% during summer season, whereas between 5-25% during winter. Similarly, the proportion of Fe in ambient PM_{10} across different sampling locations varied between 5- 16% during summer season and between 7- 30% during winter season. Sulhpur (S) was observed to be dominating in ambient PM_{10} during winter season, with highest contribution (39%) recorded at Residential-1 location. The presence of S could be attributable to combustion of coal in industries, tandoors (restaurants and dhabas) and small eateries as local sources surrounding different locations. In addition, urban and regional scale industrial coal combustion will also contribute to S element concentrations at different locations. Furthermore, Na and Cl were also found in the ambient PM_{10} during summer season, which could be attributed to presence of air borne sea salt possibly coming from the local beach through winds. In summers, wind direction from the sea side ensures contribution of salt in the PM samples.

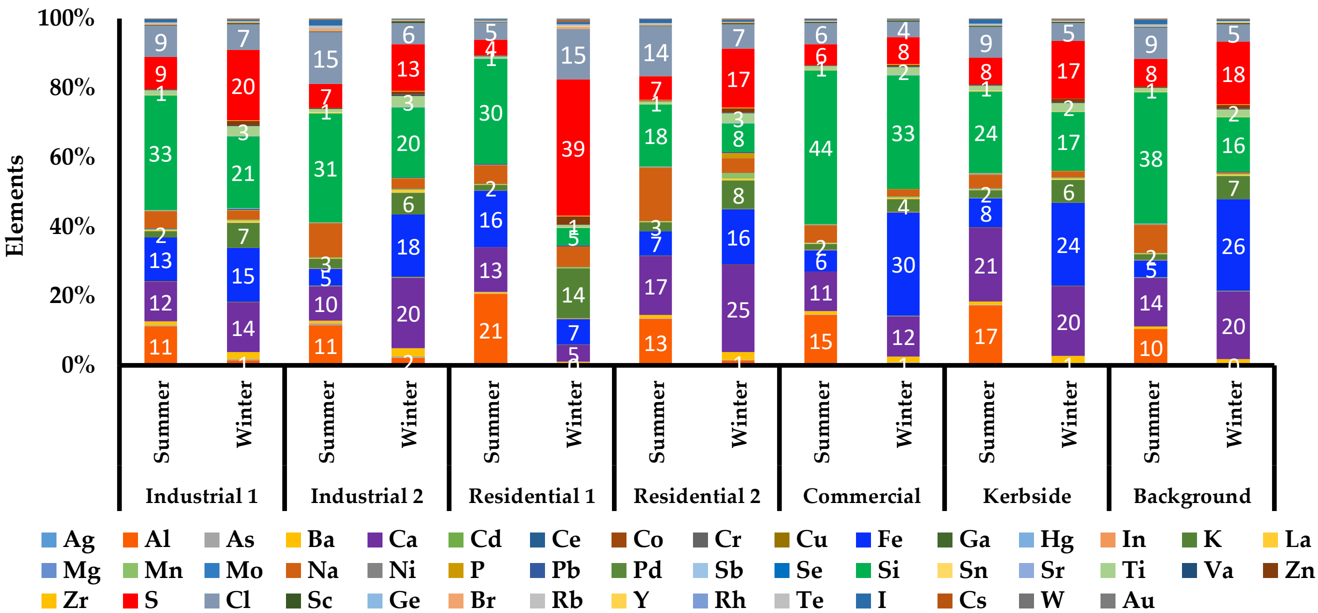


Figure 3.2: Seasonal variation in shares of various elements in ambient PM_{10} concentrations at seven monitoring locations in Surat

3.1.2 Ions

NH_4^+, Ca^{2+}, Na^+, Cl^-, SO_4^{2-} and NO_3^- were identified as the most dominating ionic species in ambient PM_{10} across different monitoring locations during both summer and winter seasons. The proportion of NH_4^+ in ambient PM_{10} varied between 23-41% during summer season, with highest contribution (41%) recorded at the Commercial location. Higher share of NH_4^+ at this location is because of contributions from long range transport of secondary aerosol particles, and also due to secondary contributions from local sources located in the upwind direction. Similarly, during winter season monitoring, proportion of NH_4^+ in ionic part of ambient PM_{10} varied between 41 -50%, with highest contribution was recorded at the Background location. Higher share of NH_4^+ at background location points towards significant contributions of inorganic secondary particulate formed by chemistry of ammonia, sulphur dioxide and oxides of nitrogen. The proportion of SO_4^{2-} varied between 17 and 36% during summer season, with highest fraction (36%) was observed at commercial location. While, during winter season proportion of SO_4^{2-} varied between 23 and 28%, with highest contribution (28%) was observed at industrial-1 location. The presence of SO_4^- at commercial location could be attributed to combustion of sulphur containing coal in restaurants, dhabas, and small eateries surrounding the region and also due to combustion of diesel and gasoline fuel in vehicles (although sulphur content in automotive fuels has been reduced considerably). In addition, long range transport of secondary sulphates from the upwind industrial based sources could have also contributed to S concentrations at this location. Presence of SO_4^- at industrial-1 location is mainly because of combustion of coal in industries. Proportion of NO_3^- remained higher during winter season compared to summer period, mainly due to lower temperatures in winters which enhance nitrate formation. Higher proportion of NO_3^- at some locations in winters could also be attributed to secondary aerosol formation due to gasoline and diesel combustion in automobiles and high temperature fuel combustion in industries/power plants in the upwind regions.

In winter, the molar ratio of NH_4^+ and $SO_4^{2-}$was>1. This suggests that in addition to $(NH_4)_2SO_4$, NH_4NO_3 is also formed due low temperatures and excess amount of atmospheric NH_4^+. Ambient NH_3 concentrations play an important role in the formation of secondary particles in and around Surat city.

Proportion of Ca^{2+} in ambient PM_{10} concentrations varied between 7-15% and 3-8% during summer and winter seasons, respectively. The presence of Ca^{2+} in ambient PM_{10} is possibly due to dust generated from wind-blown soil, roads and on-going construction activities surrounding the region. Higher shares in summers also indicate the contribution of widn blown dust with higher wind speeds in the season. On the other hand, the proportion of Cl^- in ambient PM_{10} was between 7-24% and 4-6% during summer and winter seasons. While, the proportion of Na^+ varied between 5 and 11% during summer season. Higher contribution of Na^+ and Cl^- during summer season could be attributed to sea salt containing particles coming from sea side.

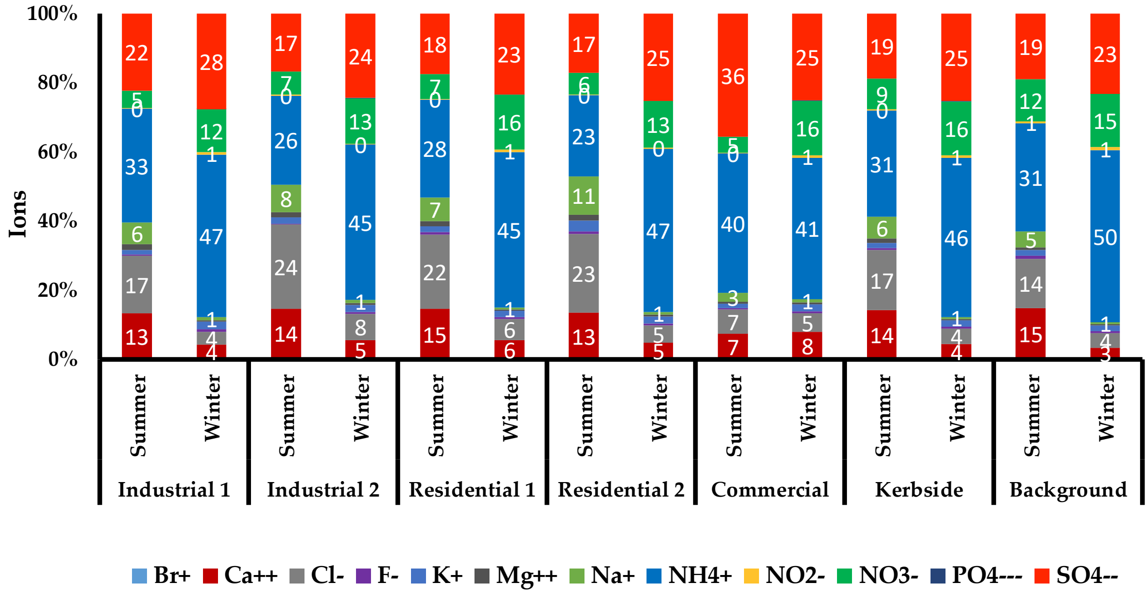


Figure 3.3: Seasonal variation in ionic composition of ambient PM_{10} at different monitoring locations in Surat

3.1.3 Carbon (Elemental and Organic)

In the total carbon concentrations observed at different monitoring stations, the share of organic carbon (OC) dominates over elemental carbon (EC). The proportion of EC ranged between 12 to 47% and 25 to 35% of total carbon in PM_{10} at different monitoring locations during summer and winter seasons respectively (Figure 3.4). Lowest proportion of OC in ambient PM_{10} was recorded at the commercial (53%) location and industrial-2 (69%) location during summer and winter seasons, respectively. Local sources of elemental carbon are vehicles, industries, biomass burning, refuse burning which emit elemental carbon in significant shares along with organic carbon.

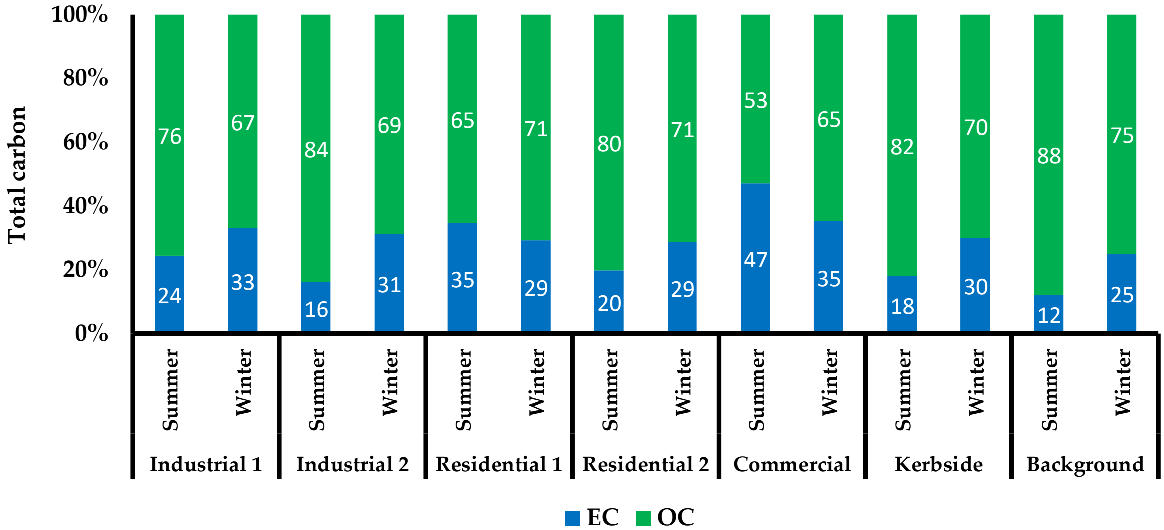


Figure 3.4: Seasonal variation of different fractions of carbon in ambient PM_{10} at different monitoring locations in Surat

3.2 Chemical characterization of ambient $PM_{2.5}$

Ions were the most dominating chemical constituents in ambient $PM_{2.5}$ samples across the monitoring locations during both summer and winter seasons. The proportion of ions in the ambient $PM_{2.5}$ at different monitoring locations followed the order: Residential -2 (51%) > Industrial-2 (39%) > Industrial-1 (33%) = Residential – 1 (33%) = Kerbside (33%) > Commercial (31%) = Background (31%) during summer season and Residential-1 (52%) > Industrial-1 (49%) > Residential-2 (48%) > Kerbside (46%) > Industrial– 2 (44%) > Commercial (44%) > Background (42%) during winter season (Figure 3.5). Higher ionic fraction amongst chemical constituents during winter season is because of higher nitrate particulate formation. On the other hand, elements were the second most dominating chemical species in ambient $PM_{2.5}$ among different monitoring locations during the summer season. Carbon was the second most dominating chemical species in ambient $PM_{2.5}$ during the winter season depicting higher shared of combustion based sources. Higher elemental proportion in ambient $PM_{2.5}$ during summer season can be attributed to flyash, road dust and ongoing construction activities near the vicinity of monitoring site. Higher carbon fraction observed during winter season is attributable to tailpipe emission from vehicles and use of DG sets in the commercial area.

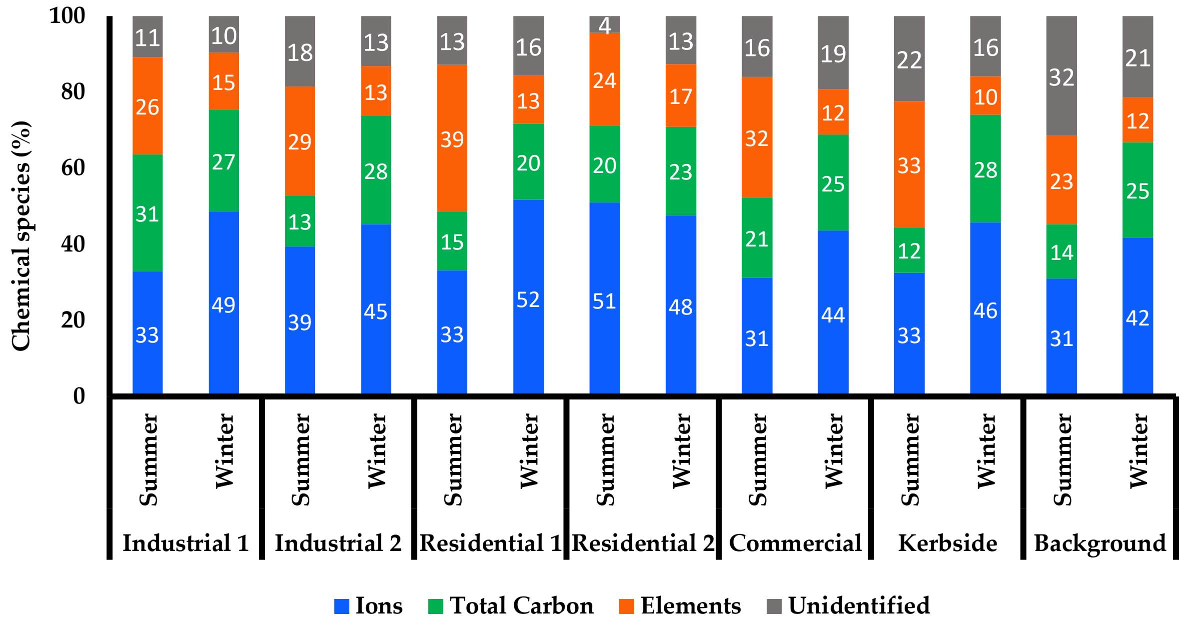


Figure 3.5: Seasonal variations in chemical characterization of ambient $PM_{2.5}$ at different monitoring locations

Proportion of elements in ambient $PM_{2.5}$ amongst different monitoring locations followed this order: Residential – 1 (39%) > Kerbside (33%) > Commercial (32%) > Industrial-2 (29%) > Industrial-1 (26%) > Residential-2 (24%) > Background (23%) during the summer season. Further, highest proportion of carbon fraction in ambient $PM_{2.5}$ was recorded at the Industrial-1 location (31%) during summer season. On the other hand, during winter season monitoring highest proportion of carbon fraction in ambient $PM_{2.5}$ was recorded at Kerbside location (28%) and Industrial-2 location (28%) respectively (Figure 3.5). Moreover, a total chemical mass of 4 to 32% and 10 to 21% remained unidentified during summer and winter season respectively across the monitoring locations.

3.2.1 Elements

Like in case of PM_{10}, Si, Al, Fe, Ca, Na, Cl and S were identified as the most dominating element species in ambient $PM_{2.5}$ across respective monitoring locations during both summer and winter season. Irrespective of monitoring locations, Al, Si and Ca were identified as the most abundant elemental component in ambient PM_{10} during both summer and winter seasons. This can be attributed to dust generated from flyash, wind-blown soil, road dust, and construction activities. Other than locally generated dust, long range transport of dust is possibly a source contributing to higher concentrations of these elements. The proportion of Si in ambient $PM_{2.5}$ varied between 22-43% during summer season, with higher contribution (43%) was observed at Residential-1 location. This could partially be because of local dust generating activities on roads and construction activities. The proportion of Ca varied between 7-12% during summer season; whereas between 5-7% during winter season. Similarly, the proportion of Fe in ambient $PM_{2.5}$ across different sampling locations varied between 6-26% during summer season; whereas found to be between 9-11% during winter season. The presence of Ca and Fe in ambient $PM_{2.5}$ can be attributed to the presence of dusty sources both near and distant to this location.

Sulphur was identified as the most abundant element in ambient $PM_{2.5}$ during winter season, with highest contribution (43%) was recorded at Residential-1 and Kerbside location. The presence of S at Residential-1 location could be because of combustion of coal in tandoors (restaurants and dhabas) and small eateries surrounding the location. Whereas, the presence of S at Kerbside location could be attributed to combustion of gasoline and diesel fuel due to vehicular movement. In addition, long range transport of secondary sulphates from upwind industrial/power plant based sources can also add to S concentrations.

Na and Cl were also found in the ambient $PM_{2.5}$ during summer season which could be attributed to presence of sea salts attributable to nearby sea coast with the wind direction from the same side. In addition, Chloride is an indicator of waste burning, and along with 'K' becomes a good indicator of biomass burning too.

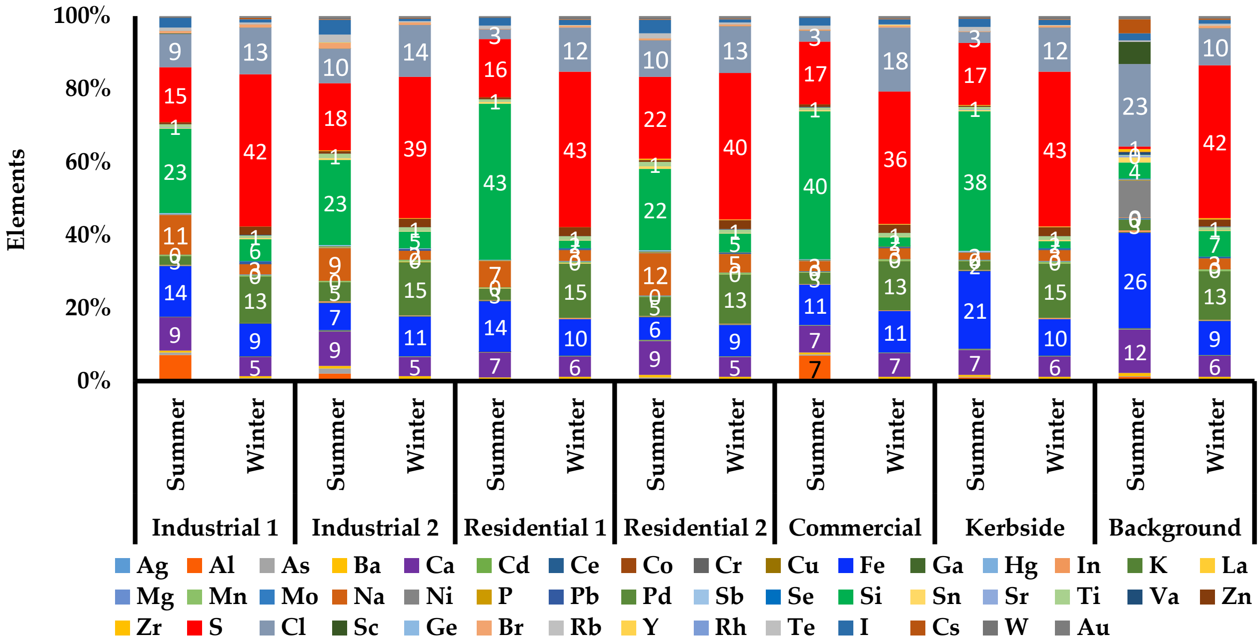


Figure 3.6: Seasonal variation in speciation of elements in ambient $PM_{2.5}$ at different monitoring locations in Surat

3.2.2 Ions

NH_4^+, Ca^{2+}, Na^+, Cl^-, SO_4^{2-} and NO_3^- were identified as the most dominating ionic species in ambient $PM_{2.5}$ across different monitoring locations during both summer and winter seasons. The proportion of NH_4^+ in ambient $PM_{2.5}$ varied between 37-42% during summer season, with highest contribution (42%) was recorded at the Background location. This indicates long range transport of secondary particulates towards the city. Ammonia is generally released from fertilizer use, livestock, drains etc and generally found to be higher outside of cities. It forms secondary particulates after going through a series of reactions involving SO2 and NOx, which are released by several regional scale sources like industries, power plants, vehicles etc. Similarly, during winter season monitoring, proportion of NH_4^+ in ambient $PM_{2.5}$ varied between 47-52%. Consistent presence of NH_4^+ at all the locations indicates towards widespread contribution of secondary inorganic particles mainly from outside of the city limits.

Proportion of SO_4^{2-} varied between 23-29% during summer season, with highest fraction (29%) observed at industrial-1 location. During winter season, the proportion of SO_4^{2-} varied between 24-32%, with highest contribution (32%) were observed at industrial-1. Highest fraction of SO_4^- at industrial-1 location could be attributed to combustion of coal and other sulphur containing fuels in the industries at local and regional scales. Proportion of NO_3^- remained higher during winter season compared to summer period. Higher proportion of NO_3^- at commercial and kerbside locations could be attributed to secondary aerosol formation due to gasoline and diesel combustion in automobiles, industries at both urban and regional scales.

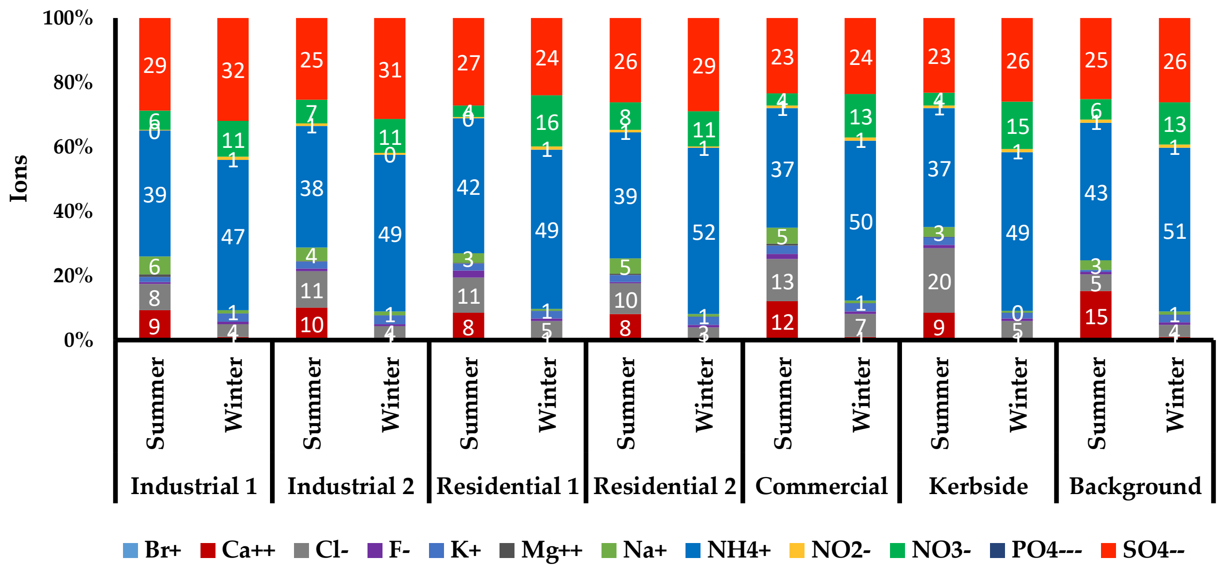


Figure 3.7: Seasonal variation in ionic composition of ambient $PM_{2.5}$ at different monitoring locations

In winter, the molar ratio of NH_4^+ and $SO_4^{2-}$was >1, owing to the fact that NH_4NO_3 is also formed in addition to $(NH_4)_2SO_4$, due to lower temperatures and excess atmospheric NH_4^+. Thus ambient NH_3 concentrations play a very important role in the formation of secondary particles in and around the Surat city.

Proportion of Ca^{2+} in ambient $PM_{2.5}$ ranged between 8%-15% during summer season. On the other hand, the proportion of Cl^- in ambient $PM_{2.5}$ ranged between 8-20% during summer season. The presence of Ca^{2+} in ambient $PM_{2.5}$ is indicative of the dusty sources in the surrounding region. Also, the proportion of Na^+ varied between 3%-6% during summer season. Thus, the higher contribution of Na^+ and Cl^- during summer season could be attributed to sea salt containing particles coming from local sea-side.

3.2.3 Carbon (Elemental and Organic)

Organic carbon had a larger share in overall total carbon mass in $PM_{2.5}$ across all locations. The proportion of EC ranged between 10 to 18% and 28 to 36% of total carbon in $PM_{2.5}$ amongst different monitoring locations during summer and winter seasons, respectively (Figure 3.4). High shares of EC in winters indicate contributions from combustive sources such as diesel vehicles, biomass burning etc (which are rich sources of elemental carbon). Lowest proportion of OC in ambient $PM_{2.5}$ was recorded at Residential-2 (81%) location and industrial-1 (64%) location during summer and winter seasons, respectively. Among different monitoring sites, the highest EC/OC ratio in ambient $PM_{2.5}$ was recorded at Commercial location, indicating combustion of diesel fuel in automobiles or use of diesel generators, biomass/refuse burning sources, which show high EC to OC ratios in their emissions.

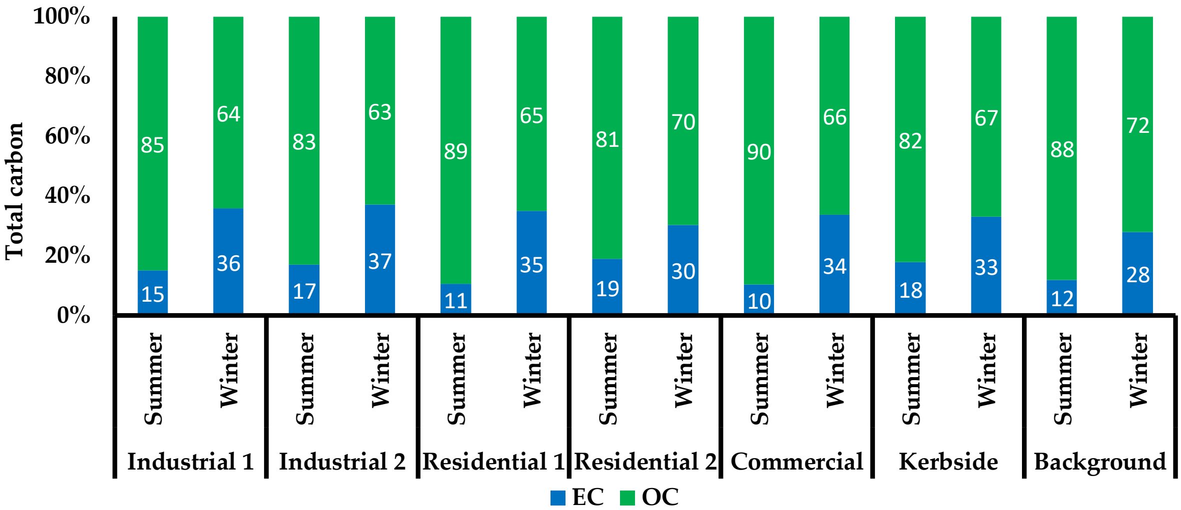


Figure 3.8: Seasonal variation of different fractions of carbon in ambient $PM_{2.5}$ at different monitoring locations

Chemical characteristics indicate towards the possible sources of PM_{10} and $PM_{2.5}$. However, in order to quantify the contributions of different sources to prevailing concentrations, these chemical characteristics are fed into a receptor model along with source profiles. Receptor models make use of these markers and provide source contribution estimates for all possible contributing sources.

SOURCE APPORTIONMENT OF AMBIENT PARTICULATE MATTER USING RECEPTOR MODEL

4

Key observations

- Dust generated from road dust, soil and construction (were estimated as the major sources of ambient $PM_{2.5}$ with contribution in the range of 27%-38% and PM_{10} contribution in the range of 33%-59% at different monitoring locations in the city during summer season and is followed by industries.
- Share of sea salt was estimated at all the locations during summer season for both ambient PM_{10} (1-13%) and $PM_{2.5}$ (2-9%) levels due to the proximity to sea.
- Contribution from transport (3-6%) and residential (4-24%) sectors to the $PM_{2.5}$ levels in summer season was found to be higher than the corresponding contribution to PM_{10} {transport (1-3%), residential (2-7%)}
- Industries (34%) are the major contributor to the ambient PM_{10} levels during winters followed by secondary particulates (28%); both are also contributing significantly to ambient $PM_{2.5}$ levels {secondary particulates (32%), industries (27%)}
- Contribution from transport sector was found to be higher in winter than in summers for both PM_{10} and $PM_{2.5}$.Transport sector contributes more to the ambient $PM_{2.5}$ levels than PM_{10} because emissions from tail pipe of vehicles have higher shares of finer fractions.

4.1 Introduction

Receptor modeling approaches have also been termed as "top down approach". These are statistical procedures that compare the profiles of gases and particles (chemical and physical characteristics) at sources (known as source profiles) and receptors (location of monitoring) in a given area to estimate the source contributions at receptor locations.

Receptor models work on the principle of mass conservation which can be used to identify and apportion sources of airborne particulate matter in the atmosphere. The input data set for receptor modelling are the large number of chemical constituents of PM concentrations in a number of samples. Receptor models use monitored pollutant concentration and their chemical composition, along with source profiles of the local air pollution sources to estimate the relative contributions of these sources on pollutant concentrations at any single monitoring location. Receptor models are retrospective, that is, they can only assess the impacts of air pollution source categories on pollutant concentrations that have already been monitored.

This approach infers source contributions by determining the best fit linear combination of emission source chemical composition profiles needed to reconstruct the measured chemical composition of ambient samples (Watson et al., 1984).

The framework for using receptor models consists of;

- Formulating a conceptual model;
- Identifying potential sources contributing to PM concentrations;
- Chemically characterizing source profiles based on literature review or developing study-specific profile;
- Obtaining and analyzing PM samples for major components (Ions, elements and organic compounds) and source markers;
- Estimating uncertainties associated with sampling and analysis different constituents of PM
- Confirming source types with receptor models;
- Quantifying source contributions with the chemical mass balance (CMB) model;
- Various diagnostic checks performed for each model run to ensure reliability of the modelled results.

Chemical Mass Balance (CMB) model (ver 8.2) was used in this study to determine different source contributions at individual monitoring locations.

4.2 Chemical Mass Balance model

Chemical Mass Balance (CMB) is a USEPA approved model which uses source profiles and speciated ambient data to quantify source contributions. Contributions are quantified from chemically distinct source-types rather than from individual emitters.

The CMB receptor model consists of a solution to linear equations that express each receptor chemical concentration as a linear sum of products of source profile abundances and source contributions.

The basic equation (eq. 1) of the CMB model as a statement of species conservation has been given by Watson et al., 1984:

$$\boldsymbol{Ci} = \sum_{j=1}^{m} \boldsymbol{f}_{ij} \boldsymbol{S}_j + \boldsymbol{e}_i \qquad \text{…. } eq.\ \boldsymbol{1}$$

where, Ci is the ambient concentration of species i; f, the fraction of species i in source j; Sj, the source contribution of source j; and, ei, for errors.
The major assumptions applicable in case of the CMB model are;

- Compositions of source emissions are constant over the period of ambient and source sampling;
- Chemical species do not react with each other (i.e. they add linearly);
- All sources with a potential for contributing to the receptor have been identified and have had their emissions characterized;
- The number of sources or source categories is less than or equal to the number of species;
- The source profiles are linearly independent of each other; and
- Measurement uncertainties are random, uncorrelated, and normally distributed.

Receptor models do not use pollutant emissions from different sources, meteorological data and atmospheric chemical transformation to simulate the contribution of different sources to receptor concentration of pollutants, unlike dispersion air quality models (USEPA, 2007).

The key steps followed to carry out CMB modelling in this study were,

- Identification of the contributing sources to the monitoring sites.
- Selection of chemical species to be included in the calculation. Various chemical species were analyzed from the PM_{10} and $PM_{2.5}$ samples collected at seven sites in summer and winter seasons.
- Selection of representative source profiles based on the source activities around the sites and also considering regional scale sources that may impact the PM concentrations at receptor locations. Details of source profiles selected and used for CMB analysis are as follows:
  a. Non-vehicular sources:
     - Study-specific road dust profile was developed for CMB analysis.
     - Refuse burning and Soil (Source: TERI & ARAI (2018)).
     - Profiles developed by IIT-Bombay (CPCB, 2009)
       - Biomass burning
       - Construction
       - Industry

  b. Vehicular Source Profiles:
     - New composite profiles of different fuel types developed for newer technology vehicles (post 2005) (TERI & ARAI (2018)).
     - Earlier profiles of pre-2005 vehicle technology. (CPCB, 2009)
- Daily average concentrations of different chemical species at seven monitoring sites in Surat city were used as an input to the receptor model, along with source profiles.
- Solution of the chemical mass balance equations was obtained through CMB-8.2 receptor model.
- Contribution of sources was finalized by averaging the daily contribution observed across the monitoring period of different sites.
- Thereafter, the results for different sites were averaged for the city of Surat for deriving city level average results of source apportionment.

Source contribution estimates (SCE) are the main output of the CMB model. The sum of SCE for different sources approximates the total mass concentrations. When SCE is less than its standard error, the source contribution cannot be considered reliable. There are various diagnostic checks performed for each model run to ensure reliability of the modelled results. These include t-statistics (source contribution divided by error of source contribution), chi-square test, regression coefficient, and percentage mass explained by the model. USEPA has set standard range for each of these diagnostic measures. The reduced Chi square (χ^2), coefficient of determination (R^2), and percent mass are goodness of fit measures for the least-squares calculation. The χ^2 is the weighted sum of squares of the differences between calculated and measured fitting species concentrations divided by the effective variance and the degrees of freedom. A value of less than one indicates a very good fit to the data. Values greater than 4 indicate that one or more of the fitting species concentrations are not well-explained by the source contribution estimates. χ^2 values less than 4 were considered acceptable. R^2 is determined by the linear regression of the measured versus model-calculated values for the fitting species. R^2 ranges from 0 to 1. The closer the value is to 1.0, the better the SCEs explain the measured concentrations. When R^2 is less than 0.8, the SCEs do not explain the observations very well with the given source profiles. Value of $R^2 \geq 0.8$ was considered acceptable. Along with these, the ratio of the sum of model-calculated SCEs to the measured mass concentration(C/M) and the ratio of residuals to uncertainty (R/U ratio) are checked, which are evaluated for each of the species while running the model. Values ranging from 80 to 120% were considered acceptable for C/M. While the receptor modelling is carried out, the results were finalized only after assuring that all the performance criteria are satisfactorily met.
The SCE estimation of ambient particulate matter using the CMB model at different monitoring locations during the two seasons are presented in following sections,

4.3 Estimation of seasonal variations of sources contributions to ambient particulate matter

In this study, the results of receptor modeling using CMB model show source contributions of industry/power plants, residential biomass burning, vehicles, agricultural burning, sea-salt, dust (wind-blown soil, road dust, construction), refuse burning and secondary particulates. It is to be noted that receptor model is not able to further apportion the sources of secondary particulates, which is being done by the dispersion model in next chapter. Also, receptor model only shows the contribution of different sources but does not specify the geographical locations of the source. The contributions geographically could range from very close vicinity of the station to far off distant sources (in the city, district, or international boundaries) in the upwind direction.

A comparative analysis of source contribution results for different monitoring sites have been discussed for PM_{10} and $PM_{2.5}$ fractions.

4.3.1 Seasonal variations of sources of ambient PM_{10} at different monitoring locations

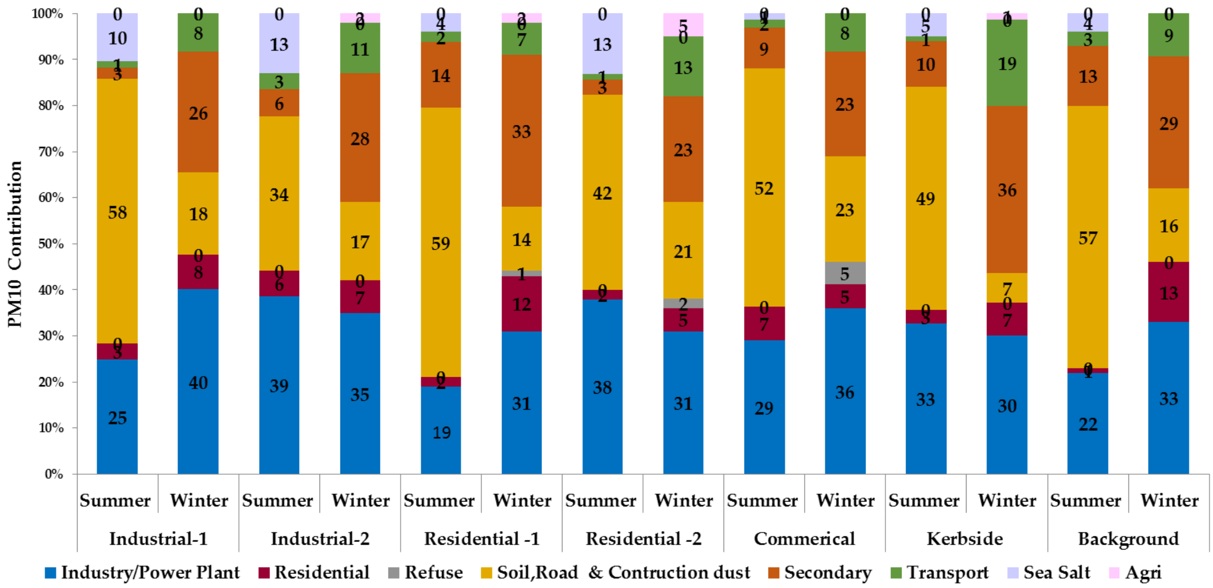


Figure 4.1: Estimated contributions of different sources to ambient PM_{10} at different monitoring locations during the two season

Summers and winters show differences in contributions of sources towards prevailing PM_{10} levels. In both the seasons, contributions are made by various regional and local sources. Summers show a dominance of dusty sources, while secondary particulates show higher contributions in winters (Figure 4.1). Higher nitrate formation during winters leads to enhanced contribution of secondary particulates in the season. Also, higher wind speeds in summers causes increased re-suspension of soil dust, and dust from construction activities. Higher wind speeds also lead to reduced contribution of local sources (e.g. vehicles) and increased influence of regional scale sources like industries, and secondary particulates.

Dust (soil, road dust, and construction) was estimated as the major source of ambient PM_{10} at different monitoring locations in the Surat city, especially in summer seasons as its contribution ranged from 33 to 59%. The dust contribution was observed to be maximum at residential location-1 because of construction activities in the nearby vicinity of this location. Dust was found to contribute 57% and 16% to ambient PM_{10} during summer and winter seasons, respectively at the background location. Due to proximity to sea (emissions of sea salt), and also possible contributions from long range dust transport from international boundaries, dust contribution is found to be high in Surat during summers. This was more pronounced at the background location, depicting the atmospheric transport from outside of city limits.

Secondary particulates were found to contribute quite consistently over the city between 3-14% in summers and 23-36% in winters. Contributions of secondary particulates were estimated somewhat higher at the kerbside location (36%), followed by the residential location-1 (33%) and industrial location-2 (28%) during winters season. Higher contributions of secondary particulates in winters are due to higher nitrate formations at lower temperatures and also lesser dispersion. In addition, the wind direction in Surat during winters is from North-East which leads to significant regional contributions from upwind landmass of state of Gujarat and rest of India.

Industrial and power plant based sources contribute quite significantly to PM_{10} concentrations in Surat varying between 19-39% in summers and 30-40% in winters at different locations. Depending on the wind direction, highest contribution of industry/power plant to ambient PM_{10} was estimated at the Industrial location – 1 (40%) in winters and Industrial location – 2 (39%) in the summer season.

The share of transport sector was found to be more (7-19%) in winters and comparatively less in summers (1-3%). Higher contributions in winters can be attributed to low wind speeds (helping higher shares of local sources) and North-east wind direction with higher contributions from upwind landmass, while in summers the wind blows mainly from the sea-side (South-west) reducing anthropogenic contributions. Please note this share does not include secondary particulates contributed by vehicles in the form of nitrates. Among different monitoring locations, as expected highest contribution to ambient PM_{10} from the transport sector was estimated at the kerbside location (19%), followed by the residential location-2 (13%) and industrial location -2 (11%) locations during the winter season. Higher nitrate formation from the NO_x released by vehicular sources contributes more to secondary particulates during winters.

Biomass burning/residential was estimated to contribute to ambient PM_{10} more in winters (7%) than in summer seasons (4%). About 5-12% of contributions have been observed at the 6 stations within the city indicating effect of local and regional scale pollution during winner season.

The highest contribution to the ambient PM_{10} from refuse burning was observed at commercial location (5%) during winter season. The average of six locations in the city of Surat contributes to 1% and 2% from refuse and agriculture burning sectors, respectively, during winter season.

Contribution to ambient PM_{10} concentrations from sea salt is also observed during summer season which ranges from 1-13% among six different monitoring locations. Contributions were significant in summers as the dominant wind direction (South-west) was found to be from sea-side only.

4.3.2 Seasonal variations of sources of ambient $PM_{2.5}$ at different monitoring locations

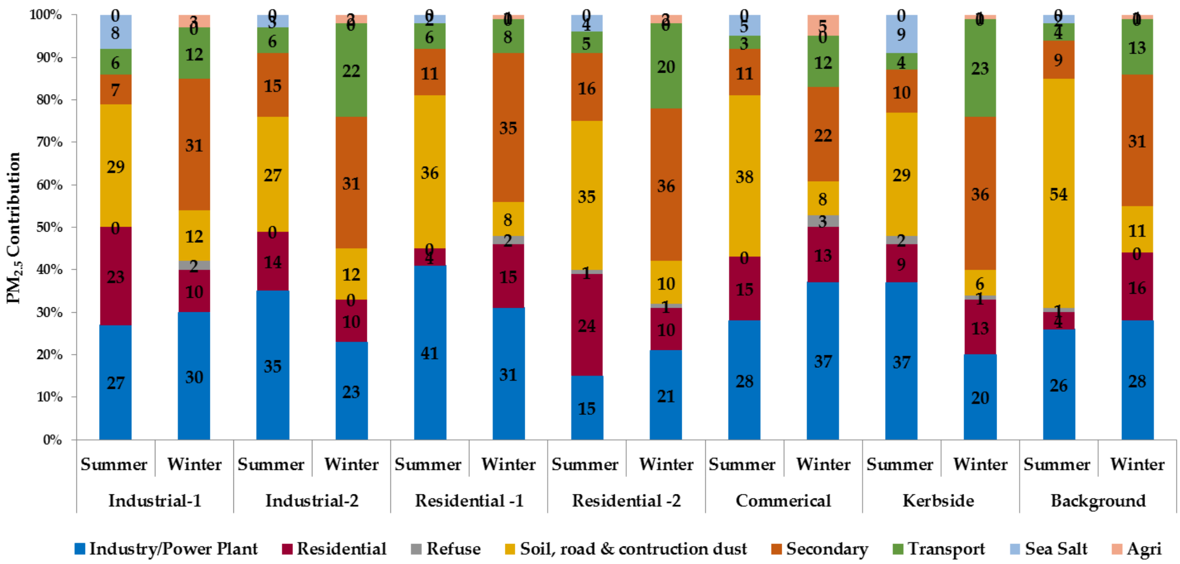


Figure 4.2: Estimated contributions of different sources to ambient $PM_{2.5}$ at different monitoring locations

Like PM_{10}, seasonal variations are observed in source contributions of different sources towards prevailing $PM_{2.5}$ concentrations.

During summer season, dust (soil, road dust & construction) contributed 27% to 38% to the ambient $PM_{2.5}$; whereas, inorganic secondary particulates contributed 22% to 36% during winters season at most of the monitoring locations in the Surat city. Dust was estimated as the major source of ambient $PM_{2.5}$ at the background location during the summer season and contributed about 54% to the ambient $PM_{2.5}$ concentration. This is mainly because of the dominant wind direction (from East and South east) which transports the outside contributions towards the city. Also, background location is near to a sea beach which significantly contributes to the high dust concentrations. Industry/ power plants were second major contributor to ambient $PM_{2.5}$; contributions range and contributed in range of 19%-37% and 15-41% during the winter and summer season, respectively. Surat district is surrounded by large number of small to large scale industries (Red Category- 650 and orange category-119) and 2 coal based power stations, which contributes substantially to $PM_{2.5}$ concentrations in both the seasons. Estimated contributions of the industry/power plant at different monitoring locations followed the order: Residential-1 (41%) >Kerbside (37%) > Industrial– 2 (35%) >Commercial (28%) > Industrial – 1 (27%) > Background (26%) > Residential- 2 (15%) during the summer season. Highest contribution from industries at the residential and commercial locations could be attributed to the presence of industries in the upwind areas. Both Residential 1 and Kerbside locations are close to the Pandesara industrial cluster, where more than 100 numbers of chemical manufacturing industries and textile and other industries are located. The presence of Hazira industrial cluster (Hazira port, NTPC, ONGC, GAIL, cement manufacturing, etc) at the upwind direction of Residential 1 location also contributes to high$PM_{2.5}$ concentrations at this location.

As noticed among different monitoring locations, major contribution to ambient $PM_{2.5}$ was observed from the transport sector; contributed to about 23% at the kerbside location, followed by the 22% contribution at industrial location-2 and 20% contribution from residential location -2 during the winter season.

As evident from Figure 4.2, transport sector contributed in the range of 8%-23% $PM_{2.5}$ and 3%-6% in winter and summer season, respectively. Higher shares in winters are observed because the pollutants emitted from this local source are not dispersed completely due to adverse meteorological conditions such as relatively low wind speed and shallower mixing heights in winters. Under these conditions, pollutants are not able to disperse adequately and remain in the city for much longer duration. In addition, the wind direction in winters is from North-east, which brings contributions from upwind Indian landmass; that is not the case in summers when wind direction is from sea side.

Residential sector was found to contribute between 4%-24% $PM_{2.5}$ in summers and 10-15% $PM_{2.5}$ in winters. This is attributed to use of solid biomass fuel for residential cooking purposes in the surroundings of Surat city and to some extent within the city also. Residential -2 location shows highest contributions from biomass burning among all different monitoring locations and contributed about 24% $PM_{2.5}$ during summers. While biomass burning contributions are regional in nature and affect all locations, higher contribution of biomass burning at this location can be attributed to additional burning of biomass in small eateries and dhabas in the nearby vicinity.

Dust concentration from soil, road, construction activities are more in summers than winters due to drier conditions and higher wind speeds leading to dust suspension and also long range transport from far off sources. At all the locations, contribution of secondary particulates was found to be higher in winters than in summers due to higher nitrate formation in low temperature.

The contribution from other sectors like refuse and agriculture burning is 1% and 2% during winter season, respectively. Contribution to ambient $PM_{2.5}$ concentrations from sea salt is also observed during summer season which ranges from 2%-9% among six different monitoring locations. Winds from sea-side during summers ensure sea-salt contributions, which are not so significant in winters due to opposite wind direction.

4.3.3 Average sources contributions to ambient particulate matter in Surat in two seasons

The average source contributions to PM_{10} and $PM_{2.5}$ in Surat city (average of 6 locations in the city) are provided in Figure 4.3.

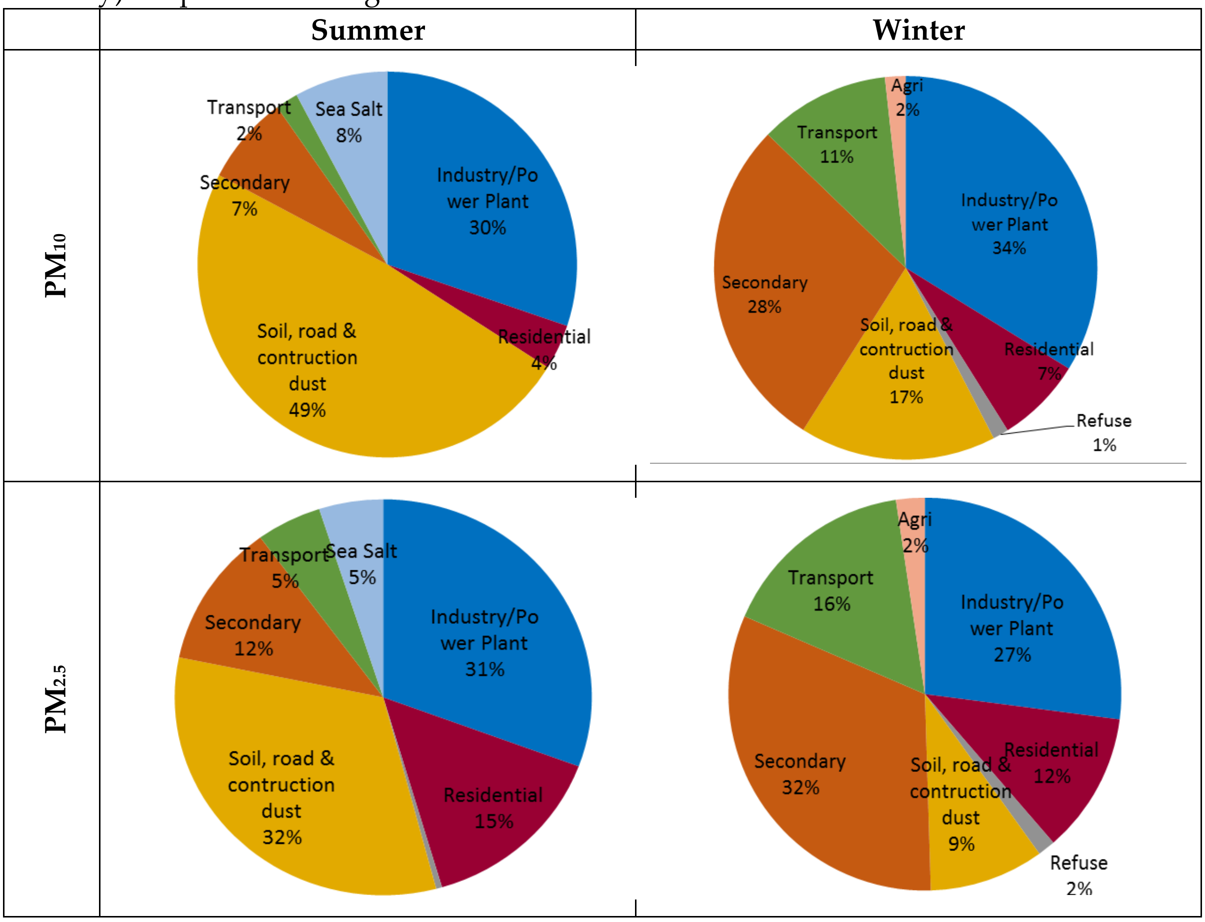


Figure 4.3: Estimated seasonal contributions of different sources to ambient PM_{10} and $PM_{2.5}$ in Surat city (average of 6 locations) during summers and winter seasons.

During summer season, dust (soil, road dust and construction) was estimated as the major sources of atmospheric pollution and contributed 49% PM_{10} and 32% $PM_{2.5}$ in the city of Surat. Dust contributions are low in winters due to reduced wind speeds (which is a major factor responsible for re-suspension of dust) and also reduced contributions from far off dusty sources. Wind direction (North-east) in winters is opposite of summers, which has more anthropogenic source contributions from Indian landmass than dust.
The contribution from secondary particulates to ambient $PM_{2.5}$ (32%) level were found to be higher than PM_{10} levels (28%) during the winter season. Higher contributions of secondary particles in the $PM_{2.5}$ fractions show dominance of these particles in the finer range *<2.5 ◎m).
Contribution of Industries/Power Plant was estimated as second major source of ambient PM_{10} and $PM_{2.5}$ during summer season. About 30% PM_{10} and 27% $PM_{2.5}$ were estimated to be contributed from the industries/ power plant. Higher contributions from industries/power plant can be attributed to presence of large number of small to large scale industries and power plants in and around the Surat city. In winters, contribution from industrial sector to ambient PM_{10} was 34%, which was found to be higher than $PM_{2.5}$ levels (27%).
Biomass burning contributes 12%-15% to ambient $PM_{2.5}$ and about 4%-7% to ambient PM_{10} in the two seasons. Higher share of biomass burning in $PM_{2.5}$ indicates towards dominance of finer particles in biomass PM emissions. Sea salt contributes 5% to $PM_{2.5}$ and 8% to PM_{10} in summers indicating a bias towards coarser fraction of particulate matter. The dust impact of beach sources is observed at all the monitoring locations in Surat city during summer season, because the predominant wind direction during summer season is South-westerly, and the Dumas beach is located in the Southwest of the city.

As observed, dust originated from soil, road and construction activities contributed more in summer than in winter for both PM_{10} and $PM_{2.5}$ due to drier conditions and higher wind speeds in summer leading to dust re-suspension and atmospheric transport from far off sources (including sources outside of India in the upwind direction. On the contrary, the contribution of secondary particulates to the PM_{10} and $PM_{2.5}$ levels were found to be higher in winter than in summer as lower temperatures provide favorable conditions for formations of ammonium nitrate through reactions of nitric acids (formed by NOx) with ammonia. For both the seasons, the contribution of secondary particulates to the ambient $PM_{2.5}$ levels were found to be higher than in PM_{10}, indicating that they lie more in fine range of particles. The contribution from transport sector is 16% and 11% to the ambient $PM_{2.5}$ and $PM_{10,}$ respectively during winters, and 5% $PM_{2.5}$ to 2% $PM_{10,}$ respectively during summer season. Irrespective of size fraction, contribution of tail pipe emissions from transport sector is found to be higher in winters than in summers because the pollutants emitted from this local source are slowly dispersed due to calmer conditions in winters. This leads to accumulation of the pollutants and hence higher contributions from transport sector is observed. In winters, wind from north-east direction ensures higher anthropogenic contributions from upwind landmass, which is not the case in summers as the dominant wind blows from the sea side. Additionally, irrespective of the season, contribution of tail pipe emissions from vehicles was found to be higher in the $PM_{2.5}$ fraction than in PM_{10} fraction. This is because emissions from tail pipe of vehicles contribute majorly to fine finer fractions of particulate matter.

EMISSION INVENTORY OF AIR POLLUTANTS

5

Key observations

At district level

- Major sources of PM_{10} emissions are road dust (47%), industry (27%), transport (11%) and thermal power plants (5%)
- Industry (35%) is the major contributor to the total $PM_{2.5}$ emissions followed by road dust (25%), and transport (24%)
- In case of SO_2, industry (49%) and thermal power plants (47%) are the major contributor to the total emissions
- NOx is majorly contributed by transport sector (50%) followed by industry (36%) and power plants (12%)

At city level

- Major sources of PM_{10} emissions are road dust (55%), industry (25%) and transport (12%)
- For $PM_{2.5}$ emissions, road dust (33%), transport (30%) and industry (27%) are the major contributors
- Sources of SO_2 emissions are primarily from industry (85%) followed by residential sector (12%)
- 85% of NOx emissions are contributed by transport sector followed by industries (12%)

5.1 Introduction

Developing an air pollutant emission inventory is an important initial step towards developing an action plan for improvement of air quality in a region to prevent adverse effects on the health of humans and ecosystems. Emission Inventory is one of the fundamental components of "Air Quality Management" plans which aims to assess the contribution of different sources in the pollution loads emitted in the region. Emission inventorisation is carried out to understand the spatio-temporal distributions of emissions from different sources existing in a region. In this study, we developed and evaluated sectorial emission inventory of particulate matter and other gaseous pollutants in Surat city and district for the year 2019.A proper emission inventory is very important for planning pollution control programs, particularly in densely populated city like Surat, where air quality has become a growing concern due growth trajectories, and typical meteorological conditions. In this study, emission inventory for Surat (both Surat district and Surat city), which is a highly industrialized area situated in the western part of India has been developed.

5.2 Methodology

Source wise multi pollutant inventories for PM_{10}, $PM_{2.5}$, SO_2, NO_x, CO and NMVOCs have been prepared for the year 2019 with a resolution of 2 km × 2 km. The main objective of inventories is to improve knowledge of sources, types of pollutants and their emission rates in Surat region. For control of air pollution, understanding of source emission rates and characteristics is essential, as pollutant emissions together with prevailing meteorological conditions and topographical factors, determine the ambient concentrations of pollutants, which the residing community will be exposed to. The major sectors covered for estimation of emissions in Surat are shown in Figure 5.1.

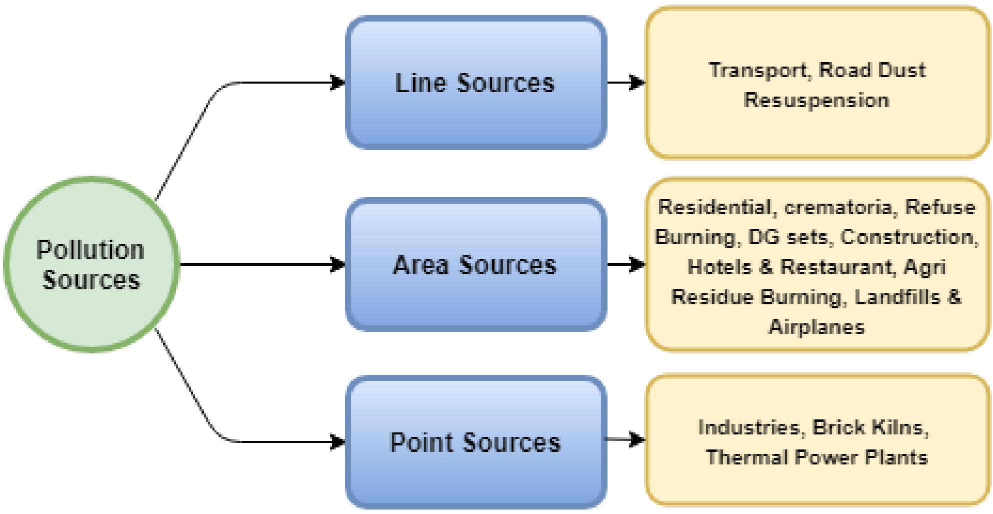


Figure 5.1– Different pollution sources inventorised in this study for Surat

Emissions inventory is the quantitative compilation of pollutants emitted from different source categories in a region. While there are several ways of developing an emission inventory, most commonly air pollutants are inventoried using the emission factor approach based on activity data and emission factors as per equation (1). Activity data is described as the measure of activities generating emissions of different types of pollutant. Emission factors are the average emission rate of a given pollutant from a given source per unit source activity such as burning of fuel or vehicle kilometer travelled. In absence of actual measurement of emissions from different sources (which is a resource and time intensive exercise), emissions factor approach is extremely useful and reliable (equation 1).

$$E_M = D_A * E_F * (1-E_c) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where, E_M is emissions, D_A is the activity data, E_F is emission factor, Ec is the efficiency of control device.

Information on sectoral activities is mainly collected from secondary databases of government statistics, however in absence of these, primary surveys are carried out. Emission factors are generally adopted from indigenous sources and in absence of these, default factors are used based on the international literature.

In this study, activity data has been collected from different secondary and primary ways to establish a baseline profile for the study area. Emission estimates were made based on activity type, emission factors, pollution abatement technologies used and efficiency of the control devices used. Data collected from primary surveys and secondary sources were used for estimation of emission loads from different sectors. The data gaps and limitations in data collection were identified for transport, industries, DG sets and restaurants/hotels. Primary survey was conducted for transport, DG sets, restaurants/hotels and industrial sectors in order to fill in the data gaps. Traffic count and parking lot surveys were carried out in the study area in order to estimate vehicular emission loads in the study domain. In addition to this, representative dust samples were collected from different categories of roads in the study domain and were tested for their silt content, which was further used for the estimation of emissions from road dust re-suspension due to movement of vehicles. The estimated emissions from different sectors have been suitably allocated over the study domain.

A literature review was carried out for selection of emission factors. Emission factors for vehicular sector were adopted from Automotive Research Association of India (ARAI), while for other sectors indigenous emission factors have been used as far as possible. . Emission inventory has been prepared for the study area and thereafter allocated grid-wise at a resolution of 2 km X 2 km grids using ARCGIS software. Emission inventory is developed on a GIS platform for spatial allocation of emissions and for its further use in the dispersion model. The study area was divided into grids in each direction at 2km x 2 km resolution. The methodologies followed for estimation of emissions from different sectors are described in subsequent sections.

5.2.1 Industry Sector

Accelerating growth in the industrial sector is increasingly responsible for worsening air quality in many Indian cities. Surat being industrial hub of Gujarat, is also known for significant quantities of emission loads from industrial sector. Industrial sources are mainly responsible for emissions of particulate matter (PM_{10} & $PM_{2.5}$), oxides of sulphur (SO_x) and oxides of nitrogen (NOx). Emissions from industries are generated as a result of various processes during manufacturing activities in the study area. A large part of emissions are caused due to burning of different types of fossil fuels in boilers, furnaces, etc. Different pollutants thus generated are released through industrial chimneys/stacks to the surrounding areas after passing through the air pollution control devices.

The central pollution control board (CPCB) has classified industries into red (highly polluting), orange (moderately polluting) and green (non-polluting) categories based on the pollution generated by the particular industry and further sub-categorized into small, medium and large industries, based on the scale of setup. Activity data required for estimations of emissions from this sector was collected from GPCB. In the entire Surat district, there are 165 large, 115 medium and 587 small industries. We have considered only red and orange categories of industries falling under the study area of Surat district for estimation of emissions. The data on red and orange category of industries in Surat City were collected from regional office GPCB, Surat. Data from 10 sub-districts of Surat was collected. These subdistricts are Chorasi, Kamrej, Mahua, Mandvi, Mangrol, Olpad, Palsana, Surat city, Umarpada, and Bardoli. Major types of fuel used in industries of Surat are coal, wood, high speed diesel (HSD), Furnace Oil (FO), Natural Gas, Liquefied Petroleum Gas (LPG) and bagasse (biomass).

The approach followed for estimation of emissions from industrial sector is based on the activity data of fuel consumption in the manufacturing processes, fuel type and the type of air pollution control device (APCD) installed in the industries. Industries report their fuel consumption details to their respective pollution control boards through documents of consent to operate (CoO), consent to establish (CoE) and annual environmental statements. There are a variety of air pollution control devices which are used in industries around Surat. Types of APCD devices operated in the industries along with their control efficiencies are shown in Table 5.1 - Emissions from industrial sector are estimated from the fuel consumption data and emissions factor using the equation:.

$$Ep = Cf \times EF \times (1 - \eta) \qquad \text{……………... (2)}$$

Where, E_p is the emission of pollutant p, E_f is the emission factor of the fuel consumed and C_f is the fuel consumed in the industry, η is the efficiency of the APCD device installed in a particular industry. The fuel type emission factor used for estimation of emissions of different pollutants are shown in Table 5.2 and the estimated emissions from industries in Surat city and district are shown in Table 5.3.

Based on discussion with officials from GPCB, it was realized that Surat that industries in Surat district are mainly using imported coal (Indonesian coal) which has very low ash content (7%) and sulphur content (0.05%)

Table 5.1: APCDs used by industries in Surat and their removal efficiencies

APCD device	PM_{10}	$PM_{2.5}$	Gaseous	Source
ESP	0.99	0.97	0	EPA 3 ESP Parameters and Efficiency- PPC Air
Dust Collector	0.1	0.08	0	EPA-452/F-03-009
Wet Scrubber	0.94	0.93	0.8	EPA/452/B-02-001 SECTION-6
Cyclone	0.6	0.3	0	EPA - 42
Multi Cyclone	0.5	0.5	0	EPA-452/F-03-032
Bag filter	0.99	0.99	0	EPA/452/B-02-001
SCR (NO_x)	0	0	0.85	EPA-452/F-03-032
FGD (SO_x)	0	0	0.9	EPA-452/F-03-032

Table 5.2: Fuel wise emission factors for various pollutants in industries

Emission factor of fuel (g/Kg)	PM_{10}	$PM_{2.5}$	SO_2	NOx	CO	NMVOC
*Wood	17.3	15.743	0.2	1.3	126.3	-
*HSD (g/L)	0.24	0.216	9.405	1.2	0.6	-
*Furnace Oil (g/L)	2.592	1.73664	37.68	6.6	0.6	0.091
*Natural Gas (kg/m^3)	0.000122		9.6E-06	0.0016	0.001344	2.566
*LPG (Kg/10^6 m^3)	2.1		0.4	1.8	0.252	88
*Bagasse	7.8	5.07	0.18	0.6	12.39	-
**Coal	37.52	13.13	0.975	4.5	0.3	-
**Lignite	187.6	65.66	9.75	4.5	0.3	-
*LDO (Kg/Kl)	0.24	0.216	0.33858	1.2	0.6	-
***Rice Husk	5300	4823	0.11	0.19	14.05	

Source: *SA Six cities, CPCB, **based on ash content and sulphur content for PM and SO_2, ***M Irfan et.al 2014

Table 5.3: Estimated Emissions from Surat city and district from industrial sector

Study Area	Emissions (Kt/yr)					
	PM_{10}	$PM_{2.5}$	SO_2	NOx	CO	NMVOC
City	8.1	3.87	3.59	4.46	40.42	0.00312
District	31.68	18.67	39.44	84.16	299.02	0.06

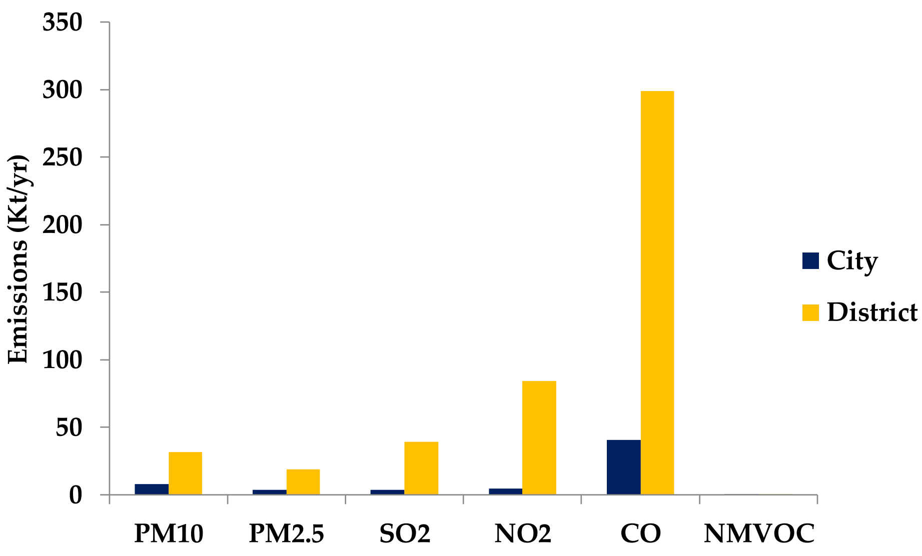


Figure 5.2: Emission from industries in Surat situated in district and city.

Fuel wise emissions estimated for the study domain are shown in Table 5.4. It is evident from the emissions that solid fuels like coal and wood are the most polluting fuel, emitting high quantities of PM. Wood is also the major contributor to CO emissions whereas particulate matter is highly emitted by combustion of coal and wood. Coal and furnace oil are the major emitter of SO_2. Natural gas with higher temperature of combustion shows high contributions to NOx emissions.

Figure 5.3 shows that out of all the fuels used in the industries at Surat industries, wood burning emits majorly to the PM_{10} (25%) and $PM_{2.5}$ (42%) and CO (86%) emissions. Coal contributes to about 68% PM_{10}, 53% $PM_{2.5,}$ 50% SO_2 and 37% NO_x of the total emissions from all the fuels. Natural gas majorly emits 53% NO_2 and SO_2. Furnace oil emits majorly to 45% $SO_{2.}$.

Table 5.4: Fuel based emissions (Kt/yr) of different pollutants in Surat District

Fuel type	PM_{10}	$PM_{2.5}$	SO_2	NO_x	CO	NMVOC
Wood	8.07	7.90	0.38	2.29	256.91	-
HSD	0.00	0.00	1.24	1.64	0.83	-
FO	0.77	0.64	17.94	4.32	0.39	0.06
Natural Gas	0.03	0.00	0.25	45.02	37.87	0.00
LPG	0.00	0.00	0.00	0.00	0.00	-
Bagasse	1.32	0.25	0.00	0.00	0.01	-
Coal	21.49	9.87	19.60	30.78	2.94	-
LDO	0.01	0.01	0.03	0.11	0.06	0.00
Rice husk	0.00	0.00	0.00	0.00	0.00	0.00
Total	**31.68**	**18.67**	**39.44**	**84.16**	**299.02**	**0.06**

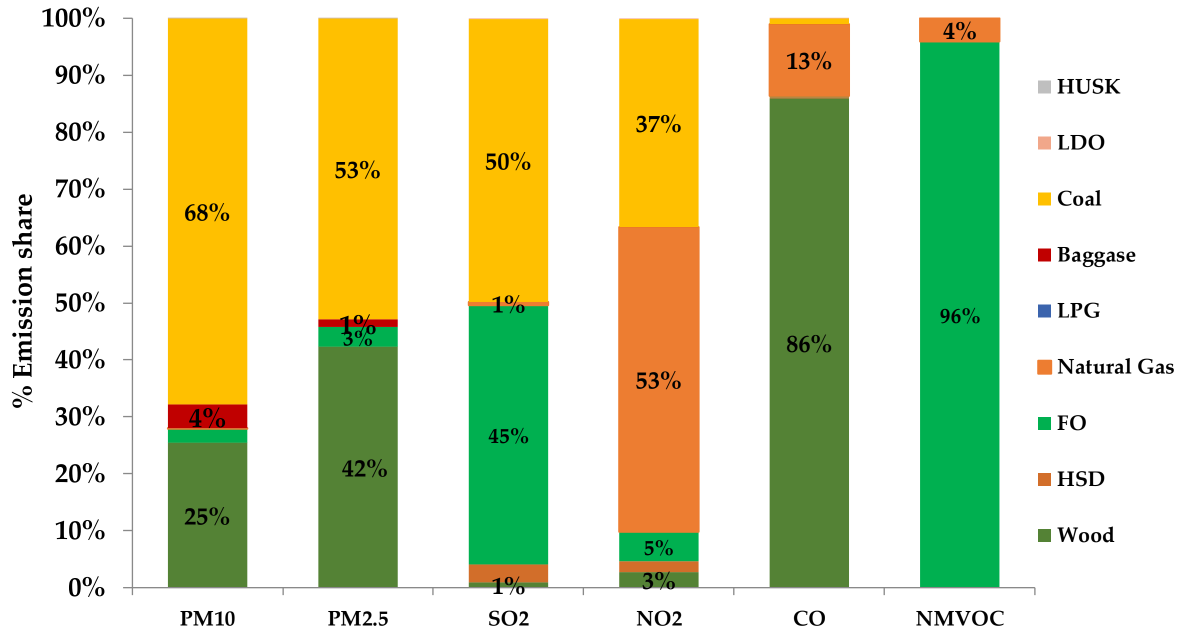


Figure 5.3: Pollutant wise percent contribution of different fuels to industrial sector emissions in Surat district

5.2.2 Transport sector

Vehicular pollution is a major issue in context of air quality problems faced by Indian cities. Road transport sector has grown at a very fast pace in recent times, mainly due to increasing population, economic growth, and technological and financial flexibilities. Diesel vehicles emit huge quantities of PM and NO_x, while gasoline vehicles are known to emit more of other gaseous pollutants such as CO and VOCs. NOx and VOCs released from transport sector become precursors for the secondary pollutants such as ground level ozone (O_3), and secondary particulate which are also known to cause several respiratory diseases (Liu et al., 2018). Transport sector emissions in Surat has been estimated using the on road vehicle kilometres travelled approach(i.e. VKT) which is based on Traffic count survey and parking lot surveys at different locations in Surat. Broad methodology used to quantify tailpipe emission for the transport sector is,

$$E_p = \sum_{c=1}^{n} \sum_{s=1}^{4} VKT_{c,s} \times EF_{c,s,p} \times \varepsilon_{c,s} \times n_c \quad \ldots\ldots\ldots\ \ldots\ldots.. \quad (3)$$

Where, Ep is the total emission of a pollutant (p); c is the category of vehicle; s is the emission control norm (BSI to BSIV) and CNG penetration; VKT is the Vehicle Kilometer Traveled; *EF* is the emission factor of pollutant p and ε is the percentage of vehicle under an emission control norm and n is the total number of vehicle in category c.
The EF of PM_{10}, $PM_{2.5}$, NO_x, SO_x, hydrocarbon and CO for this study are adopted from ARAI (2016). ARAI has carried out series of measurements to ascertain indigenous emission factors for different categories of vehicles in Indian conditions. Both VKT and ε are considered on the basis of primary survey results analyzed from traffic count survey and parking lot survey within the district, details of which are explained below.

Traffic count survey and parking lot survey

Traffic count survey has been conducted in Surat to analyse the behavior of vehicular population plying on the roads. This was done by counting number of vehicles and their variation on different roads (major, minor and arterial) of the study domain. For conducting traffic count, total of 39 roads were selected in the entire district, comprising of 12 major (arterial) roads, 12 sub-arterial (connecting) roads, 12 minor (local) roads and 3 highways which interconnects Surat with neighborhood cities. These roads were chosen in different grids of the study domain representing different land use pattern - residential colonies (high, medium and low density), commercial areas, industrial hubs or mixed settlements etc. In order to analyze the diversity in different types of vehicles on roads, manual method of traffic counting was used. A survey team of field personnel was deployed to count and classify vehicles under different categories of roads (Kadivali, 1997) for both the directions of travel. A representative sample of traffic count in a period of time is collected from major, minor and connecting roads in the different land use regions in the Surat district. The digitized road network of Surat city and district is shown in Figure 5.4. The traffic count survey was carried out for 24-hours excluding weekends and holidays and the results of survey for different road locations is shown in Figure 5.5.

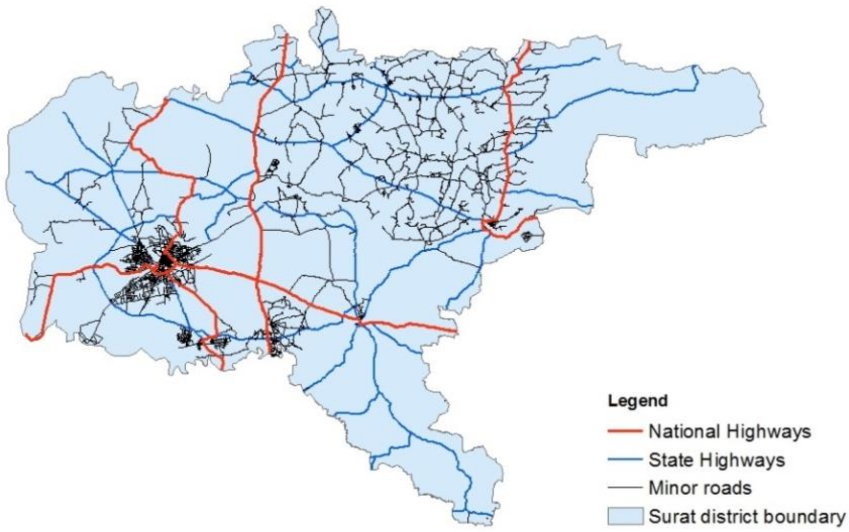


Figure 5.4: Road network of Surat district

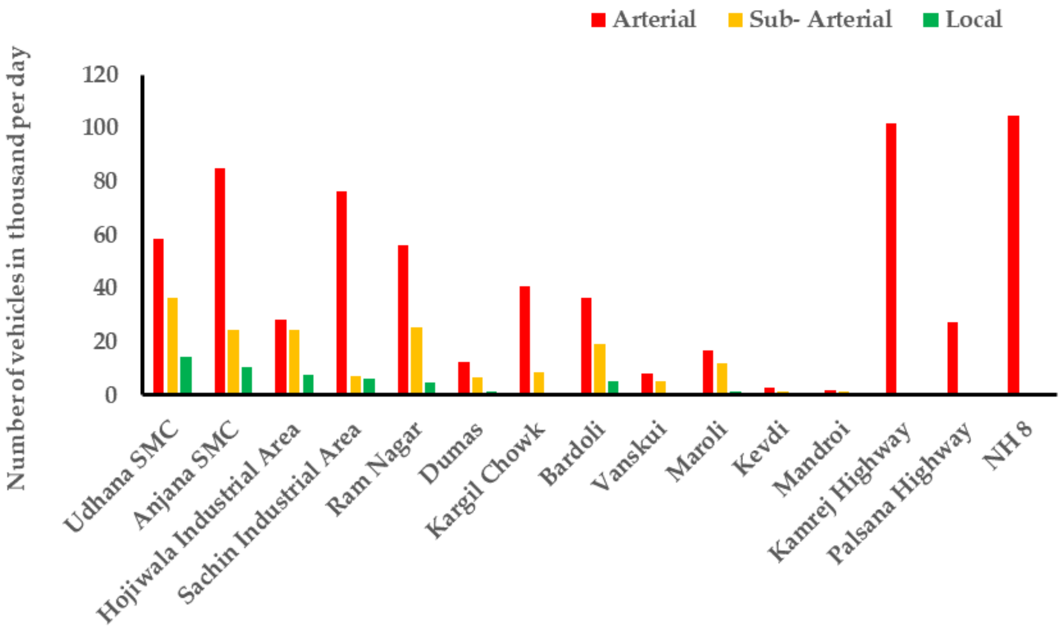


Figure 5.5: Traffic count statistics at arterial, sub-arterial and local roads in Surat

Based on the traffic count results, it is evident that traffic count at arterial road is broadly 4 times of that at sub-arterial road and about 12 times of that at local road. Traffic count at arterial road near Anjana SMC in the city is the highest as it is near national highway passing from the centre of the district followed by Sachin Industrial Nagar and Ram Nagar, whereas, Udhana SMC accounted for maximum vehicular density at sub – arterial road. However, for application of appropriate emission factors, traffic count data has to be divided into different sub-categories of make, model, vintage and fuel categories. This information is obtained from parking lot surveys. Parking lot surveys were also conducted to understand the existing fleet of vehicles and their distributions in the city by collecting information such as model, vintage, technology, fuel mix, average daily distance travelled, occupancy and mileage through the parking lot survey. An illustration of the subdivisions made is shown in Figure 5.6.

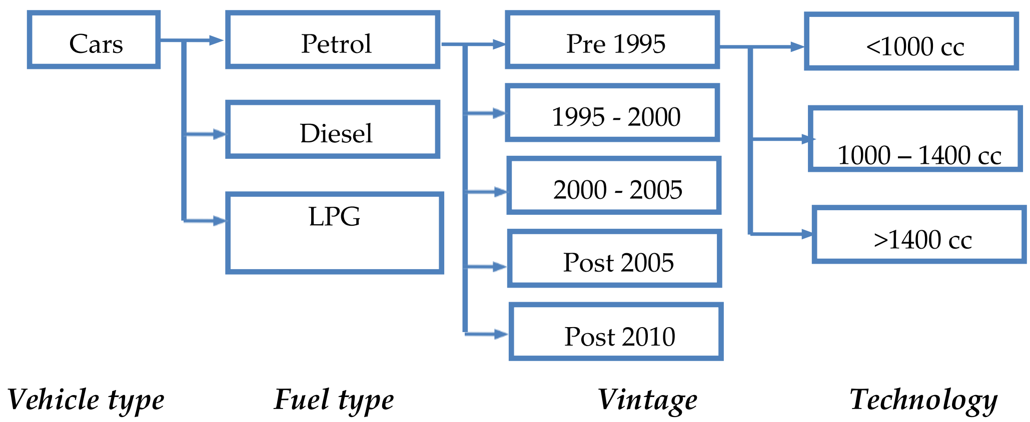


Figure 5.6: Sub-divisions based on fuel consumption, vintage and technology from parking lot survey

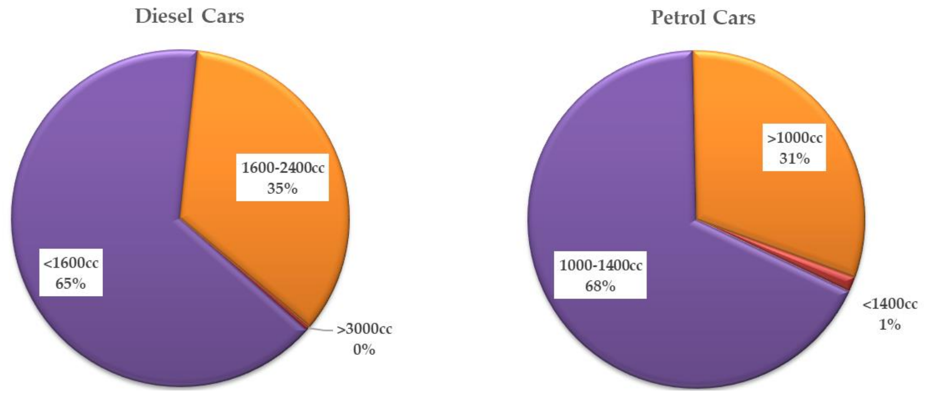


Figure 5.7: Technology wise distribution of cars in Surat based on parking lot survey

A representative sample size is selected for each category of vehicles for carrying out parking lot survey. Sample size to conduct parking lot survey was calculated using equation 4 (Cochran (1977):

$$ss = t^2 \times (p) \times (1-p) \div c^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

ss : Sample size, t : t value (1.96 for 95% confidence level or 0.05 alpha value), p : percentage picking a choice, expressed as a decimal (0.5 used for sample size needed), p* (1-p) is measure to estimate variance and will produce the maximum possible sample size when both are equal i.e. p = 1-p = 0.5. So, sample size obtained by assuming p = 0.5 is big enough to ensure precision, c : confidence interval, expressed as decimal or acceptable margin of error. Alpha value (t) represents the level of risk the researcher is willing to take that true margin of error may exceed the acceptable margin of error. In most of the research studies alpha level of 0.05 or 0.01 is used (Bartlett et. al., 2001) and in Cochran formula, alpha level is incorporated by using t value based on selected alpha level. In the present context, 95% precision with ±5% confidence interval (for categorical data, 5% confidence interval or margin of error is assumed (Bretlett et al., 2001) is used to estimate minimum sample size for parking lot surveys. In all, a sample size of about 4000 different categories of vehicles is taken to carry out the questionnaire based parking lot surveys in Surat district. The surveys are random for each category of vehicles without any bias to fuel, age, model or any other factor. This survey data is further used to distribute the on-road vehicles into different categories. Result of parking lot surveys in terms of technological distribution of petrol and diesel driven cars are shown in the Figure 5.7. Petrol cars less than 1000 cc accounted for 31% and 1000-1400 cc accounted for 68% of petrol cars. On the other hand, diesel cars less than 1600 cc accounted for 65% of all diesel cars in Surat district. Vintage distribution of different categories of vehicles is provided in the Table 5.

It can be clearly seen that in all categories, majority of vehicles outside of Surat city follow BS III norms. However, within the Surat city most vehicles are found to be following the BS-IV norms as these norms were ordered to be implemented in earlier in 2010 in 13 cities including Surat.

Table 5.5: Vintage distribution for different categories of vehicles based on parking lot survey

For Out-side city Locations

Year	Emission Norms	2W	Cars	LCV	Truck	Buses	Tractor
2000-2005	BS-I	0%	0%	0%	0%	0%	0%
2005-2010	BS-II	19%	1%	17%	13%	9%	6%
2010-2017	BS-III	71%	74%	62%	87%	71%	87%
Post 2017	BS-IV	10%	25%	21%	0%	20%	7%

For Inside-city Locations

Year	Emission Norms	2W	Cars	LCV	Truck	Buses	Tractor
2003-2005	BS-II	**0%**	0%	0%	0%	0%	0%
2005-2010	BS-III	**19%**	3%	14%	16%	9%	13%
2010-2019	BS-IV	**81%**	97%	85%	84%	91%	88%

Tailpipe emission of different pollutants

Tailpipe emission for the road transport for various pollutants is estimated using the following approach:

Emissions = EF (g/km) x VKT (km) ………… (5)

Where, EF = Emission Factor based on vehicle technology, fuel and vintage; VKT = Vehicle Kilometer Travelled.

VKT = Traffic count on road (in a given location) × road length (of the given grid)…. (6)

Emission factors play a vital role in computing the emissions from a typical vehicle category. In the current study, indigenous emission factors developed by ARAI (2016) are used. ARAI (2016) is the compilation of extensive work carried out on developing emission factors for in use vehicles of different categories, which followed different vehicular emission norms (Pre-BS, BS-I, BS-II, BS-III) during different time frames.

Emissions from the transport sector are estimated following the methodology briefly illustrated in Table 4.6.

Table 5.6: Methodology for emission estimation

S. No	Protocol	Approach
1.	Assessment of the number of vehicles plying on roads	Traffic counts
2.	Analyzing the distribution of vehicles based on vintages, technologies, and fuel types	Parking lot surveys
3.	Computation of vehicle kilometer travelled (VKT) for all sub-categories of vehicles	Traffic counts and road length
4.	Selection of emission factors for each sub-category	ARAI, 2011
5.	Emission Computation	VKT x Emission factor

The traffic count information of the 39 locations is used to extrapolate emissions for the whole study domain (Figure 5.8). By estimating traffic intensities in the surveyed 7 grids, traffic intensities were allocated to other grids based resemblance to the landuse categories. Finally, VKTs in the remaining grids were estimated using allocated traffic intensities, and their respective road lengths. VKTs were finally multiplied with emission factors to estimate emissions for all the grids in the area.

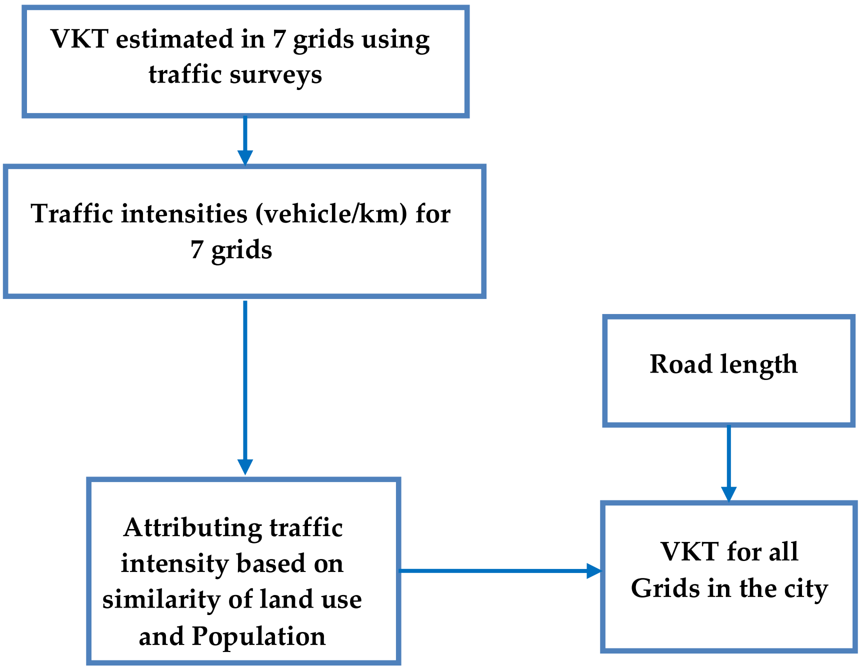


Figure 5.8: Method used for emission assessment of transport sector in the study area

City level assessments of transport sector

Estimated PM_{10} and NO_x emissions from the transport sector in Surat city are shown in the Figure 5.9. As seen in Figure 5.9, 2-wheelers (42%) followed by trucks (24%) LCV's (11%) and 3-w (7%) are the major contributor of particulate matter emissions. Trucks (32%) are the major contributor to NOx emissions in the study domain, followed by 2-w (20%) and 3-w

(11%). Also, 97% of PM_{10} emissions from vehicles are $PM_{2.5}$ which account for 4.18 kt/year of $PM_{2.5}$ emissions from vehicular sector in the city of Surat.
In total, 4.31 kt/year of PM_{10} and 32.87 kt/year of NOx is released from transport sector in Surat city. Emission estimates for other pollutants are provided in the Table 4.7.

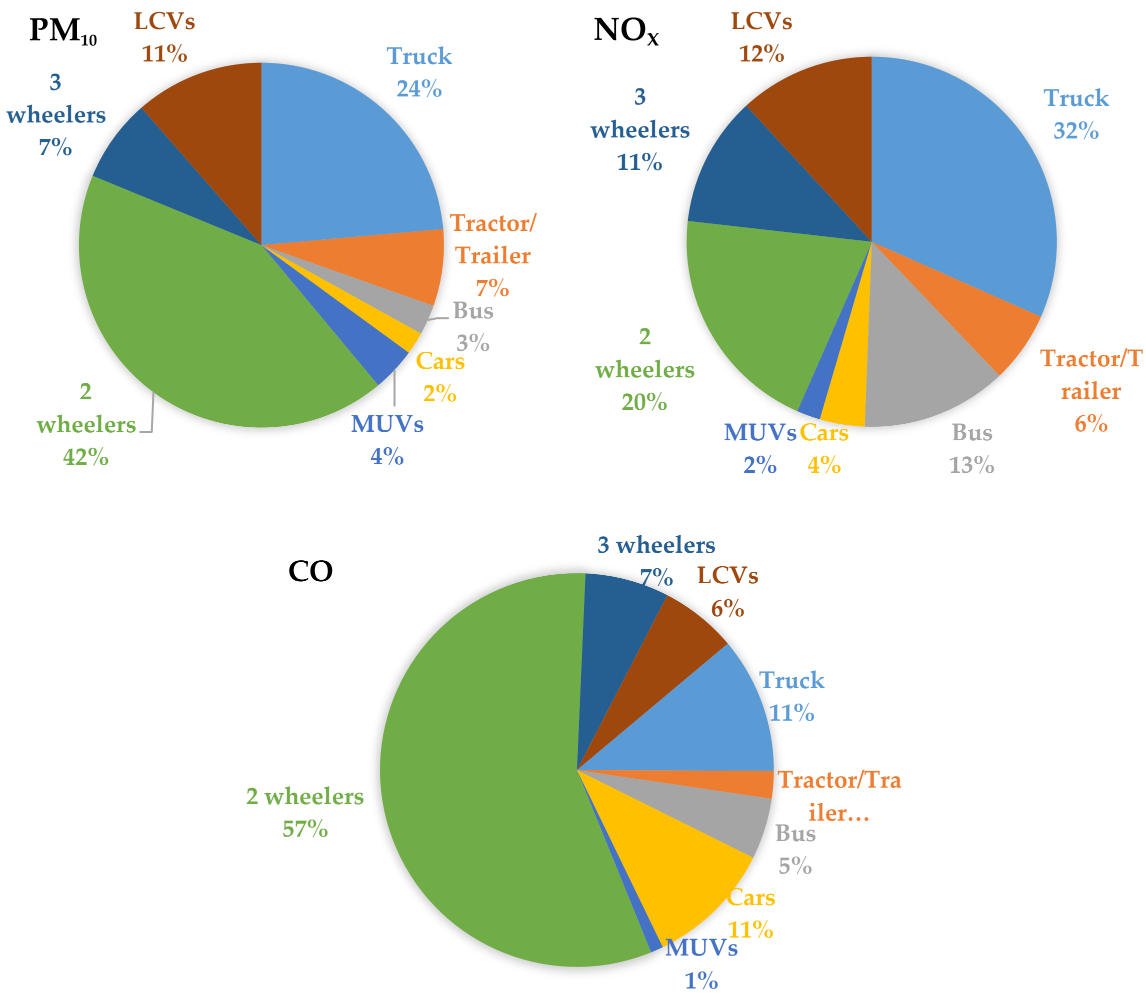


Figure 5.9: Distribution of PM, NOx and CO emissions in Surat City

Table 5.7: Emission estimates in Kt/year of Surat City

Pollutants	Truck	Tractor/ Trailer	Bus	Cars	MUVs	2 wheelers	3 wheelers	LCVs	Totals
PM_{10}	1.02	0.29	0.11	0.09	0.17	1.83	0.32	0.49	**4.32**
$PM_{2.5}$	0.99	0.29	0.11	0.08	0.16	1.77	0.31	0.48	**4.19**
SO_2	0.04	0.00	0.00	0.02	0.00	0.00	0.00	0.02	**0.09**
NO_x	10.40	2.05	4.18	1.29	0.68	6.64	3.73	3.89	**32.86**
CO	9.59	1.95	4.30	8.98	0.89	48.75	5.92	5.40	**85.78**
HC	11.07	1.17	2.56	1.09	0.29	16.58	12.80	1.25	**46.79**

District level assessments of transport sector

Estimated PM_{10} and NO_x emissions from the transport sector in Surat district are shown in the Table 4.8. In total, 13.0 kt/year of PM_{10} and 115.7 kt/year of NOx is released from transport sector in Surat district. Emission estimates for other pollutants are provided in the Table 9. Also, 97% of PM_{10} emissions from vehicles are $PM_{2.5}$ which account for 12.6 kt/year of $PM_{2.5}$ emissions from vehicular sector in the Surat District.

The emissions from transport sector are generally underestimated using emission factors which are developed at laboratory scale. Real world conditions are dramatically different from laboratory based test driving cycles. Ligterink (2017) shows the difference in emission factors of various types of vehicles in real world conditions in cities which deal with congestion and low vehicular speeds. In this study, we have accounted for real world conditions, and hence the final transport emissions have been estimated by multiplying with real world adjustment factors based on Ligterink (2017). In addition to this high emitters (vehicles which emit much higher than the laboratory estimated emission factors mainly because of deteriorated engine conditions) have also been accounted in estimation of emissions from transport sector.

Table 5.8: Emission estimates in Kt/year of Surat District

Pollutant	**Truck**	**Tractor/ Trailer**	**Bus**	**Cars**	**MUVs**	**2 wheelers**	**3 wheelers**	**LCVs**	**Totals**
PM_{10}	6.37	0.65	0.38	0.23	0.44	3.32	0.65	0.97	**13.00**
$PM_{2.5}$	6.18	0.63	0.37	0.22	0.42	3.22	0.63	0.94	**12.61**
SO_2	0.11	0.00	0.02	0.07	0.00	0.00	0.02	0.04	**0.26**
NO_x	64.92	4.52	13.85	3.34	1.76	12.06	7.59	7.67	**115.71**
CO	59.86	4.30	14.24	29.03	5.81	102.87	12.05	15.24	**243.40**
HC	69.10	2.58	8.49	2.76	0.75	30.14	26.05	2.45	**142.31**

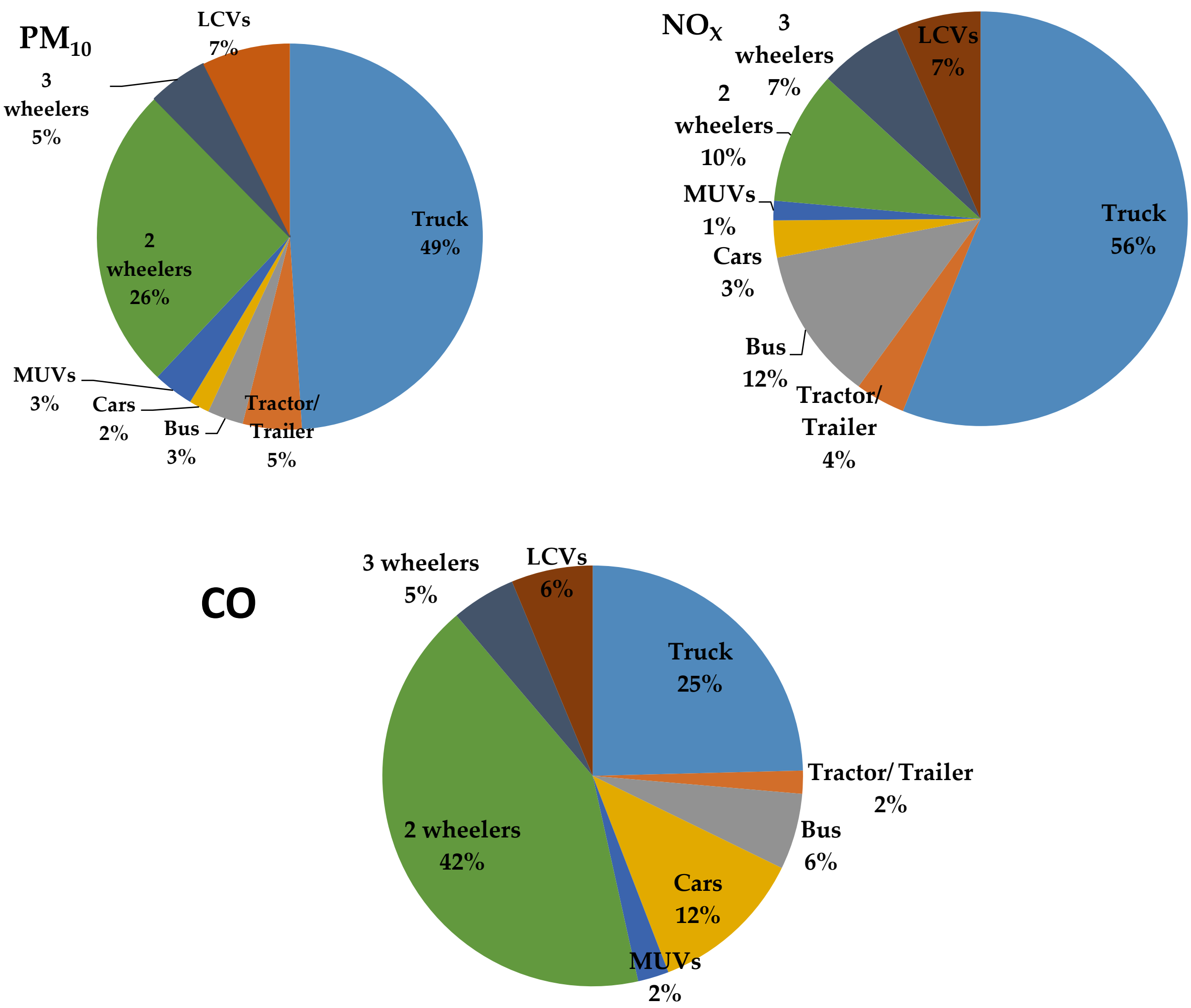


Figure 5.10: Distribution of PM, NOx and CO emissions in Surat District

5.2.3 Road Dust re-suspension

Re-suspended dust is not directly related to vehicular tail-pipe emission, and is generated due to movement of vehicles on dusty roads. Emissions from road dust re-suspension due to movement of vehicles are calculated using USEPA (AP-42) method. These dust emissions due to movement of vehicles are found to be varying with the silt loading on the road surface and also with the average weight of the vehicles plying on the road. The term silt loading refers to the mass of the silt-size material (equal to or less than 75 µm in physical diameter) per unit area of the travel surface.

Dust samples are collected from various roads in the study area as per USEPA AP42 method and are tested for their silt content and then converted into silt loading (g/m^2), which is used for estimation of emissions from the sector. A portable vacuum cleaner was used for the collection of samples from a designated area in the middle of the road. Filter bag of the vacuum cleaner was emptied and weighed before the sampling. Sampling material is collected only from the portion of the road over which the wheels and carriages travel routinely. Collected sample were weighed and stored in a clean and labelled container. After collecting the sample, sieve analysis was performed for 10 minutes by stacking the sieves of mesh no. 20, 28, 60, 100 and 200. The material collected underneath the mesh no. 200 is then collected and weighed as it represents the silt content of the sample.

Road dust samples were collected from all the same roads (covering arterial, sub arterial and minor roads) identified for carrying out traffic count survey. Road dust samples were collected from the study region and its silt contents are estimated. Particulate matter emissions from re-suspension of road dust due to movement of vehicles on paved roads are calculated using following equation 8 as provided in AP-42,

$$[E_p]_t = \sum VKT_r \times k \times w^{1.02} \times Mo^{0.91} \quad \text{............ (8)}$$

where, $[E_P]_t$ is the fugitive emission of pollutant (p) from the transport sector; r is the type of road (arterial, sub-arterial and local); VKT is Vehicle Kilometer Travelled, k is function of particle size (0.62 for PM_{10} and 0.15 for $PM_{2.5}$); w is the average weight of vehicle travelling on the road and Mo is road surface silt (≤ 75 μm in physical diameter) loading in unit area. The $[E_P]_t$is directly proportional to the silt loading on the road surface and average weight of the vehicles plying on the road. Based on k factor, 15% of the $[E_P]_t$ is considered as $PM_{2.5}$, while 62% is considered as PM_{10}.

For Surat district, average value of silt loading is found to be 1.5 g/m^2, 2.4 g/m^{2}and 2.6 g/m^{2}on arterial, sub-arterial and local roads, respectively. The VKT for Surat is estimated by using the method explained in the transport sector emission estimation. After estimating $[E_P]_t$ using the above equation, the effect of rainy days was considered to finalize the fugitive emission ($f[E_P]_t$) from road dust re-suspension using the equation 9,

$$f_{[E_p]_t} = [E_p]_t \times (1 - D_p)/(4 \times 365) \quad \text{.................... (9)}$$

Where, D_P is the number of rainy days in a year. Total of 112 days are considered as rainy days in a year based on the meteorological conditions in Surat District. The estimated PM_{10} and $PM_{2.5}$ emissions from road dust re-suspension in Surat city are 19.55 and 4.73 kt/year respectively. The estimated PM_{10} and $PM_{2.5}$ emissions from road dust re-suspension in Surat district are 55.24 and 13.29 kt/year respectively.

5.2.4 Residential Sector

Residential sector emissions are caused by burning of fuel mainly for cooking purposes. In this sector, emissions are estimated by estimating the category-wise fuel use in the district of Surat. The basic approach (equation 10) employed for emission estimation from the residential sector is,

$$[E_P]_R = \sum_{a=1}^{2} \sum_{f=1}^{6} Pop_{(a,f)} \times C_{(a,f)} \times EF_{(f,p)} \quad \text{............ (10)}$$

where, $[E_P]_R$ is the emission of a particular pollutant (p) from the residential sector, $Pop_{(a,f)}$ is the population of Rural (a=1) and Urban (a=2) region in Surat district using a particular type of fuel (f), $C_{(a,f)}$ = Region specific per capita consumption of a particular fuel, $EF_{(f,p)}$ = Emission factor of the particular pollutant (p) of the particular fuel type (f).

City and district specific population in 2019 was estimated following population growth equation using the population of 2011 and district population growth rate in rural and urban areas using equation 11 (India Census, 2011).

$$\boldsymbol{Pop_{2019}} = \boldsymbol{Pop_{2011}}[\mathbf{1} + \boldsymbol{R}\%]^{\boldsymbol{t}} \qquad \text{………… (11)}$$

Where, Pop_{2019} is projected population of Rural (a=1) and Urban (a=2) region in Surat city and district, $Pop_{2011}$is the population of Rural (a=1) and Urban (a=2) region in Surat district during 2011, R%district specific population growth rate in rural and urban areas and t is the time period between 2011 and 2019.

Ward-wise population and household data of the Surat city was collected from the India census (2001 and 2011) for the year 2001 and 2011. These data were used to derive the annual population growth rate and growth rate of number of people living in one household. These growth rates were then used to project the ward-wise population and number of households in 2019.

District specific monthly per capita consumption of different fuels in the rural and urban areas was collected from NSSO (2014). Six major fuels those are used in the residential households for cooking and lighting purposes were included in the emission inventory preparation – a) Fuel wood, b) dung cake, c) crop residue, d) coal, e) kerosene and f) LPG. During estimation 80% of per capita kerosene consumption in the rural areas was assumed to be used for lighting purpose while 80% of per capita kerosene consumption in the urban areas was assumed to be used for cooking purpose. Electricity used in the residential sector has no reported emission of air pollutants, so it was not considered during the preparation of emission inventory. On the other side, emissions from the PNG and gobar gas uses in residential sector were not considered owing to their very low usages (India census, 2011).

Fuel specific emission factors of different pollutants (Table 4.9) ($EF_{(f,p)}$) were taken from Datta and Sharma (2014) and Pandey et al. (2014)

Table 5.9: Emission factors (g/kg) of different pollutants from different fuel types used in the residential sector

Pollutant	Fuel wood	Crop Residue	Cow Dung Cake	Coal	Kerosene_ Cooking	LPG	Kerosene Lightning
PM_{10}	6.77	8.6	10.5	8.26	3.6	0.35	91.33
$PM_{2.5}$	4.6	5.7	4.4	4.04	3	0.35	91.33
SO_x	0.8	0.7	0.6	15.33	0.4	0.4	NA
NO_x	1.7	1.8	1	2.16	1.3	2.9	NA
CO	66.5	64	78.6	59.46	43	2	29.3
NMVOC	15.89	8.5	24.1	10.5	13.3	3.7	NA

NA: Not available

Estimated fuel consumption in residential sector in Surat district

Annual consumption of different types of fuels in the residential sector of Surat city and district during 2019 is illustrated in Figure 5.11. Region wise annual fuel consumption revealed that rural households report higher consumption of fuel wood (175.07 Kt/annum) and crop residue (19.39 Kt/ annum) compared to consumption of 7.32 Kt/annum and 0.93 Kt/annum, respectively in urban households. In urban households, coal used for cooking was estimated with higher consumption of 7.06 Kt/annum compared to 2.16Kt/annum in rural households. Whereas, LPG consumption in rural and urban households of district were estimated at 13.72 Kt/annum and 12.36 Kt/annum respectively. Consumption of different types of fuels (Kt/annum) in residential households of Surat district and city is shown in Table 4.10

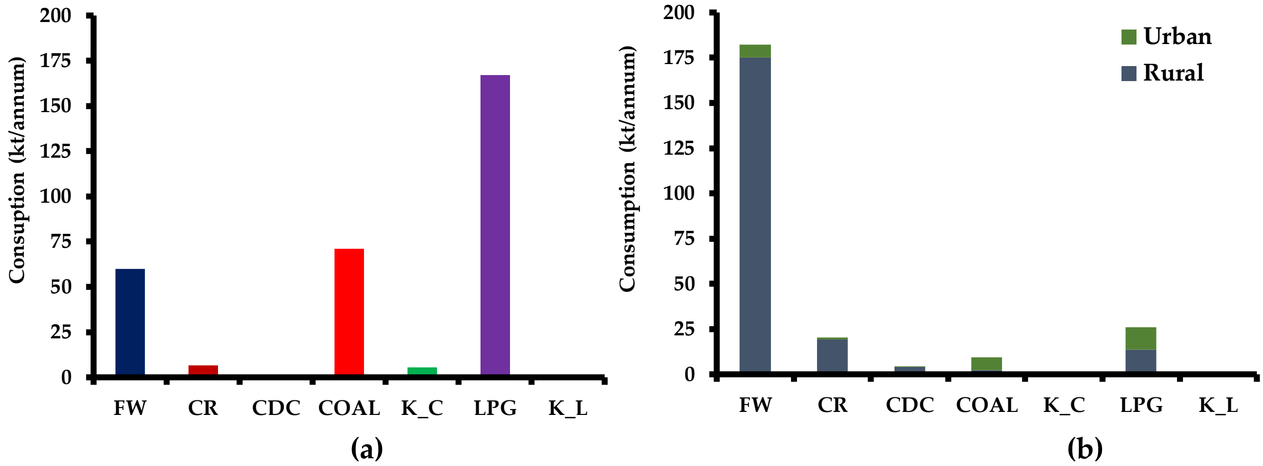


Figure 5.11: Consumption of different fuels in urban and rural households of Surat (a) city (b) district

FW: Fuelwood; CR: Crop Residue; CDC: Cow Dung Cake; K_C: Kerosene for Cooking; K_L: Kerosene for Lightning; LPG: Liquified Petroleum Gas

Estimated fuel consumption in residential sector in Surat city

Estimated city level annual consumption of different fuel (Figure 5.11 (a)) revealed that households of Surat city using LPG for cooking were estimated with higher consumption at 167.05 Kt/annum, followed by coal at 68.85 Kt/annum and fuel wood at 66.28 kt/annum (Table 4.10).

Table 5.10: Consumption of different types of fuels (Kt/annum) in residential households of Surat district and city

Location	Fuel wood	Crop residue	Cow dung cake	Coal	Kerosene_ cooking	Kerosene_ Lightening	LPG
Rural	175.07	19.40	3.93	2.16	0.46	0.68	13.72
Urban (Excluding city)	7.32	0.94	0.09	7.07	0.91	0.01	12.36
City	59.75	6.41	0.79	71.00	5.39	0.04	167.06

Emission inventory of residential sector in Surat

The activity data of different fuels is used along with the fuel specific emission factors to calculate the emissions from the Surat city (Table 4.11) and Surat district (Table 4.12).

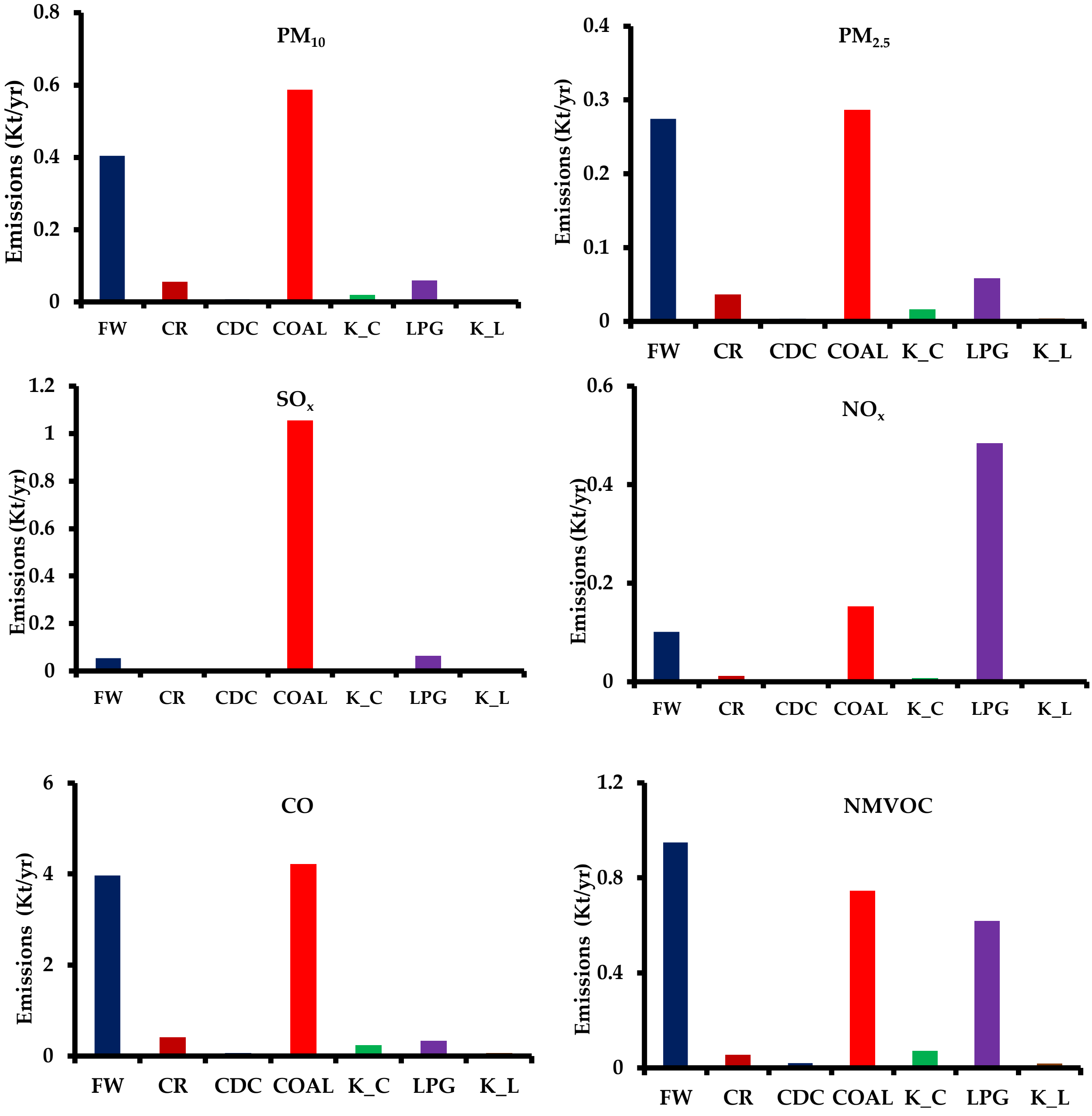


Figure 5.12: Fuel wise emissions of different pollutants from residential household of Surat city during 2019

FW: Fuel wood; CR: Crop residue; CDC: Dung cake; K_C: Kerosene used for cooking; K_L: Kerosene used for Lighting (Wicked Lamp); LPG: Liquid Petroleum Gas

Fuel-specific emission of different pollutants revealed that households in the Surat city using coal and biomass for cooking contribute to higher emission compared to other fuels during 2019 (Figure 5.12). Significantly higher SO_x emission from residential sector in Surat city are attributable to coal consumption in city households. Further, since there is significant population base dependent on LPG, significant NO_x emissions are attributed to it. Moreover, the findings suggest that although the LPG consumption in city households have increased emission of different pollutants remain significant as there is still significant proportion of city population dependent on non-efficient fuel (coal and fuel wood) for meeting their energy demands.

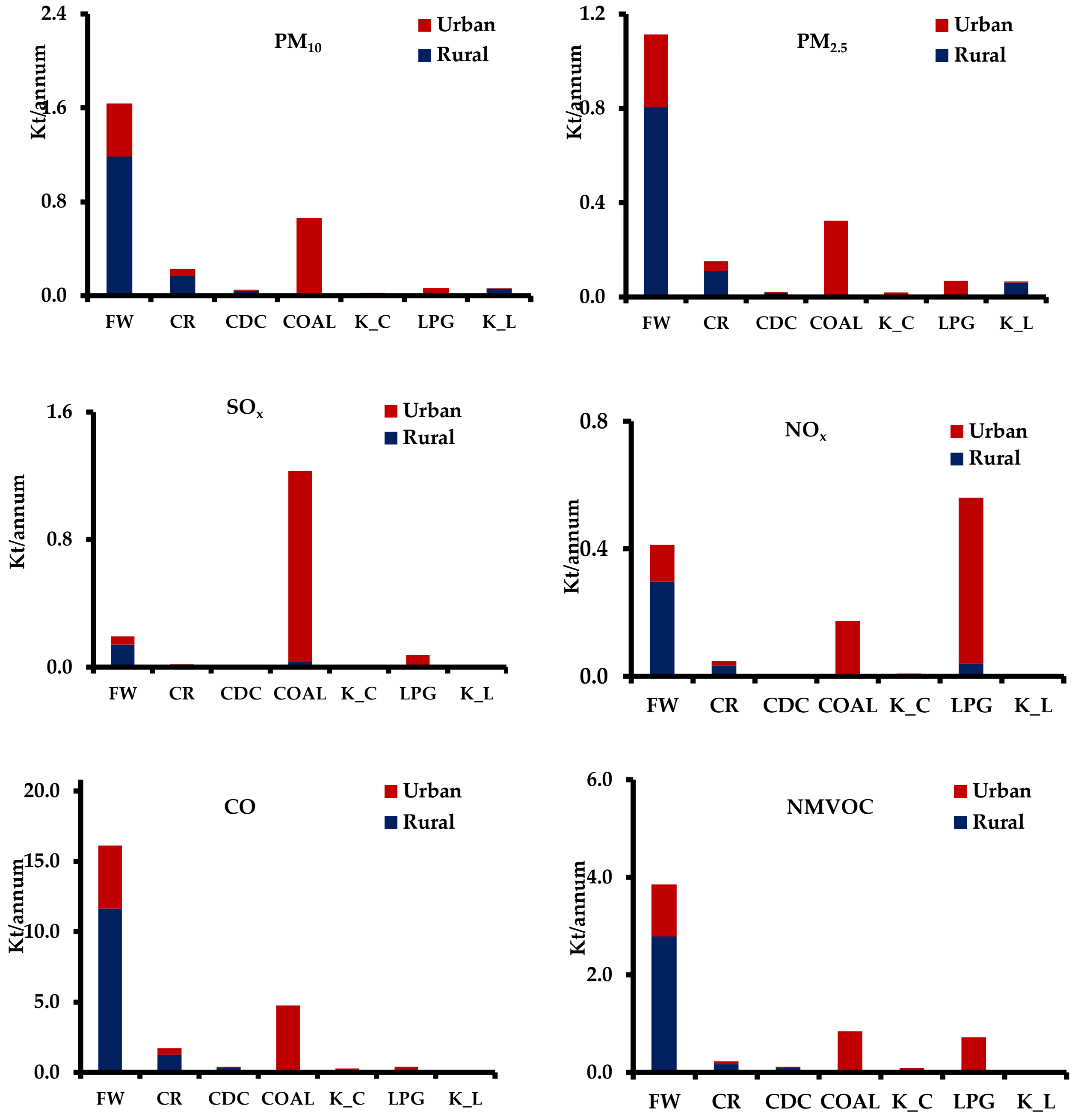


Figure 5.13: Fuel wise emissions of different pollutants in Kt from rural and urban household of Surat district during 2019

FW: Fuel wood; CR: Crop residue; CDC: Dung cake; K_C: Kerosene used for cooking; K_L: Kerosene used for Lighting (Wicked Lamp); LPG: Liquid Petroleum Gas

Emission inventory of different pollutants (Figure 5.13) from residential sector shows higher loads in rural households compared to urban households of Surat district during 2019. Fuel wood used for cooking is reported with highest share of emissions. Since significant proportion of rural population in Surat depends on fuel wood to meet energy demands, the emissions were higher from fuel wood compared to other non-efficient fuels (dung cake, crop residue, and kerosene). Moreover, higher SO_x emission estimated in urban area of Surat district is attributable to higher coal consumption in urban households.

Table 5.11: Fuel-wise emissions (kt) of different pollutants in residential households of Surat city during 2019.

Pollutant	FW	CR	DC	COAL	K-C	LPG	K-L	Total
PM_{10}	0.405	0.055	0.008	0.586	0.019	0.058	0.005	1.137
$PM_{2.5}$	0.275	0.037	0.003	0.287	0.016	0.058	0.004	0.680
SO_X	0.048	0.004	0.000	1.088	0.002	0.067	0.001	1.211
NO_X	0.102	0.012	0.001	0.153	0.007	0.484	0.002	0.760
CO	3.973	0.410	0.062	4.221	0.232	0.334	0.058	9.291
NMVOC	0.949	0.055	0.019	0.745	0.072	0.618	0.018	2.476

Table 5.12: Fuel-wise emissions (kt/yr) of different pollutants in urban and rural areas of Surat district during 2019.

Region	Pollutant	FW	CR	CDC	COAL	K_C	LPG	K_L	Total
Rural	PM_{10}	1.19	0.17	0.04	0.02	0.00	0.00	0.06	1.48
Urban	PM_{10}	0.45	0.06	0.01	0.64	0.02	0.06	0.00	1.26
Rural	$PM_{2.5}$	0.81	0.11	0.02	0.01	0.00	0.00	0.06	1.01
Urban	$PM_{2.5}$	0.31	0.04	0.00	0.32	0.02	0.06	0.00	0.76
Rural	SO_x	0.14	0.01	0.00	0.03	0.00	0.01	0.00	0.19
Urban	SO_x	0.05	0.01	0.00	1.20	0.00	0.07	0.00	1.33
Rural	NO_x	0.30	0.03	0.00	0.00	0.00	0.04	0.00	0.38
Urban	NO_x	0.11	0.01	0.00	0.17	0.01	0.52	0.00	0.83
Rural	CO	11.64	1.24	0.31	0.13	0.02	0.03	0.02	13.39
Urban	CO	4.46	0.47	0.07	4.64	0.27	0.36	0.00	10.27
Rural	NMVOC	2.78	0.16	0.09	0.02	0.01	0.05	0.00	3.12
Urban	NMVOC	1.07	0.06	0.02	0.82	0.08	0.66	0.00	2.72

* Urban includes city and towns

5.2.5 Agriculture Sector

Emission inventory of different pollutants from burning of different crop residues in the agriculture fields has been developed following the IPCC (2006) inventory preparation guideline. The crops that are considered for inventory preparation were based on the primary survey of the district, as well as literature survey of the previous studies conducted in the study area. Emission from the in-situ burning of crop residue is calculated using equation 12,

$$E_P = \sum_{a=1}^{x} \mathbf{Pa} \times \mathbf{Ra} \times \mathbf{fDa} \times \mathbf{fBa} \times \mathbf{Bf} \times \mathbf{Ef} \ldots\ldots\ldots\ldots\ldots \text{(12)}$$

Where, E_P is the emission of a particular pollutant p (g); P_a is the total production of a particular crop (a) in kilogram and (x) is the number of crops selected for estimation of emission; R_a is the fraction of residue generated for the production (P_a) of the particular crop (a); fD_a is the fraction of dry matter in the residue of the particular crop (a); fB_a is the combustion efficiency of crop residue that is burnt, B_f is the burning fraction of the crop estimated on the basis of MODIS FRP data (has been explained below) and E_f is the emission factor of the particular pollutant (g/Kg).

The emissions for this sector have been estimated for the year 2016 based on availability of crop production datasets. Thereafter, the emissions have been projected to 2019 based on the percent change in the net fire radiative power (FRP) value (based on satellite detection of agricultural fires) between 2016 and 2019. The residue to crop fractions (R_a) of different crops has been adopted from Datta and Sharma (2014). The dry matter fraction in different crop residues (fD_a) were taken from Jain et al. (2014). The combustion efficiency (fB_a) of different crop residues was used as reported in Turn et al. (1997) (Table 4.13).

Table 5.13: Coefficients of different crop residues to estimate the emissions of different pollutants

Co-efficient	Rice	Wheat	Cotton	Maize	Sugarcane	Others
Residue to Crop ratio (Ra)[1]	1.59	1.70	0.40	3.00	2.00	2.00
Dry Fraction (*f*Da)[2]	0.86	0.88	0.80	0.90	0.80	0.90
Combustion efficiency (*f*Ba)[3]	0.89	0.86	0.90	0.92	0.68	0.91

[1] Datta and Sharma (2014); Jain et al. (2014)., Turn et al. (1997)

Burning fraction (Bf) of residues has been calculated using the MODIS Fire Radiative Power (FRP) data. The FRP dataset of the NASA's MODIS (Aqua and Terra) satellites was used to identify the crop residue burning locations at 2 Km × 2 Km grid over the study region. This was further employed to spatially allocate the emissions.

The MODIS active fire products provide fire detections at the satellite overpass times. Terra and Aqua respectively cross the equator at approximately 10:30 a.m. and 1:30 p.m. local time during daytime and 10:30 p.m. and 1:30 a.m. during night-time. The MODIS Level 2 active fire products (abbreviated MOD14 for Terra and MYD14 for Aqua) contain for each fire pixel the detection time, geographical coordinate, confidence (low, nominal, and high), fire radiative power (units: MW per pixel), brightness temperature at the MODIS band 21 (3.660–3.840 μm) and band 31 (10.780–11.280 μm), and average brightness temperature of the surrounding non-fire pixels at bands 21 and 31 (Giglio, 2015). The FRP estimates in MODIS Collection 6 (C6) active fire product are retrieved following the method developed by Wooster et al. (2003).

The FRP products for the whole country retrieved from MODIS C6 datasets are plotted on GIS along with LULC (land use and land cover) for each studied year. The FRP's detected over agricultural land use area was extracted for further analysis, as it is assumed that rest of the FRP's detected belongs to some other form of burning. The distribution of FRP was scaled between 0-90% of burning activity using national level FRP datasets. The fraction obtained from this exercise is used as Bf in estimation of agricultural residue burning emission.

The emission factors applied in process have been shown in Table 4.14 while, the final agriculture residue burning emissions estimated for the Surat district are shown in Table 5.15.

Table 5.14 : Emission Factor (kg/t) of different pollutants for different types of crop residues

Crop residue (Kg/t)	PM_{10}	$PM_{2.5}$	SO_X	NO_X	CO	NMVOC
Rice	7.1	5.45	2.4	0.45	58.9	6.3
Wheat	8	5.4	1.45	0.5	65.5	0.5
Cotton	10	5.5	0.5	1.7	28.1	19.1
Maize	6.6	6	1.8	0.2	46.4	4.5
Sugarcane	6.9	5.4	0.5	1.5	28.1	0.5

Source: Sharma et al., 2016

Table 5.15: Annual emission (kt) of different pollutants for Surat district

Pollutants	Emissions (Kt/yr)
PM_{10}	2.94
$PM_{2.5}$	2.28
CO	13.15
SO_X	0.29
NO_X	0.59
NMVOC	0.54

5.2.6 Thermal Power Plants

Thermal power plants convert heat energy into mechanical energy and further into electricity using turbines and generators. For this conversion, primary energy fuel like coal, lignite, natural gas are used as fuel to produce steam by heating up distilled water in boiler. Large quantities of coal, lignite and natural gas is burnt annually in the power plants, which leads to the production of fly ash and bottom ash and flue gasses and results air pollution also.

The activity data required for estimation of emissions from power plants in and around Surat were collected from GPCB. As per the data provided by GPCB, there are, four gas based power plants, one-lignite based, one coal based power plants in the district of Surat. Different fuel used in power plants of Surat are shown in Table 5.16

Table 5.16: Types of fuels used in power plants in Surat

Name	Fuel type
Gujarat State Electricity Corporation Limited	Natural Gas
Torrent Power Ltd (Sugen 1530 MW Power Plant)	Natural Gas
Gujarat Industries Power Co. Ltd. (Surat Lignite Power Plant)	Lignite
National Thermal Power Corporation Ltd,	Naphtha
Gujarat State Energy Generation Ltd	Natural Gas
Essar Power Hazira Ltd	Coal
Bhander Power Ltd.(Essar Group Co.-525 Mw)	Natural Gas

For emissions estimation of power plants, information such as fuel consumption data, type of APCD (retrieved from GPCB) has been used. Ratio of flyash to bottom ash was gathered from literature. Coal based power plants in Surat use imported coal with relatively low contents of ash (7%) and sulphur (0.05%).
Emissions from gas based power plants are estimated using fuel consumption data and EF of natural gas. As there is no ash content remains in gas combustion process, emissions of $PM_{2.5}$, PM_{10}, SO_2, CO are estimated directly with assumption of no ESP installed in ags based power plants but for NO_x emissions, Selective Catalytic Reduction (SCR) with 80% of efficiency is assumed. Emissions from coal and lignite based power plants are estimated using fuel consumption data, efficiency of APCDs (mainly ESP), sulphur content, ash content with bottom ash percentage. Equation used for emissions estimation from gas based power plants;

For PM_{10}, $PM_{2.5}$ and other gases

$$[E_P]_g = \sum_{a=\_}^{n} [P_g]_a \times EF_P \qquad \text{.............. (13)}$$

For NO_x

$$[E_N]_g = \sum_{a=1}^{n} [P_g]_a \times EF_N \times (1-\eta) \qquad \text{............. (14)}$$

Where, E_P is the emission of particular pollutant (p), [Pg]a is the annual gas consumption in power plant , EFp = Emission factor of the particular pollutant (p). EF_N = Emission factor of the NO_X and η is the efficiency of installed emission control equipment i.e. SCR (80% efficiency).

Emissions from coal fired power plants are function of the quality of fuel (ash content and sulphur content), the type of boilers, and the types of air pollution control devices used and their efficiency. Equation used for emissions estimation from coal and lignite based power plants are;

For PM_{10} and $PM_{2.5}$

$$[E_{PM}]_{C\&L} = \sum_{a=1}^{n} [P_{C\&L}]_a \times A_c \times (1-fb_r) \times M \times (1-\eta) \qquad \text{........ (15)}$$

For gases

$$[E_g]_{C\&L} = \sum_{a=1}^{n} [P_{C\&L}]_a \times EF_g \times (1-\eta) \qquad \text{............ (16)}$$

where, E_{PM} is the emission of particulates, E_g is the emission of gaseous pollutants, $[P_{C\&L}]_a$ is annual coal consumption in plant a, A_c is ash content of coal (7%) and lignite (33%), fb_r is the ratio of bottom ash to total ash, M = particulate mass fraction (0.6 for $PM_{2.5}$ to PM_{10} and 0.75 for PM_{10} to total particulates), η is the efficiency of installed emission control equipment and E_{Fg} is the emission factor of the particular gaseous pollutant. For SO_2 emission factor, sulphur content of 0.05% was used for imported coal and 0.5% was used for lignite.

Emission factors for specific fuels and pollutants were taken based on review of published literature. For coal and lignite PM_{10} is taken as 75% of total fly ash and $PM_{2.5}$ is 60% of PM_{10} (USEPA, 2015). Gaseous pollutants emission factor for coal and lignite fuel are summarized in Table 5.17.

Table 5.17: Emission factor of coal, lignite and naphtha consumed in power plants

Pollutant	**Emission factor (g/Kg)**	
	Coal/ Lignite	**Naphtha**
PM_{10}	Based on ash content	4.49
$PM_{2.5}$	60% of PM_{10}	-
SO_2	Based on sulphur content	0.89
NO_x	4.5	3.14
CO	0.3	1.79
NMVOC (Mg/PJ)	15	

**Emission factor of SO_2 derived from sulphur content of coal and lignite, NO_x and CO emission factor was used from the source apportionment study, Pune CPCB-2010. NMVOC taken from GAINS Asia data base*

Similarly, emissions from gas based powers plants were estimated using emissions factors taken from Source apportionment, Pune - CPCB 2010 and GAINS Asia Database. Emission factors for particulate matter and gaseous pollutants for natural gas are presented in Table 5.18.

Table 5.18: Emission Factor of various pollutants emitted from natural gas

Pollutant	Emission factor ($Kg/10^6\ m^3$)
PM_{10}	121.60
$PM_{2.5}$	121.60
SO_2	9.60
NO_x	1600
CO	1344
NMVOC	0.091

Total pollutant emissions and fuel-wise distribution of emissions from the thermal power plants in Surat are shown in Table 5.19 and Table 5.20 respectively

Table 5.19: Emission of pollutants from thermal power plants in Surat district

Pollutants	Emissions (Kt/yr)
PM_{10}	4.719
$PM_{2.5}$	3.130
SO_2	37.699
NO_x	27.291
CO	11.554
NMVOC	0.729

Table 5.20: Fuel based emissions from thermal power plants in Surat district

Fuel	Emissions (Kt/yr)					
	PM_{10}	$PM_{2.5}$	SO_2	NO_x	CO	NMVOC
Gas	0.793	0.793	0.063	2.088	8.768	0.001
Coal/Lignite	3.89	2.34	37.01	23.005	1.534	0.728
Naphtha	0.031	0.031	0.623	2.198	1.253	-

It is evident from the Figure 5.14 that coal emissions account for about 99% of the SO_x emission, 86% of the PM_{10} emissions followed by 84% NO_x emissions and 72% $PM_{2.5}$ emissions from this sector. Whereas, natural gas power plants contributes about 76% of the total CO emissions and 25% of the $PM_{2.5}$ emissions from power generation sector. Major pollutant from naphtha is CO which accounts for only 11% of the total emissions from the sector. Due to ESPs, emissions of PM are somewhat controlled but SO2 and NOx emissions are high to absence of flue-gas desulphurization and SCR control technologies.

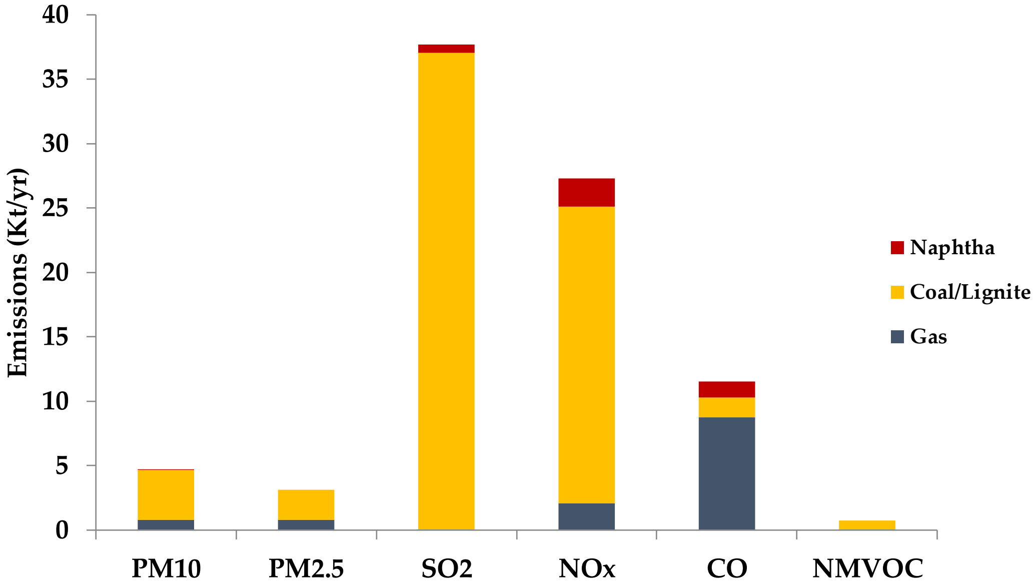


Figure 5.14: Total emissions of different pollutants from different fuel based thermal power plants

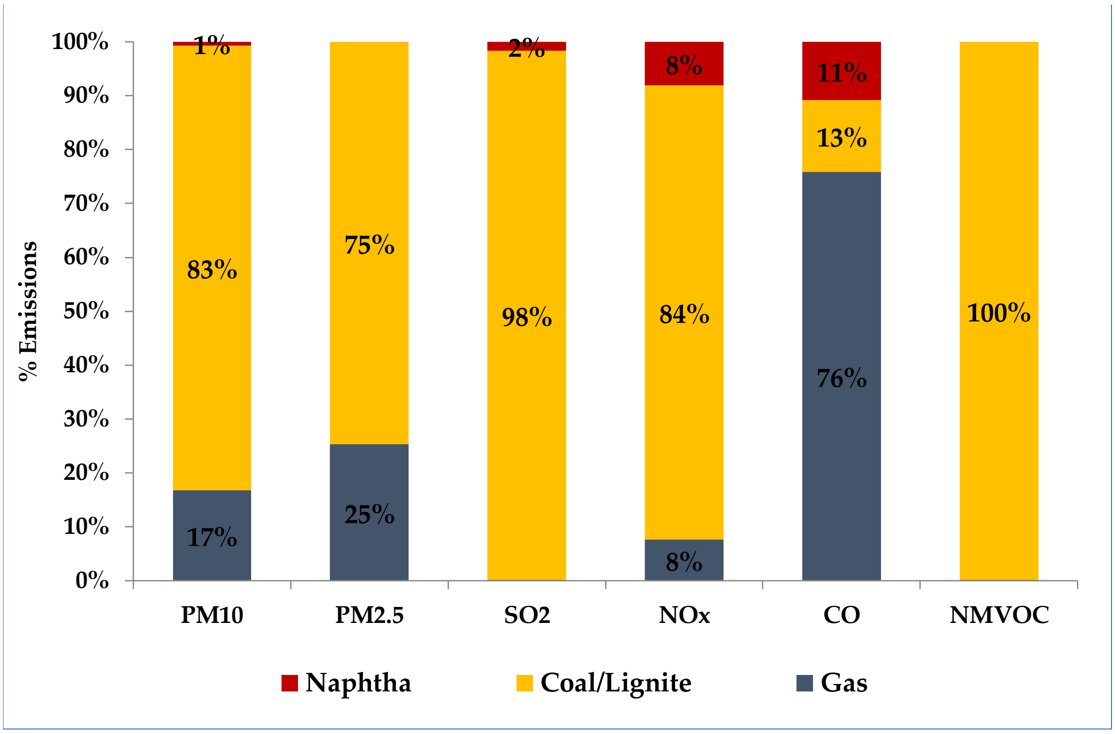


Figure 5.15: Percentage shares of pollutants emitted from different fuel based thermal power plants in Surat

5.2.7 Municipal Solid Waste Burning

Solid waste management in Indian cities has emerged out as a major concern over the past few decades. The quantum of waste generated in Surat has increased over time due to rapid increase in population and increased per capita waste generation. According to Surat Municipal Corporation, on an average 450 gm/day/person of waste is generated in Surat. The problem of MSW management becomes much more severe due to limitations of collection in all the areas across the city, which leads to accumulation of a significant quantity of hazardous MSW in open spaces across the city. For settlement of illegally dumped waste, people usually practice open waste burning which results in release of toxic air pollutants.

In order to estimate emissions from refuse burning, the amount of waste generated and burnt is the main information to be collected. The data related to total waste burnt in Surat city and in other sub districts were collected from WRI based on the primary survey carried out by them in the city and district and emission factors used for estimation were taken from Akagi et al. (2011).

The basic equation employed for emission estimation from the refuse burning sector is:

$$E_p = W_B \times E_f \quad \text{...} \; (17)$$

Where, E_p is the emission of pollutant p, W_B is the waste burnt and E_f is the emission factor Emission factors (g/kg) and total emissions (Kt/year) from refuse burning activity for Surat district and city are presented in Table 5.21.

Table 5.21: Emission Factors and emissions of pollutants from MSW burning in city and district of Surat

Pollutant	Emission factor (g/kg)	Emissions City (Kt/year)	Emissions District (Kt/year)
PM_{10}	11.9	0.27	0.39
$PM_{2.5}$	9.8	0.23	0.32
SO_2	0.5	0.01	0.02
NO_X	3.74	0.09	0.12
CO	38	0.87	1.26
NMVOC	14.5	0.33	0.48

It can be seen in Figure 5.16 that due to complete combustion, CO accounts for maximum emission from MSW burning followed by NMVOC. The emissions could be attributed to the high amount of organic waste present in the MSW which almost holds around 50-55% of the total waste share.

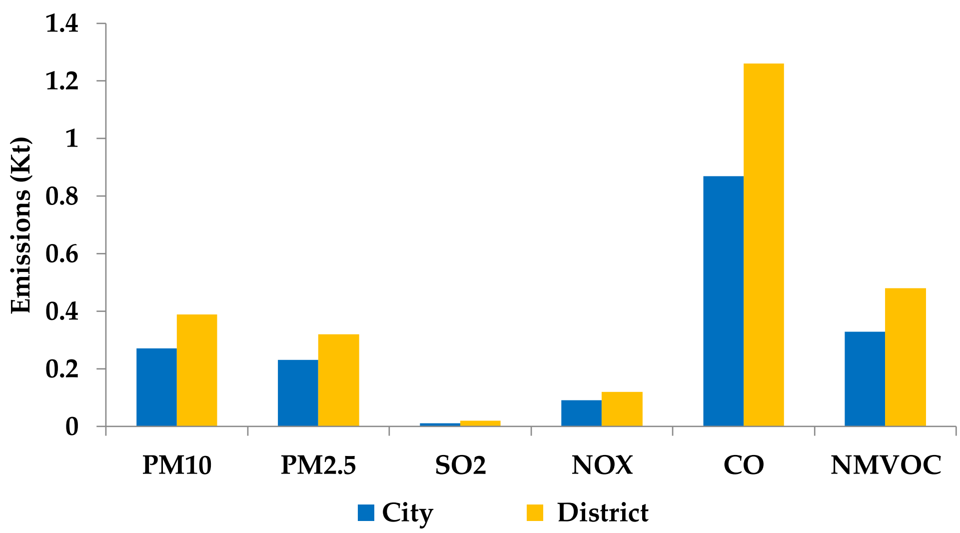


Figure 5.16: Emission of pollutants emitted from MSW burning in Surat city and district.

5.2.8 Brick kilns

Apart from major polluting sectors like transport, residential sector and MSW burning, brick kilns contributes significantly to deterioration of ambient air quality. Brick kilns are one of the largest consumers of coal, accounting for around 35-40 million tones annual consumption in the country (Rajaratnam et.al 2016). Surat district consists of 92 brick kilns which were marked spatially using Google earth. In order to estimate the emissions from brick kilns, an approach based on bricks production and technology used for production, was employed.

The production based approach accounts for weight of each brick (3 Kg) as the activity data. Cumulative weight of the bricks produced annually from all the kilns was used to estimate emissions for brick kiln industry.
Emission were calculated using following equation

$$E_p = W_B * E_f \quad \text{...} \quad (18)$$

where, E_p is the emission of pollutant p, W_B is cumulative weight of bricks produced annually and E_f is the production based emission factors.

There are a variety of technologies which can be used for produciton of bricks. It was understood from GPCB that the main technology used for production of bricks in Surat is Fixed Chimney Bull Trench Kilns (FCBTK). The total weight of the bricks produced by a particular firing technology is estimated from the total number of brick produced annually in a region and weight of the fired brick. After consultation with experts and based on TERI's past experience in this sector, we have assumed the weight of the fired brick as 3 kg. Technology wise emission factors for different pollutants are selected based on review of published literature (GAINS Asia, Greentech Energy Solutions, Rajaratnam et al., 2014). Total emissions along with their emission factors used for Brick kilns in Surat city and district are summarized in Table 5.22. Brick kiln emisisons are allocated at their respective locations marked on google earth.

Table 5.22: Emission Factors and total emission of different pollutants from Brick Kilns in Surat

Pollutant	Emission factors (g/kg fired brick)	Emission (Kt/year)
PM_{10}	0.86	1.07
$PM_{2.5}$	0.18	0.224
SO_2	0.66	0.82
***NO_x**	0.00005	0
****CO**	3.63	4.508
***NMVOC**	0.1	0.124

*GAINS Asia data set, ** Rajaratnam et.al 2016

5.2.9 Diesel Generators (DG) sets

Power cuts are common in India due to high demand of electricity. For uninterrupted work operations in sectors like residential buildings, shopping complexes, industries and commercial buildings, IT centres, malls use DG sets as source of backup power. Emissions from this sector mainly depend on DG set capacity and fuel consumption during operation time. In order to inventorise emission from DG sets, the information on number of DG Sets, their capacity, operational hours and fuel consumption were collected by primary survey at twelve different locations in the Surat district (each location representing a grid of 2 X 2 km^2). The survey locations covered residential areas, industrial locations, commercial hubs, transport congested areas in the district to capture the actual scenario of DG sets usage and emissions.

The following equation is used to calculate emissions from DG sets,:

$$E_p = C \times t \times 36 \times 10^5 \times E_f \text{ .... (19)}$$

Where, E_p is the emission of particular pollutant *p*, C is the capacity of DG set installed (KWh), t is the number of DG running hours, 36×10^5 is the conversion factor. The data collected in these twelve grids is extrapolated for other grids in the study domain based on population density for estimation of total emissions from both Surat city and district. Emissions factors are taken from AP-42, USEPA and shown in table along with estimated emissions.

In case of DG sets emission, NO_x is a major concern. The emissions from city and district along with the emission factors is shown in Table 5.23. Emissions from city and districts are also shown in Figure 5.17. It is to be noted that with limited interruptions of power, the DG set emissions are found to be small in comparison to other sectors in Surat.

Table 5.23: Emission of various pollutants from Diesel generators in Surat district

Pollutant	Emission factor (ng/Joule)	Emissions – City (Kt/year)	Emissions – District (Kt/yr)
PM_{10}	133.3	0.018	0.123
$PM_{2.5}$	113.31	0.015	0.104
SO_2	124.7	0.017	0.115
NO_X	1896.3	0.258	1.748
CO	408.5	0.056	0.376
NMVOC	154.8	0.021	0.143

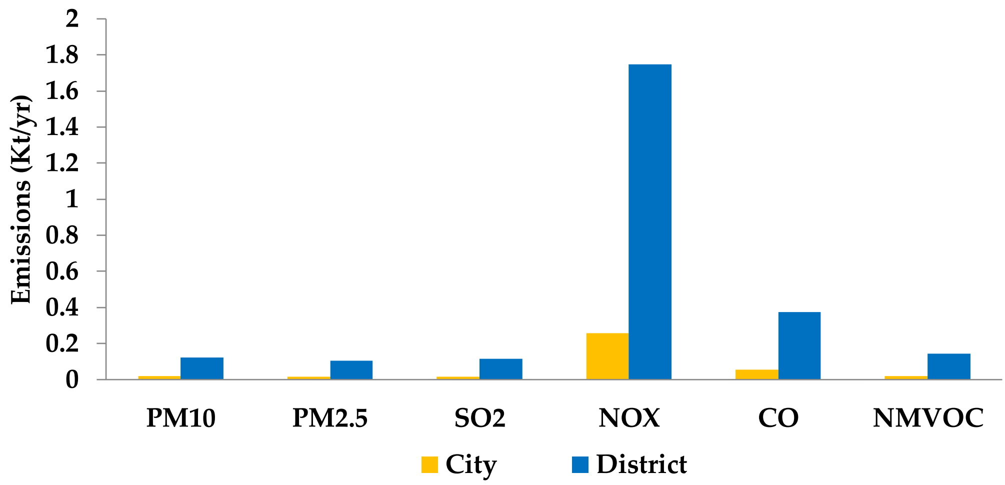


Figure 5.17: City and district level emissions from diesel generators

5.2.10. Hotels and Restaurants

As a result of tremendous growth of hotel & restaurant industry in India during last few decades, emissions from this industry have been growing. Use of different cooking fuels for cooking (liquefied petroleum gas (LPG), charcoal and wood) in tandoors/barbeques in hotels and restaurants generates emissions of different pollutants. In order to inventorise emission of various pollutants from hotel and restaurants, a primary questionnaire-based survey was carried out at twelve locations (at 12 different grids) in Surat district to gather information on type of fuel consumption in restaurant/hotels. Based on the survey, charcoal and LPG were identified as the major fuels used in eateries in addition to wood and coal. Data collected in these 12 grids were extrapolated for other grids in the study domain based on population density and landuse pattern. The data on unauthorized small eateries were estimated based on the primary survey carried out by WRI in around 101 Municipal wards. Estimation of emissions from this sector has been carried out using equation

$$\mathbf{Ep = C_f \times E_f} \ldots\ldots\ldots\ldots \mathbf{(20)}$$

Where, E_p is the emission of particular pollutant *p*, C_f= Fuel consumption by the hotel/ restaurant, E_f= Emission factor of different fuels used in cooking.

Emission factor for different fuel types were collected based on review of published literature. Emission factors and annual emissions from Hotels and Restaurants sector are summarized in Table 5.24**.** It can be seen that the emissions are low but significant from restaurant and hotel sources.

Table 5.24: Emission factors and emission of pollutants from Hotels/ Restaurants in Surat

Pollutants	Emission Factors (g/Kg)				Emissions (Kt/yr)	
	Coal	LPG	Wood	Charcoal	City	District
PM_{10}	14	2.1	17.3	1.95	0.111	0.158
$PM_{2.5}$	8.4	2.1	12.1	0.6825	0.073	0.092
SO_2	13.3	0.4	0.2	0.34	0.042	0.089
NO_x	3.99	1.8	1.3	2.34	0.072	0.086
CO	24.92	0.252	126.3	275	1.14	6.129
NMVOC			9	10.5	0.010	0.092

5.2.11 Landfill Emissions

Emissions from landfills are estimated on the basis of the municipal waste generated and collected and dumped at the landfill sites. The waste left untreated finally lands into open sites or landfills. A major fraction of urban MSW is biodegradable (51%), recyclable (17.5%) and inert (31%). Currently, Surat municipality generates about 2200 MTD of waste daily, out of which 2150 MTD of waste is collected and transported through primary and secondary collection techniques. Primary collection techniques include sweeping during day time, door to door collection, night scrapping etc. While secondary collection includes municipal solid waste collected through primary collection system being sent to the Khajod Disposal in a mechanically compacted way. Emissions from landfill sites are estimated assuming that ~2% of waste is burnt at dumpsite by rag pickers and landfill fires. Equation employed for the estimation is –

$$\boldsymbol{E_p = 2\% \times W_L \times E_f} \quad \ldots\ldots\ldots\ldots (21)$$

Where Ep is the emission of pollutants p, W_L is the waste collected at landfill site and Ef is the emission factor adopted from USEPA – 42. Emission factors for the waste burning at the landfill sites and the resultant emissions in Surat are shown in Table 5.25

Table 5.25: Emission factors and emissions from landfill sites

Pollutant	Emission Factor (Kg/MT)	Emissions (Kt/ year)
PM_{10}	8	0.131
$PM_{2.5}$	5.44	0.089
SO_x	0.5	0.008
NO_x	3	0.049
CO	42	0.686
VOC	21.5	0.351

It can be seen that emissions are small but not insignificant. This is due to presence of organic waste present in the landfills.

5.2.12. Aircraft emissions

The methodology used to estimate aircraft emissions is based on an aggregate figure of fuel consumption for aviation to be multiplied with average emission factors. The pollutants emitted by aviation sector mainly come from the combustion of aviation turbine fuel that is used as fuel for the aircraft engine. These emissions have been estimated for three phases including take-off, cruise and landing phase. The Landing/Take-off (LTO) cycle includes all activities near the airport that take place below the altitude of 3000 feet (1000 m). Cruise phase includes travelling above 3000 ft (1000m) above the ground level. However, emission of pollutants in the cruise phase does not add to the emission loads as these emissions occur quite above in the atmosphere. Emission inventory of pollutants emitted from aircrafts is dependent on the number of LTO's conducted. Emission factors for pollutants per LTO are taken for estimation. The emissions are evaluated using the eq .

$$E_p = N_{LTO} \times E_F \qquad \text{……………..} \; \textbf{(22)}$$

Where, E_P is the emission of pollutant p; N_{LTO} is the fuel consumption for aviation in respective district (s); EF = Emission Factor. The emissions from aircrafts along with emission factors are shown in Table 5.26

Table 5.26: Emission Factors and total emissions from Surat airport

Pollutant	Emission Factor (Kg/LTO)	Emissions (Kt/year)
PM	0.3	0.004
NO_x	19.1	0.262
SO_x	1.5	0.020
CO	39.5	0.543
NMVOC	20.4	0.282

The emissions estimated are small but are allocated in one grid only, over the location of airport, and hence can be influential for the surround grids in terms of air quality.

5.2.13. Crematoria

Hindus, Sikhs and Jains perform wood based cremations as the last rituals towards their deceased. The estimation of emissions from cremation is done on the basis of total wood burnt during the ceremony. As per census 2011, there are about 86.5% Hindus, 0.09% Sikhs and 1.86% are residing in Surat district. Projected population for the year 2019 of these groups is accounted for emission estimation of this sector. For each cremation, on an average 350 kg wood is consumed (NEERI, 2010). For the purpose of activity data, total wood burnt over the year 2019, throughout the district was estimated based on accounted population and crude death rate (total number of deaths per year per 1,000 people) which is found to be 6.1 per 1000 for sub districts and 4.14 per 1000 for Surat city as per census 2011 and SMC respectively. This approach of estimation is referred as secondary assumption based approach and emissions were calculated using equation-

$$E_p = (P_{2019} \times F \times D_R \times 350) \times E_F \quad \ldots\ldots\ldots\ldots\ldots \mathbf{(23)}$$

Where, P_{2019} is the total population of Surat district, F is the fraction of hindus, sikhs and jains in Surat district, D_R is the crude death rate (per thousand population), E_F is the emission factor. Based on amount of wood consumption in crematoria in Surat, emissions from the crematoria in Surat city and district are presented in Table 5.27

Table 5.27: Emission of various pollutants from crematoria in city and district

Pollutant	Emission factor (kg/T)	Emissions (Kt/year)- City	Emissions (Kt/year) - District
PM_{10}	18.5	0.156	0.205
$PM_{2.5}$	9.1	0.077	0.101
SO_2	0.4	0.003	0.004
NO_x	2.55	0.021	0.028
CO	93	0.783	1.028
NMVOC	51.9	0.437	0.574

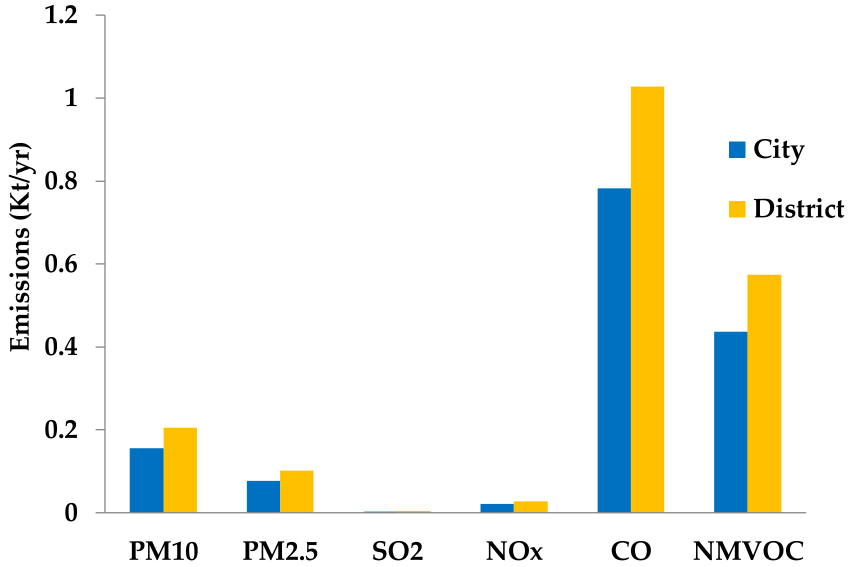


Figure 5.18: City and district level emissions from crematories

5.2.14 Construction

Construction or demolition within the study region, during a certain period of time plays an important role in emissions of particulate matter (Total PM, PM_{10} and $PM_{2.5}$). In order to inventories the emissions from this sector, high resolution images using GIS tools were used to the identify different construction sites and to demark the area of construction. In this process, digitization of the identified sites was carried out manually with the help of Google Earth in-built tools. For map creation and post processing for the polygons marked in the Google earth, ArcGIS software was used for estimation of area under construction or demolition in the study domain.

Following equation is used for emission estimation;

$$\mathbf{E_p = A_c \times T \times E_f} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (24)$$

Where, E is the suspended particulate emissions

A_C = is

T = Activity duration i.e. time duration of construction or demolition for a site.

(Rainy months (RM) not considered in activity duration, i.e. Activity duration considered as (12 – RM)

EF = Emission Factor (tons/month/acre)

The emissions of SPM from construction activities are estimated using emission factor (1.2 tons/acre/month) (*source: EPA*). PM_{10} is estimated as 35% of total PM, while $PM_{2.5}$ is 6% of total PM (*Ahuja et al. 1989; Houck et al., 1989, 1990*). Emissions factors and emissions are represented in Table 5. 28

Table 5.28: Emission of particulate matter from construction or demolition activity in Surat district

Pollutant	Emission factors	Emission - city (Kt/year)	Emission district (Kt/year)
SPM	1.2tons/acre/month	4.76	9.12
PM_{10}	35% of SPM	1.67	3.19
$PM_{2.5}$	6% of SPM	0.29	0.55

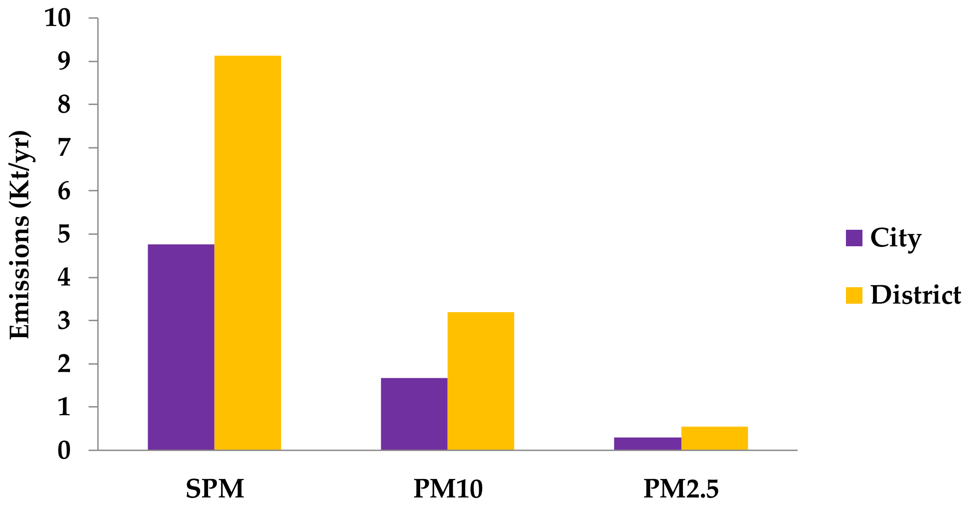


Figure 5.19: City and District level emissions from construction activities

It is to be noted that these emissions will be important in their zones of influence.

5.2.15 Hazira Port emissions

Coal handling areas at the port are a substantial source of dust emissions. Usually the coal handling areas are kept open partially because of the need for frequent material transfer into or out of storage. Movement of trucks and loading equipment, material loading onto the pile, and disturbances by strong wind currents, and load out from the pile are major factors responsible for dust emissions from coal storage and handling areas. The emissions from coal handling and storage piles from Hazira port are calculated as per AP 42 method. The emission factor is estimated using:

$$\mathbf{EF = k(0.0016)\ \{(U/2.2)^{1.3}/\ (M/2)^{1.4}\}\ \ldots\ldots\ldots\ (1)}$$

Where E_f is the emission factor in kg/megagram (kg/Mg), k is the particle size multiplier (dimensionless), k for PM_{10} is 0.35, U is the mean wind speed in meters per second (m/s), M is the material moisture content in %

$$\mathbf{Ep = EF \times Fc \ldots\ldots\ldots\ldots\ldots\ldots\ (2)}$$

Where, Ep is the emission load, EF is the emission factor estimated using equation 1,Fc is the quantity of coal ,U, the mean wind speed is taken from weather online

(https://www.weatheronline.in/weather/maps/city?WMO=42840&CONT=inin&LAND=IGJ&ART=WST&LEVEL=162&MOD=tab)
Fc, the quantity of coal handled is taken from
http://www.environmentclearance.nic.in/writereaddata/Online/TOR/17_Oct_2018_155344467O52BUVIGPFR.pdf
The estimated emissions from coal handling at the Hazira port is shown in Table 5.29

Table 5.29: Estimated emissions from Hazira Port

Parameter	Emissions (kt)
PM_{10}	0.64
$PM_{2.5}$	0.14

5.2.15 Total Emissions from Surat

Emissions inventory of all the 15 sectors have been developed which are found to be affecting the air quality of Surat city. In this section, we have summarized the entire findings of the emission inventory and identified the key emitting sectors at district and city levels. Table 5.29 shows the emission of various sectors in Surat district and Figure 5.20 is the graphical representation of the percentage shares contributed by each source to overall emission inventory of a pollutant.

Table 5.29: Total estimated emissions from various sources in Surat District

Sector	Emissions (Kt/yr)					
	PM_{10}	$PM_{2.5}$	SO_2	NO_x	CO	NMVOC
Industry	31.68	18.67	39.44	84.16	299.02	0.06
Transport	13	12.6	0.26	115.7	243.4	57.85
Road Dust Resuspension	55.2	13.29				
Solid Waste burning	0.39	0.32	0.02	0.12	1.26	0.05
DG sets	0.12	0.1	0.12	1.75	0.38	0.14
Agriculture	2.94	2.28	0.29	0.59	13.15	0.54
Residential	2.74	1.77	1.52	1.21	23.66	5.84
Brick Kilns	1.07	0.22	0.82	0	4.51	0.12
Hotel & Res	0.16	0.09	0.02	0.02	6.13	0.09
Thermal Power Plants	4.72	3.13	37.7	27.29	11.55	0.73
Construction	3.19	0.55	-	-	-	-
Crematoria	0.21	0.1	0.004	0.028	1.03	0.57
Port	0.64	0.13	-	-	-	-
Total	**116.06**	**53.25**	**80.19**	**230.84**	**604.09**	**65.99**

***NMVOC emissions in transport sector denote total hydrocarbon emissions**

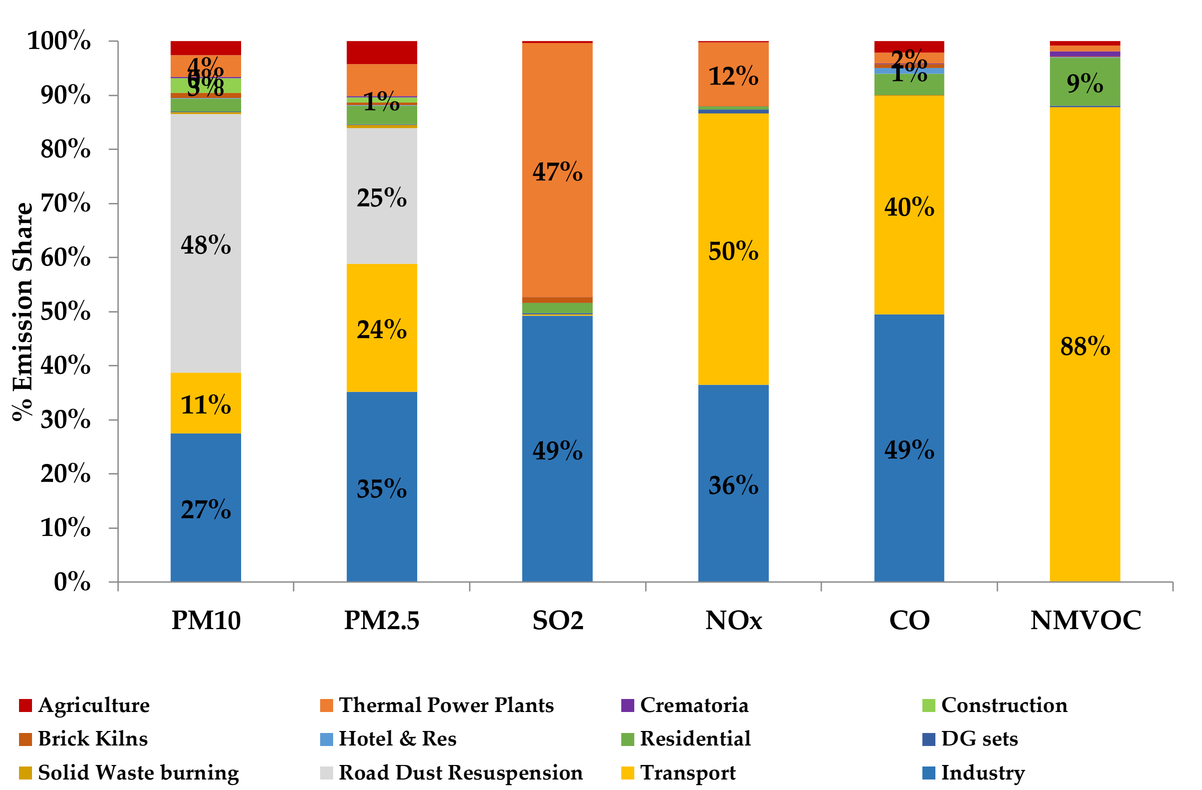


Figure 5.20: Percentage emissions share of various sources in Surat District

As evident from Figure 5.20, industries have the highest share towards the total emission loads at district level. Industries emit about 27% PM_{10}, 35% $PM_{2.5}$, 42% SO_2, 36% NOx and 50% CO towards the total emissions in the Surat district. Road dust res-suspension has a share of 47% PM_{10} and 25% $PM_{2.5}$ emissions. Other polluting sources include thermal power plants which have a share of 47% in the total SO_2 emissions and 12% NOx emissions in the Surat district. Agriculture sector accounts for 7% NMVOC emissions and 4% $PM_{2.5}$ emissions. Table 5.30 summarizes the overall emission from all the sources in Surat city.

Table 5.30: Total estimated emissions from various sources in Surat City

Sector	Emissions (Kt/yr)					
	PM_{10}	$PM_{2.5}$	SO_2	NO_x	CO	NMVOC
Industry	8.10	3.87	3.59	4.46	40.42	0.003
Transport	4.31	4.18	0.09	32.8	85.8	19.02*
Road Dust Resuspension	19.55	4.73	-	-	-	-
Solid Waste burning	0.27	0.23	0.01	0.09	0.87	0.33
DG sets	0.02	0.02	0.02	0.26	0.06	0.02
Residential	1.14	0.68	1.21	0.76	9.29	2.48
Hotel & Restaurant	0.11	0.073	0.042	0.072	1.14	0.010
Landfills	0.13	0.09	0.01	0.05	0.69	0.35
Construction	1.67	0.29	-	-	-	-
Crematoria	0.16	0.08	0.00	0.02	0.78	0.44
Aircraft	0.00	-	0.26	0.02	0.54	0.28
Total	**35.35**	**14.17**	**5.19**	**38.64**	**139.66**	**22.93**

*** NMVOC emissions in transport sector denote total hydrocarbon emissions**

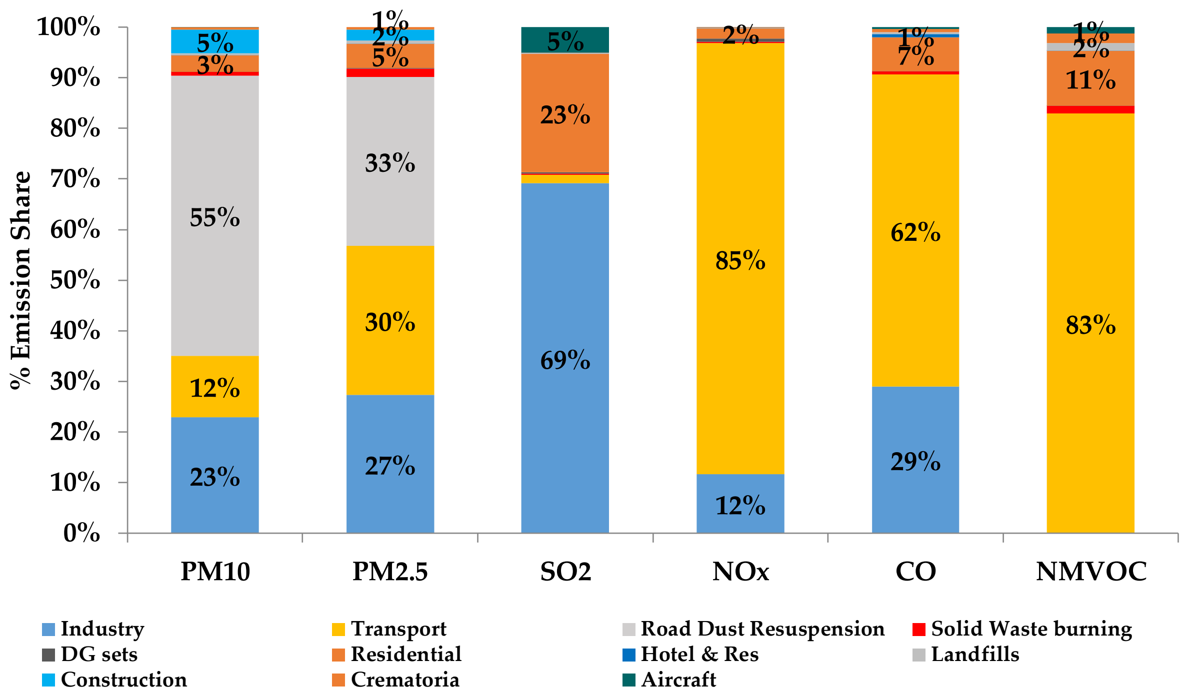


Figure 5.21: Percentage emissions share of pollutants from various sources in Surat city

It is evident from Figure 5.21 that in Surat city, industries holds a major share of SO_2 and accounts for 69% of the total SO_2 emission from all the sectors. This is followed by residential sector (23%) due to significant coal consumption in households Surat city. Similarly, NOx is the major gaseous pollutant emitted from transport sector with has a share of 85% in the total NOx emissions, followed by 12% share from industries. Moreover, transport holds 62% share in the total CO emissions. Among PM, road dust resuspension accounts for high shares in PM_{10} and $PM_{2.5}$ followed by transport and industries. Road dust resuspension in Surat city accounts for 55% of the total PM_{10} and 33% of the total $PM_{2.5}$. Transport sector accounts for 12% PM_{10} and 30% $PM_{2.5}$ whereas industries account for 23% PM_{10} and 27% $PM_{2.5}$ share. Apart from transport sector, 29% CO is emitted by industries and 7% from residential sector. Construction activities shares about 5% and 2% to the PM_{10} and $PM_{2.5}$ emissions, respectively. Aviation sector emits 5% SO_2 and 1% NMVOC.

This is to be noted that shares in emission inventories of Surat are not reflective of exact contributions of sources in $PM_{2.5}$ and PM_{10} concentrations observed in the city. $PM_{2.5}$/PM_{10} concentrations observed in Surat are inclusive of direct emissions of $PM_{2.5}$/PM_{10} as primary particles, but also include secondary particulates (sulphates, nitrates, organics) formed by gases such as SO_2, NOx, ammonia (NH_3) and VOCs through atmospheric chemical reactions. Also, $PM_{2.5}$/PM_{10} concentrations are formed by contributions from both local and regional scale sources. Other than inventories shown for Surat district and city, pollutants from far off sources (beyond Surat district) within and outside of India will also contribute to $PM_{2.5}$/PM_{10} concentrations in Surat city. Hence, a detailed dispersion modelling is required to ascertain the actual source contributions to prevailing $PM_{2.5}$/PM_{10} concentrations. The emission inventory for all the sectors for the pollutants PM_{10}, $PM_{2.5}$, SO_2, NOx and CO are shown in Figure 5.21. Figure 5.22 shows grid wise distribution of emissions for different pollutants

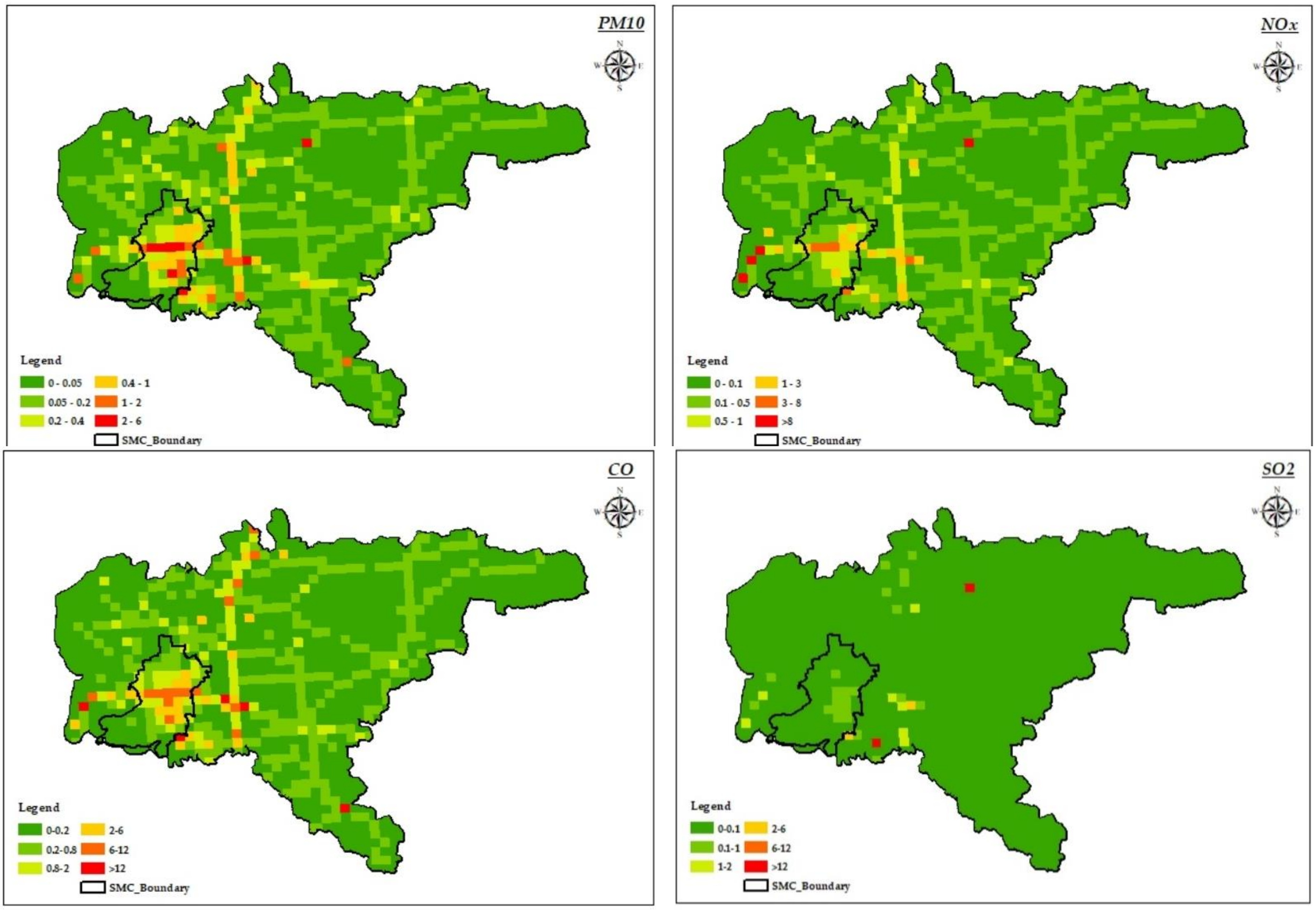


Figure 5.22: Grid wise distribution of emissions for different pollutants in Surat district

DISPERSION MODELLING

6

In this study, dispersion modelling has been carried out to use a validated air quality model for estimation of shares of different sources in prevailing PM_{10} and $PM_{2.5}$ concentrations in Surat city. The modelling framework for this study consists of a meteorological model, an air quality dispersion model and an emission inventory database which were integrated to simulate the local and regional atmospheric pollutant circulation, along with estimating the ambient pollutant concentration in the Surat city. The WRF-CMAQ modelling combination was used to simulate the ambient PM_{10} and $PM_{2.5}$ concentrations. The CMAQv5.3.1 model has been used in the study to estimate chemical transport of pollutant species under prevailing meteorological conditions. The CMAQ system employs multi-pollutant and one atmosphere approach. It has been employed in multiple air quality studies with an advantage over the traditional Gaussian-based models (ISCST3, AERMOD), which have been generally used in India in source apportionment studies. CMAQ is Eulerian model and deals with chemical reactive species hence accounts for secondary formation of pollutants. The model can deal with number of pollutants together rather than following their trajectory individually. It takes into account the photo-chemistry along with secondary inorganic and organic aerosols which is not accounted for in traditional models. Also, it can be employed over different spatial scales ranging from continental to local; additionally it can also account for long and medium range transport of pollutants.

The model is being regularly employed in various policy-based studies and researches across the world (Paza et al., 2013[14] (Mediterranean Basin), Sokhi et al., 2006[15] (London), Chen et al., 2007[16] (Beijing), Khiem et al, 2010[17] (Japan). Further TERI has employed this modelling set up in source apportionment studies of Delhi NCR, along with multiple studies on India scale. Based on the widespread applicability and requirements of multi-pollutant prediction, WRF (ver 3.9.1)-CMAQ (ver 5.3.1) combination have been chosen for carrying out the assessment in the present study.

WRF model runs have been carried out to generate 3-dimensional meteorological fields over the study domain which acts as an input to the CMAQ model along with emissions inventories. European Centre of Medium range Weather Forecasts (ECMWF) and United States Geological Survey (USGS) datasets have been used for running the WRF model, the output of which is the 3-dimensional meteorological inputs that are fed to the CMAQ model (Figure 6.1).

Surat's district-based inventory has been prepared at a resolution of 2x2 km^2. In order to account for pollutants from outside the district's boundary, India scale run has been employed with TERI's emissions inventory at 36x36 km^2. Additionally, to account for transport of pollutants from outside India, international boundary conditions have been adopted from

[14] Paza, David de la, Vedrenne, Michel, Borge, Rafael, Lumbreras, Julio, Andr_es, Juan Manuel de, P_erez, Javier, Rodríguez, Encarnaci_on, Karanasiou, Angeliki, Moreno, Teresa, Boldo, Elena, Linares, Cristina, 2013. Modelling Saharan dust transport into the Mediterranean basin with CMAQ. Atmos. Environ., 70: 337-350.

[15] Sokhi, R.S., Jos_e, R., San, Kitwiroon, N., Fragkou, E., P_erez, J.L., Middleton, D.R., April 2006. Prediction of O3 levels in London using the MM5eCMAQ modeling system. Environ. Model.Softw., 21(4): 566-576.

[16] Chen, D.S., Cheng, S.Y., Liu, L., Chen, T., Guo, X.R., 2007.An integrated MM5eCMAQ modeling approach for assessing trans-boundary PM10 contribution to the host city of 2008 Olympic summer gamesdBeijing, China. Atmospheric Environment, 41(6): 1237-1250.

[17] Khiem, M., Ook, R., Hayami, H., Yoshikado, H., Huang, H., Kawamoto, Y., November 2010. Process analysis of O3 formation under different weather conditions over the Kanto region of Japan using the MM5/CMAQ modelling system. Atmos. Environ., 44 (35): 4463-4473.

global air quality products of NCAR (National Centre for Atmospheric Research, U.S.). The global product used in this study was generated from results of Community Atmosphere Model with Chemistry (CAM-chem) model. The emissions of neighboring countries around India like Pakistan, Nepal, Bangladesh etc., (which may impact air quality of the study domain) are taken from ECLIPSE database of IIASA (2014)[18].

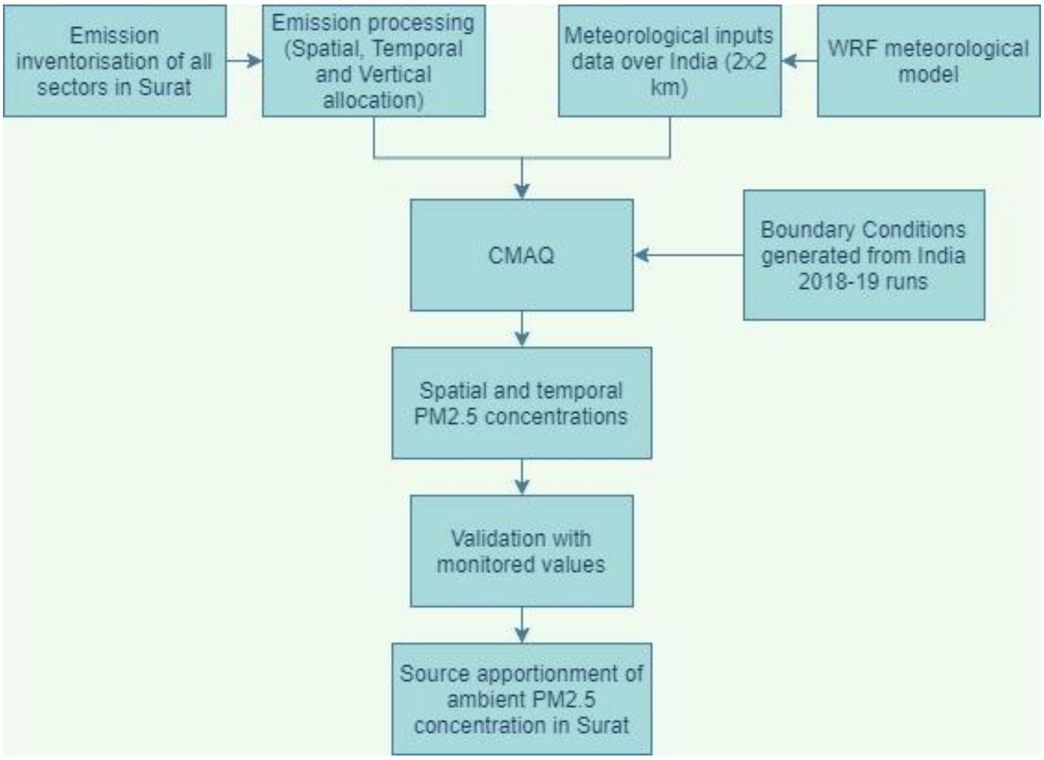


Figure 6.1 Modelling approach for the study;

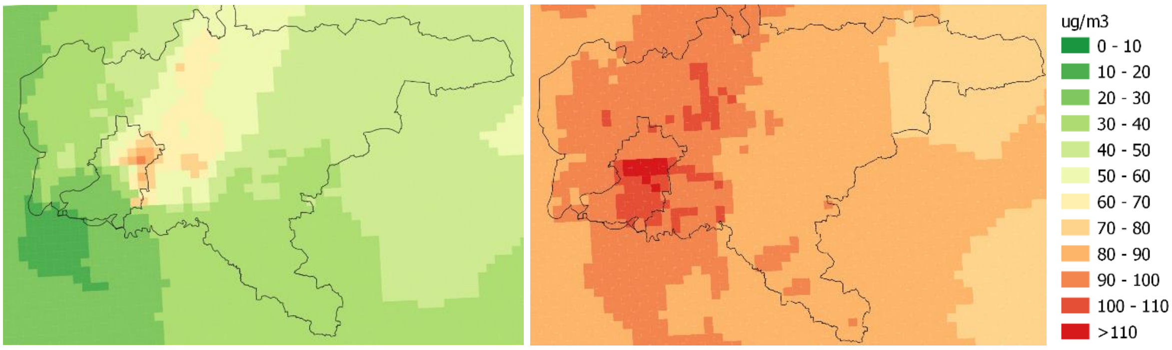
6.1 Air quality modeling

CMAQ model runs have been performed for the period May 2018 to Jan 2019 using emission inventory developed at 2x2 km resolution for the Surat district with boundary conditions from India scale runs.

The modelled summer and winter concentrations of $PM_{2.5}$ are shown in Figure 6.2. The concentrations in the months of December and January were averaged to estimate winter seasons concentration, while ambient $PM_{2.5}$ concentration in May and June were averaged for summer seasons to develop spatial $PM_{2.5}$ concentration map. It is evident that $PM_{2.5}$ concentrations are much higher during winters due to meteorological adversity-low wind speeds and shallower planetary boundary heights compared to summer season. In summers with higher dispersive conditions, there is a dip in the ambient $PM_{2.5}$ concentration when compared with winter season. In addition, the dominant wind direction in winters is from North-east which ensures substantial contributions from anthropogenic activities from the upwind regions of Surat in the Indian landmass. However during summers, the wind direction is from sea side, and there are limited anthropogenic activities which can contribute to air

[18] IIASA, 2014, ECLIPSE V5 global emission fields, URL: https://iiasa.ac.at/web/home/research/researchPrograms/air/ECLIPSEv5.html , International Institute for Applied Systems Analysis, Austria

pollution in Surat except the long range transport from international boundaries over the sea. Within the study domain, highest concentrations are visible in Surat city. However, rest of the regions in study domain also experience significantly high $PM_{2.5}$ concentrations, depicting regional scale pollution in the domain. This also indicates possibility of significant contributions from outside of study domain, from sources beyond the boundary of Surat district.



(a) Summer $PM_{2.5}$ concentration. (b) Winter $PM_{2.5}$ concentration

Figure 6.2: Spatial $PM_{2.5}$ concentration (µg/m3) in summer and winter seasons

The modelled results were validated against the observed measurements of $PM_{2.5}$ done by TERI at 6 locations around the city. Figure 6.3 shows the comparison of observed and modelled values $PM_{2.5}$. The average ratio of simulated to observed values averaged for both seasons is found to be ~ 1.08, while for summer it is ~ 0.84 and in winter it is ~ 1.21 which can be considered quite satisfactory.

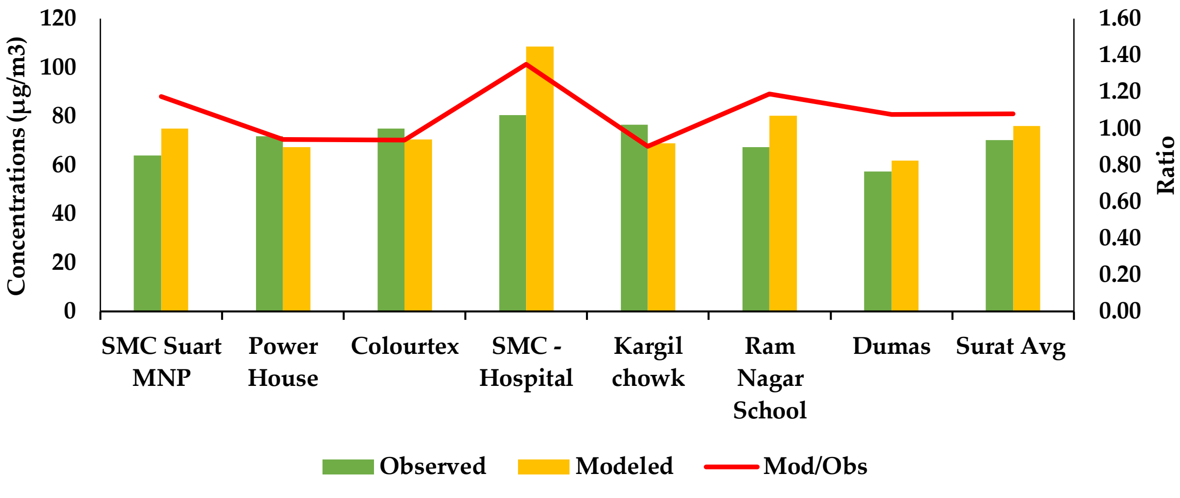


Figure 6.3: Simulated and observed concentrations (µg/m³) in across Surat.

The validation of model established that the model is able to reproduce physical and chemical processes which define pollutant concentration and it can be further utilized for running sensitivities of different sources in order to derive source apportionment and future projections.

6.2 Source apportionment of PM_{10} and $PM_{2.5}$ in Surat

The source sensitivity analysis was performed to estimate the contributions from different sources impacting the PM concentrations in Surat city using the validated WRF-CMAQ modeling setup. The simulation has been performed for the same time period in which monitoring was performed in Surat by TERI. The results of source apportionment derived using dispersion modelling approach are presented in Table 6.1 below. The winter season in table is averaged from Dec 2019 and Jan 2020, while summer is averaged from May 2019 and Jun 2019.

Table 6.1: Seasonal averaged source contribution to PM_{10} and $PM_{2.5}$ concentrations in Surat

Source	Winter		Summer	
	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$
Residential	14%	15%	1%	2%
Industry	25%	27%	12%	17%
Transport	13%	16%	4%	6%
Thermal Power plants	9%	10%	1%	1%
Brick Kilns	3%	3%	0.1%	0.1%
Waste Burning	1%	1%	0.3%	0.3%
DG Sets	0.2%	0.2%	0.2%	0.2%
Road Dust	14%	7%	12%	10%
Construction	1%	0.3%	2%	1%
Agriculture residue burning	2%	3%	0%	0%
International sources	8%	8%	64%	57%
Others	10%	9%	5%	6%

*Others include Crematoria, Surat port, landfills, biogenic and NH_3.
The contributions to PM levels in Surat city given above are total of different sectors with contributions from various geographical regions not just from sources within Surat city.

Industrial sources emerge out to be the major contributor in both the seasons with contributions ranging from 17% to 27% for $PM_{2.5}$ while 12% to 25% for PM_{10}. It is followed by road dust and transport sector. The contribution from road dust in ambient $PM_{2.5}$ concentration ranges from 7% to 10% and in PM_{10} concentration it ranges from 12% to 14%. While in transport sector the contribution of $PM_{2.5}$ ranges from 6% to 16% and in PM_{10} it ranges from 4% to 13%. In case of ambient PM_{10} concentration major contributors are residential sector (1 to 14%), others (5 to 10%) and Power (1 to 9%) sectors. The ambient $PM_{2.5}$ contribution from international sources varies from 57% in summers when the wind speed is high and from West, and drops down as low as 8% in winters when the wind speed reduced and wind direction is also reversed. The international contribution to ambient PM_{10} concentration varies from 8% to 64%. It is quite evident that agricultural burning is not a prominent sector in deteriorating the air quality of Surat with contribution reaching 2% and 3% in winter season and negligible contributions in summers for both PM_{10} and $PM_{2.5}$ ambient concentration respectively.

6.3 Geographical contributions to PM concentration in Surat

The model has also been used to estimate geographical contributions of ambient $PM_{2.5}$ and PM_{10} concentrations in Surat city. The geographical contributions vary as per prevailing wind directions and meteorological conditions. The contribution in Surat city's ambient PM_{10} and $PM_{2.5}$ concentration from city's own emissions in summer has been estimated to be about 24%

and 26% respectively while in winters it estimated to be 22% and 17% respectively. Figure 6.4 shows the contributions from different regions in Surat city's PM_{10} and $PM_{2.5}$ concentrations in summer and winter seasons. The outside district (beyond Surat district) contributions are higher in both seasons. As observed from table 6.1 outside India contributions are higher in summers for both $PM_{2.5}$ (57%) and PM_{10} (64%) respectively, while it decreases to about 8% for both pollutants in winters. This is due to prevailing windy conditions in the summers which transport dust and other pollutants from outside the boundary of India and influence air quality of the city's .

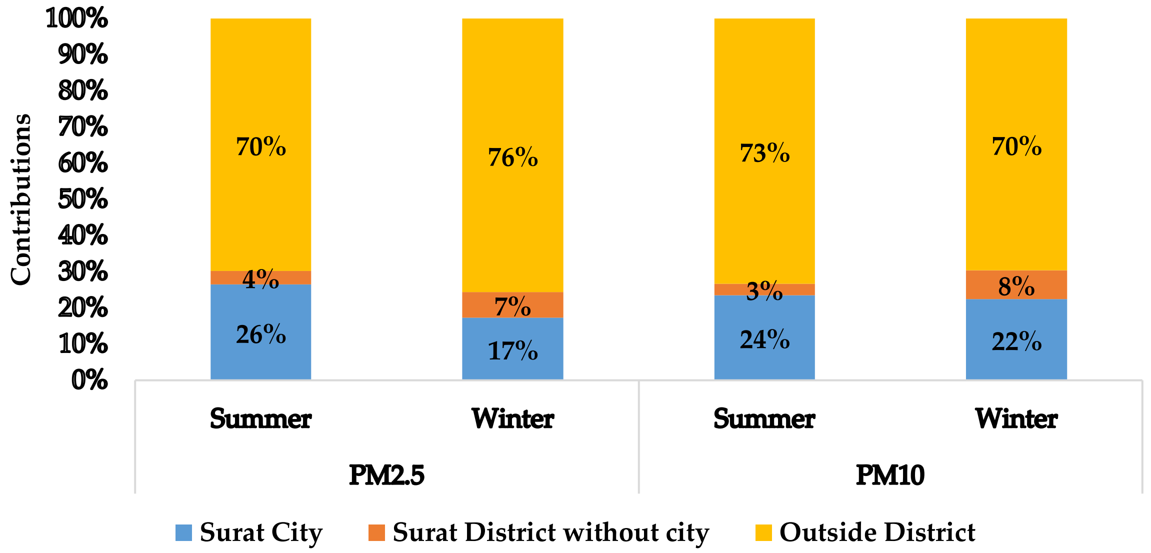


Figure 6.4: Geographical contribution of PM_{10} and $PM_{2.5}$ concentrations in Surat City

From Figure 6.4, it may be inferred that contribution from rest of India becomes dominant during the winter months when the wind direction gets reversed and the pollutants from the upwind areas of Surat city have higher impact on the air quality of the city.

7

COMPARISON OF SOURCE APPORTIONMENT USING RECEPTOR AND DISPERSION MODELS

In this chapter, the average city-wide results of receptor modelling carried out in this study have been compared with the outputs of dispersion modelling. While comparing the two results, it has been noted that the receptor modelling results show sectoral contributions of primary PM, and secondary particulates separately. Secondary particulates are not apportioned to contributing sectors as these are contributed by the reactions of gases emitted from different sectors. The dispersion model could assess contributions of different sectors to secondary particulates along with the primary fractions.

7.1 Comparative analysis of Receptor Modelling and Dispersion modeling for $PM_{2.5}$

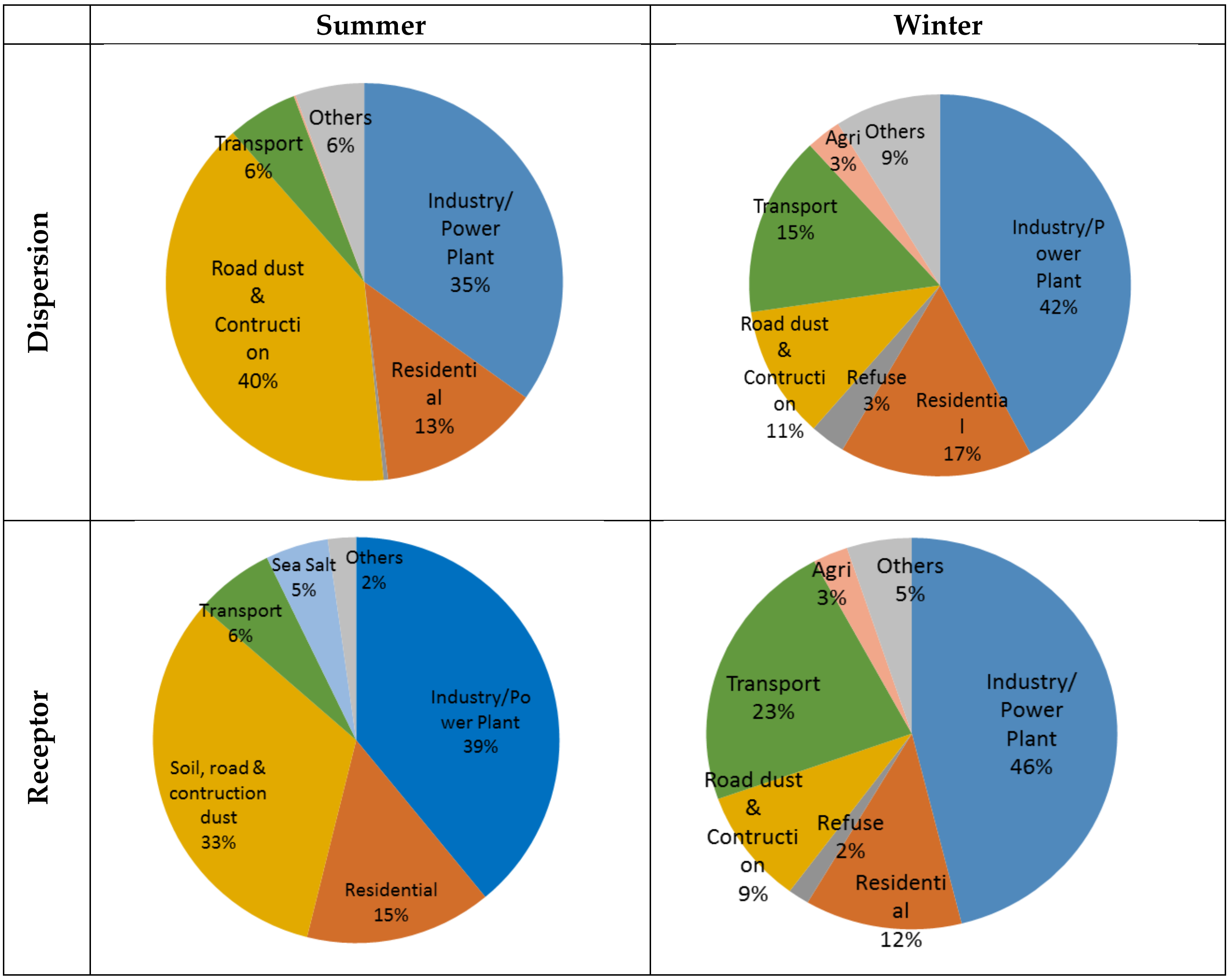


Figure 7.1: Comparative analysis of Receptor Modelling and Dispersion modeling estimates of sources contributions towards ambient $PM_{2.5}$ concentrations in Surat.

** In receptor model, results show sectoral contributions for primary particles and does not apportion secondary particulates separately. Dispersion model was used to assess contributions of different sectors to secondary particulates which is used to distribute secondary contribution in receptor model for the purpose of comparison.

In order to compare more effectively, secondary particulates in the results of receptor modelling were allocated based on their apportionment in the dispersion modeling approach. The comparative results for the two techniques are shown for $PM_{2.5}$. Overall, the results of source apportionment from the two approaches seem to be directionally consistent for most sectors as shown in Figure 7.1.

Both the source apportionment approaches indicate that industrial (along with power plants) sector is the major contributor to the ambient $PM_{2.5}$ concentrations in both the seasons. In winters, industry has 46% and 42% contribution of $PM_{2.5}$ for receptor and dispersion approaches respectively. The contributions estimated for other sectors to the winter $PM_{2.5}$ concentrations in Surat city are also found to be close proximity for the two approaches- 23% and 15% contribution from transport sector, 12% and 17% contribution from residential sector, 9% and 11% contribution from dust(road, soil & construction) sector, 2% and 3% contribution from refuse burning, 3% contribution from both the approaches, 5% and 9% contribution from agriculture burning and others for receptor and dispersion models, respectively.

In summers, industry sector contributes 39% and 35% of ambient $PM_{2.5}$ respectively for receptor and dispersion modelling approaches. This is followed by dust (road, soil & construction) which contributes 33% and 40% $PM_{2.5}$, 15% and 13% $PM_{2.5}$ residential, 6% $PM_{2.5}$ in both approaches from transport sector and 2% and 6% $PM_{2.5}$ contribution from others sectors to the ambient $PM_{2.5}$ concentrations of Surat city.
In winters, the contribution of transport is found to somewhat higher in receptor modeling approach. This can be attributed to proximity of monitoring stations to the local sources like transport, which depict higher contributions in receptor modeling approach especially in relatively calmer conditions observed in winters. In this study, dispersion model works at a resolution of 2kmx2km and presents average sectoral contributions for the whole grid, and hence somewhat lower contributions are estimated for local sources like vehicles.

Conclusively, the outcome from both the approaches are within a close range for most of the sectors and provide decision makers a clear indication to take specific actions.

7.2 Comparative analysis of Receptor Modelling and Dispersion modeling for PM_{10}

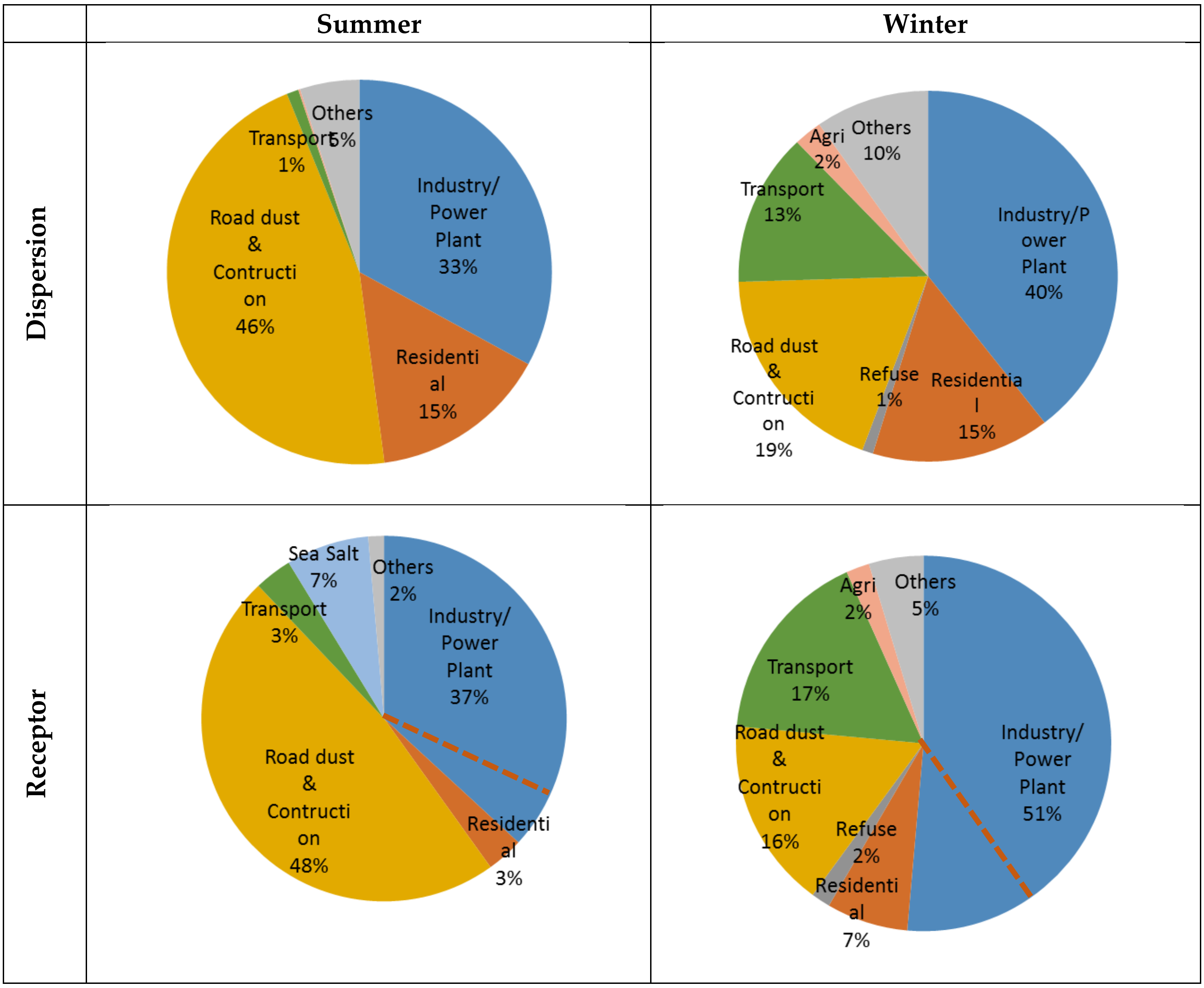


Figure 7.2: Comparative analysis of Receptor Modelling and Dispersion modeling estimates of sources contributions towards ambient PM_{10} concentrations in Surat.

Comparative analysis of dispersion modelling with receptor modelling results for PM_{10} concentration is shown in Figure 7.2. Overall, the results of source apportionment from the two approaches seem to be directionally consistent for most sectors. In summer season, dust is major contributing source with share of 48% and 46% PM_{10} for receptor and dispersion modelling approaches respectively. Dust includes contributions from road dust re-suspension, construction activities, and trans-boundary international contributions. Based on the assessment of species, it may be concluded that in summers, trans-boundary contributions are mainly composed of dust. Second major contributing source is industrial sector with contribution of 37% and 33% PM_{10} for receptor and dispersion modeling respectively, followed by 3% and 15% PM_{10} contribution from residential sector, 3% and 1% PM_{10} contribution from transport, and 2% and 5% contribution from others to the ambient PM_{10} concentrations of Surat city.

Contribution to ambient PM_{10} concentrations from sea salt is also observed during summer season with about 7% contribution as derived from receptor modelling approach. Contributions were significant in summers as the dominant wind direction (South-west) was found to be from sea-side only.

In winter season, industry is major contributing source with PM_{10} contribution of 51% and 40% from receptor and dispersion modelling approaches respectively, followed by 16% and 19% contribution from dust (dust soil & construction), 17% and 13% contribution from transport sector, 7% and 15% contribution from residential sector, 1% and 2% contribution from refuse burning, 3% contribution for both approaches agriculture burning and 5% and 10% contribution from other sectors to the ambient PM_{10} concentrations of Surat city.
It is to be noted that in the dispersion modelling approach, the industrial sector (which seems to be overestimated) includes biomass as an industrial fuel, which seems to be under-estimated by the receptor modeling technique for residential sector (shown as a dotted line).

8

FUTURE PROJECTIONS OF EMISSIONS AIR QUALITY IN SURAT

A future scenario analysis was carried out, in order to understand the growth in different sectors contributing to air pollution in the Surat region. In this regard, possible future growth scenarios have been prepared for the year 2025 (medium term) and 2030 (long term). A Business as Usual (BAU) scenario has been developed, which takes into account the most probable growth trajectories in various sectors and also the policies and interventions, which have already been notified for control of air pollution. After this, in order to assess the potential of various new additional strategies for control of PM_{10} and $PM_{2.5}$ concentrations, various interventions in different sectors have been tested using the emission and air quality model. Strategies that can provide significant air quality benefits have been identified for construction of an alternative scenario (ALT) with the aim to reduce the concentration of ambient PM_{10} and $PM_{2.5}$ for meeting the prescribed NAAQS in Surat city.

8.1 Business as usual (BAU) scenario

The BAU scenario depicts changes (both growth and controls) happening in different sectors, such as transport, industries, domestic, open burning, crematoria, restaurants, etc, till the year 2030. This scenario does not account for any additional interventions to manage air quality, in addition to the already planned policies/interventions by the government in different sectors. The growth rates of different sectors have been adopted through review of published literature. The projected growth rate in energy consumption in industries in Surat is assumed to be 5.9% as per the Surat solar city master plan by Ministry of New and Renewable Energy, Govt. of India (2012). The annual average growth rate of coal and gas in industries are 6.33% and 1.82%, respectively were also assumed based on (Surat solar city master plan by Ministry of New and Renewable Energy, Govt. of India 2013). The Hotels/Restaurants sectors has been assumed to grow at a rate of 11.2% in 2025 and 2030, on the basis of growth rate of gross district domestic product of hotel and restaurants in Gujarat during last 5 years (India Statistical Handbook, 2020). However for small unorganized eateries, a projected growth rate of 7% was assumed (FICCI, 2017). In crematoria sector, based on past trends of crude death rate of Surat Municipal Corporation for last 5 years, crude death rate for urban population is estimated to be to be 4.14 per 1000 inhabitant till 2030. For rural population, crude death rate is estimated based on past trends of crude death rate of rural population for Gujarat state (India Census 2001 and 2011) it is estimated as 6.1 per 1000 inhabitants till 2030. Power cuts are already rare in Surat and are assumed to be negligible by 2025 (as it is selected as one of the smart cities in India) and therefore it is assumed that there will be no usage of DG sets in 2025 and 2030. Based on the gross domestic product of construction activities in Gujarat during the year 2011-2018, the compound annual growth rate of this sector is assumed to be 3.07% (RBI handbook, 2019) for both 2025 and 2030.

In the transport sector, growth rates of different types of vehicle registrations are obtained from statistical year book for the road transport sector (MoRTH, 2019). Accordingly, the vehicular sector has been assumed to grow at a rate of 7% till 2025 and by 4% thereafter. As notified, BS-VI emission norms have been assumed to be effective from 2020.

In the domestic sector, population growth rate of 4.93% per annum has been assumed in 2025 and 2030, based on decadal growth rate of population in Surat city as per census data (India census, 2001 and 2011).The annual growth rate of domestic LPG connections in Surat city was assumed to be 3.75% and annual PNG growth rate in Surat city was assumed as 7.65% following MNRE, 2014.. Annual growth rate of kerosene for cooking was assumed as -6.5% (declining) and it was assumed that there will be no kerosene used for lighting purposes in Surat in 2025 and 2030. A 2% growth rate is assumed for electricity use for cooking purposes. Simultaneously, the number of fuel wood and kerosene consuming households falls by 5.75%. While, the number of crop residue, dung cake and coal consuming households falls by 1.25% annually by distributing the 3.75% annual growth rate of LPG consuming households in three fuels equally. Brick kiln sector is expected to grow at a rate of 7.5% annually based on CSE (2017). For power sector, it is assumed that no new coal based power plants will be installed in the district and accordingly no growth in emissions in power plants has been assumed for 2025 and 2030.

In case of aviation sector, it is assumed that the number of flights from Surat airport will increase due to increase in passenger counts for various national and international destinations. Based on the previous 4 years i.e. from 2015 to 2019 the growth trend in flight numbers, the annual growth rate for aviation sector is assumed to be 9.46% for both 2025 and 2030. Based on the past years (2012-2019) trend in waste disposed at landfills in Surat city (SMC, 2021) (), it is assumed that there will be 8% increase in the disposal of waste at the landfill site both in 2025 and 2030.

For refuse sector, the Surat city population growth rate of 4.93% per annum has been assumed in both 2025 and 2030. Also, according to the Surat Municipal Corporation database, the per capita waste generation and collection efficiency in the Surat city is reported as 0.45 kg/day and 97.7%, respectively during 2019. Also, quantity of non-biodegradable waste generated in the Surat city is reported as 35% during 2019. The same assumptions have been made for projecting the emissions from this sector for the 2025 and 2030.

The growth rates adopted for projections of various sectors under BAU scenario are summarized in Table 8.1. Based on the growth rates under various sectors, the BAU scenario has been developed and emission loads for different pollutants like PM_{10}, $PM_{2.5}$, SO_2 and NO_X, have been estimated. The estimates in the years 2025 and 2030 are shown in Figure 8.1, which are also compared to the estimates of base year 2019.

Table 8.1: Growth rate adopted for various sectors under BAU scenario

Sector	Growth rate	Reasoning	Controls assumed
Transport/ Road Dust	7% growth rate up to 2025, thereafter 4%	Based on the past trends of different types of vehicle registrations in Surat (MoRTH, 2019)	BSVI norms from 2020 No further control for road dust
Crematoria	Crude death rate for rural population is 6.1% in both 2025 and 2030, and for urban population 4.14% in both 2025 and 2030	Based on past trends of crude death rate of Gujarat state in India Census (2001,2011)	No further control
Restaurants	11.2% in both 2025 and 2030 and for unorganized eateries 7% in both 2025 and 2030	Based on growth rate of gross district domestic product of hotel and restaurants in Gujarat during last 5 years and for unorganized sector FICCI report, 2017	No further control
DG sets	No DG sets in 2025 and 2030	DG set usage is presently very low and is expected to further decline with improvement in power situation.	
Construction	3.07% for both 2025 and 2030	Based on the gross domestic product of construction activities in Gujarat during the year 2011-2018. RBI Handbook, 2019	No further control
Industries	5.9% for other fuels, 6.33% for coal and 1.82% for Natural gas in both 2025 and 2030	Based on growth rate in energy consumption in industries in Surat as per the Surat solar city master plan by Ministry of New and Renewable Energy	No further control
Domestic	Annual population growth rate of 4.93% in 2025 and LPG penetration will increase at the rate of 3.75% in Surat and annual PNG growth rate of 7.65	Based on decadal growth rate of population in Surat as per census data 2030 (India Census 2001,	100% LPG penetration by 2030

Sector	Growth rate	Reasoning	Controls assumed
	% in both 2025 and 2030	2011) MNRE report 2014	
Brick kiln	Annual growth rate of 7.5% for both 2025 and 2030	Based on Rajarathnam et al. 2014 & Presentation by J. S. Kamyotra (Director, CPCB) in Anil Agarwal Dialogue 2015, CSE & Surat action plan	50% kilns will be converted into Induced draught in 2025 and 100% kilns will be converted into Induced draught in 2030
Power plants	Same as in 2019 for both 2025 and 2030	No new power plants will be installed in the district and hence not projected to grow any further in future	100% implementation of Power Plant emission norms by 2025
Aviation	Annual growth rate of 9.46% in both 2025 and 2030	Based on the annual growth rate in number of flights during last 5 years as per Airport Authority of India statistics	No further control
Landfill	Annual growth rate of 8% for both 2025 and 2030	Based on the past years (2012-2019) trend in waste disposed at landfills in Surat city.	No further control

In the BAU scenario, emissions of PM_{10}, $PM_{2.5}$ and SO_2 are projected to increase by 56%, 34% and 40%, respectively between 2019-2030, while, emissions of NOx will decrease by 5%, during the same period. PM_{10} and $PM_{2.5}$ are growing at different rates as the sectors emitting coarse particles are growing while emissions from some of the sectors emitting finer particles have declined. For example, in $PM_{2.5}$ the share of transport sector has declined from 24% in the year 2019 to 5% in 2030. While this decline for PM_{10} was from 2% in 2019 to 11% in 2030. The growth in emissions is somewhat lesser than the growth of different sectors due to already planned interventions which reduces the emission intensity in the region. Emissions of particulate matter and sulphur dioxide are increasing due to increase in road dust and industrial emissions. In case of NOx, transport is one of the major contributors and due to introduction of BSVI norms in the year 2020, the NOx emissions from transport sector will reduce considerably that resulted in overall reduction of NOx emissions in the district. The detailed sectoral inventory is provided in the Table 8.2.

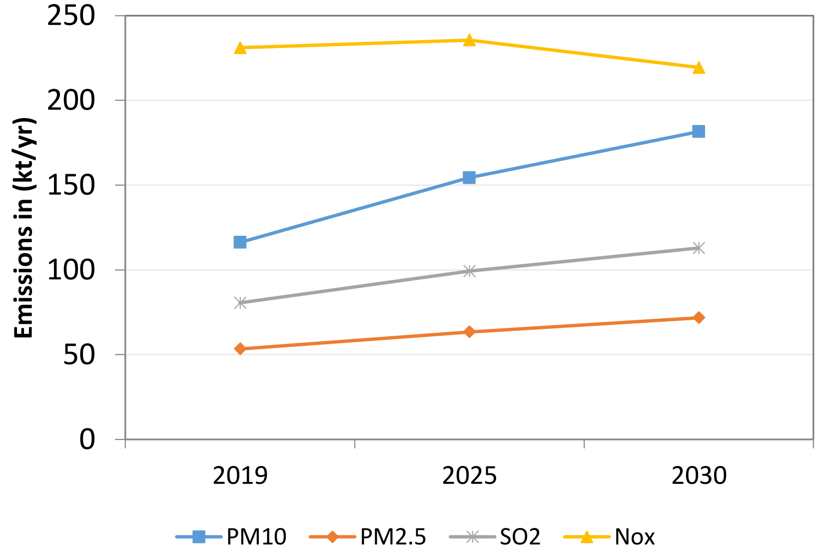


Figure 8.1: Emissions of PM_{10}, $PM_{2.5}$, SO_2, and NO_x during 2019, 2025 and 2030 for Surat city in BAU scenario

Table 8.2: Detailed sector wise emissions (kt/yr) of Surat district for the year 2019, 2025 and 2030.

Sector	2019				2025				2030			
	PM_{10}	$PM_{2.5}$	SO_2	NO_x	PM_{10}	$PM_{2.5}$	SO_2	NO_x	PM_{10}	$PM_{2.5}$	SO_2	NO_x
Industry	32	18.7	39.44	84.16	45	27	56	106	59	35	70	129
Transport	13	12.6	0.26	115.71	8	8	0	99	3.9	3.8	0.1	60.1
Road dust	55	13.3	0	0	83	20	0	0	99	24	0.0	0.0
Residential	2.74	1.8	1.52	1.21	3	2	3	1	2	1	2	1
Agriculture	3	2.3	0.29	0.59	3	2.28	0.29	0.59	3	2.28	0.29	0.59
Power plants	5	3.1	37.7	27.3	4.7	3.1	37.7	27.3	5	3.1	37.7	27.3
Refuse	0.39	0.32	0.02	0.12	0.21	0.77	0.00	4.21	0.00	0.00	0.00	0.00
Brick kiln	1	0.224	0.82	0.00	2	0.33	1.20	0.00	2	0.40	1.45	0.00
D G Set	0.12	0.10	0.12	1.75	0	0	0	0	0	0	0	0
Hotels and restaurants	0.16	0.09	0.09	0.09	0.26	0.15	0.15	0.14	0.40	0.22	0.24	0.21
Landfill	0.13	0.089	0.01	0.05	0.20	0.14	0.01	0.08	0.29	0.20	0.02	0.11
Aircraft	0.004	0.004	0.26	0.02	0.01	0.01	0.52	0.04	0.01	0.01	0.82	0.06
Crematoria	0.2	0.10	0.004	0.03	0.26	0.13	0.01	0.04	0.31	0.2	0.0	0.0
Construction	3.2	0.6			3.8	0.7			4.5	0.8		
Ports	0.6	0.1			1.1	0.2			1.9	0.4		
Total	**116.2**	**53.4**	**80.5**	**231.0**	**154.2**	**63.8**	**99.2**	**239.6**	**181.3**	**71.6**	**112.9**	**219.3**

After estimating emissions, these emissions of particulate matter and gaseous pollutant were fed in the air quality model to simulate particulate matter concentration in the future years 2025 and 2030. The results for the two seasons are shown in the Figure 8.2.

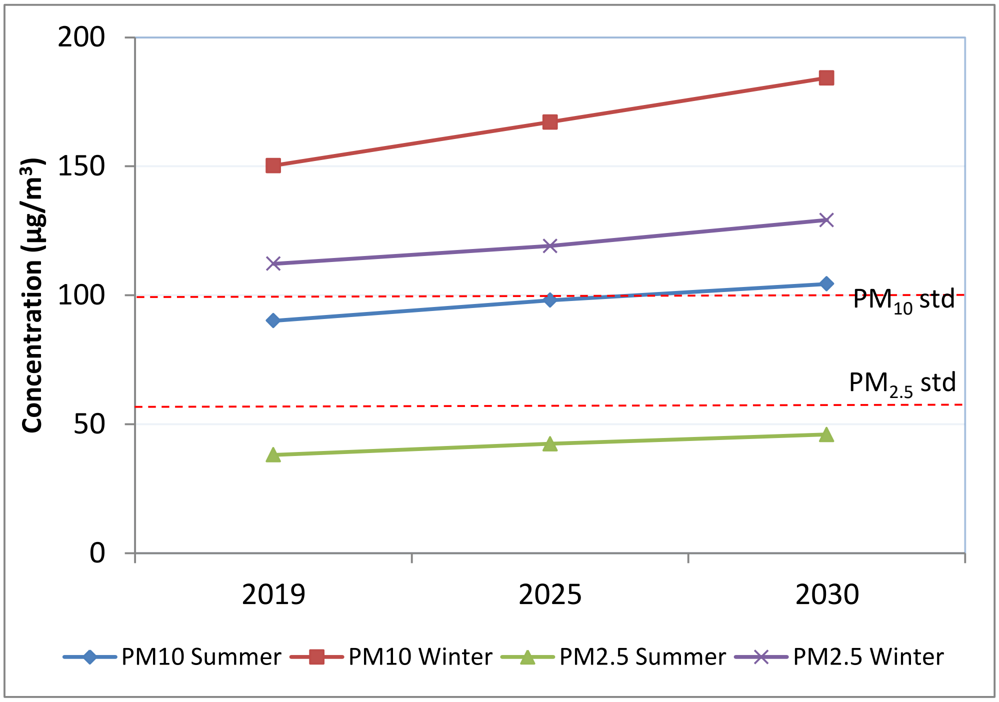


Figure 8.2: Winter and summer time projected particulate matter concentration in Surat city during the year 2019, 2025 and 2030 in BAU scenario.

As seen in the above figure, irrespective of the season, the concentration of both PM_{10} and $PM_{2.5}$ is projected to remain above the daily standards (NAAQS). Sectoral contributions in PM_{10} and $PM_{2.5}$ concentrations in BAU scenario for the year 2030 is shown in the Figure 8.3. During summer season of 2030, industry, road dust and dust from the international boundaries are projected to contribute more than 90% to the concentration of both PM10 and PM2.5. In winter season, major contributors are industry, road dust and others sector. Share of transport and residential sectors is expected to go down with influx of BS-VI vehicles, and LPG for cooking. However, despite this, NAAQS are not met even in future years; therefore there is a need to formulate an alternative scenario with an aim to achieve the NAAQS by the year 2030. In view of this, an intervention analysis has been performed to analyse the possible impact of different sectoral interventions on particulate matter concentration in Surat city. This is explained in detail in the subsequent section.

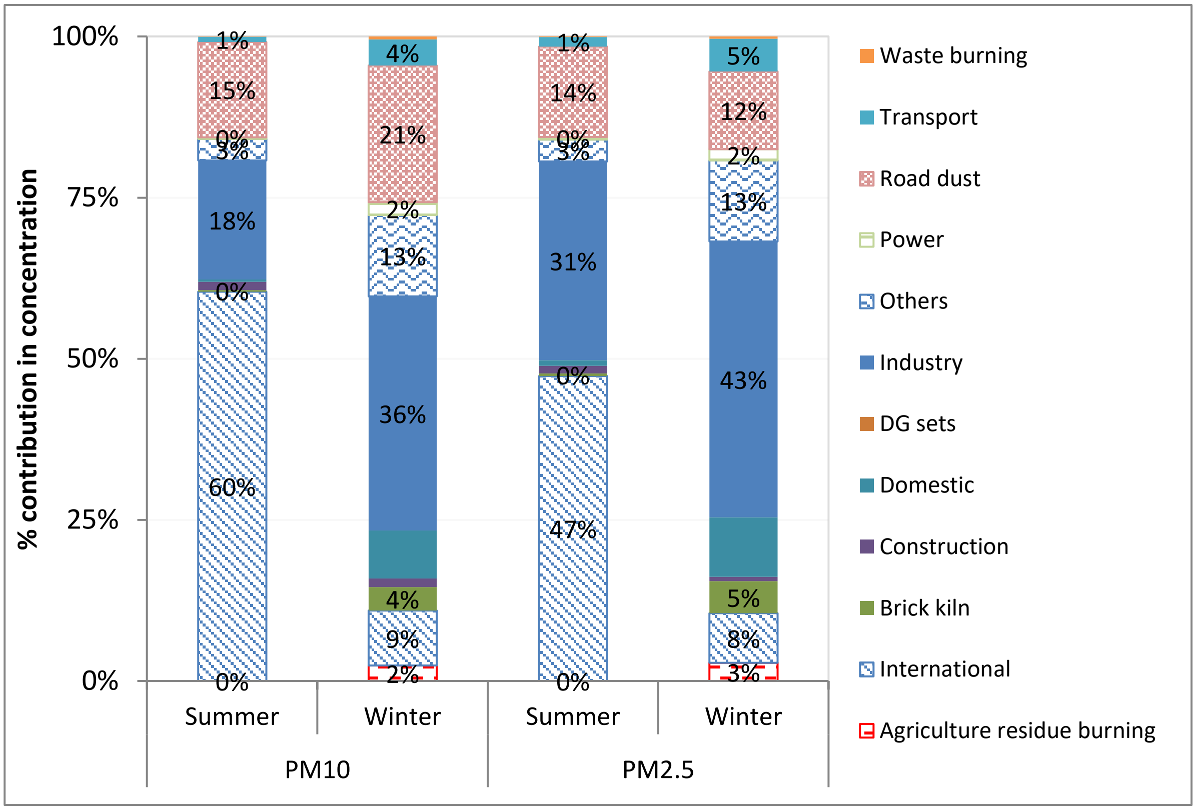


Figure 8.3: Sectoral contribution in PM_{10} and $PM_{2.5}$ concentration of Surat city in summer and winter season during the year 2030.

8.2 Intervention analysis

In order to construct the alternative scenario, intervention analysis is performed to estimate the emissions and concentrations reduction potential of different control strategies in transport, biomass, industries, and other sectors. A detailed description of control strategies in different sectors, which have been tested for their emission reduction potential, is provided in table 8.3

Table 8.3: Interventions considered under various sectors

S.No.	Strategies	Description
	Transport sector	
1.	City Mobility Plan Scenario	Do-nothing base scenario of CMP considers the road network consisting of bus services extended to new proposed arterial/sub-arterial roads along with 102 km of BRTS operational proposed as in the existing scenario of Surat (CMP Surat, 2018). Growth rate of total registered vehicle (2% in both 2025 and 2030) has been assumed based on trends of vehicular registrations provided in Comprehensive Mobility Plan (CMP) do nothing scenario of Surat.

S.No.	Strategies	Description
	Transport sector	
2.	Electrification of vehicular fleet	Bus (50-100%), two (40-100%) and three wheelers (100%), and cars (20-40%) in 2025 – 2030
2a.	Electric vehicles- 2/3 wheelers	40% in 2025 and 100% in 2030 electric two-wheelers, and 100% three-wheelers from 2025
2b.	Electric vehicles - Cars	20% in 2025 and 40% in 2030 electric cars
2c.	Public transportation- Buses	50% and 100% electric buses in 2025 and 2030
3.	Fleet modernization to BS-VI vehicles from 2025 and 2030	All vehicles to be BS-VI equivalent
3a.	Fleet modernization of 2 & 4-wheelers	100% to BS VI by 2025 and 2030
3b.	Fleet Modernization of trucks and buses	100% to BS VI by 2025 and 2030
4.	Increased penetration of biodiesel	12% penetration by 2025 and 20% by 2030
5.	Modal shifts of cars and 2-wheelers	25% Modal shifts of cars and 2-wheelers to CNG buses by 2025 and 2030
6.	Improved inspection and maintenance system	High emitter emissions go down to 50% in 2025 and 2030
7.	Reducing real world emissions from vehicles by congestion management	Reduce real world emissions to 50% in 2025 and 2030
	Industrial Sector	
8.	Introduction and enforcement of new SO2/NOx emissions standard	50% and 100% enforcement of SO2/NOx standards in other industries in both 2025 and 2030 respectively.
9.	Fuel switching	50% and 100% fuel switch to gas from solid and liquid fuels in both 2025 and 2030 respectively.
	Domestic sector	
10.	Penetration of LPG	50% of remaining biomass using households shifted to LPG in 2025.
	Construction sector	
11.	Strict implementation of construction guidelines	30% and 60% reduction in BAU based emissions in 2025 and 2030, respectively.
	Brick kiln	
12.	Conversion from induced draft brick kiln to Zig-Zag brick kiln.	50% kilns will be converted into Zig-Zag technology in 2025 and 100% in 2030.
	Road Dust	
13.	Reduction in road dust by plantation, mechanized road sweeping etc.	90% reduction in silt content of arterial, sub-arterial and local roads in 2030.
	Other	
14.	Control on hotel & restaurant; landfill and port emission	Control: 50% in 2025 and 75% in 2030.

8.2.1 Transport sector

Transport sector contributed 13% in PM10 and 16% in $PM_{2.5}$ concentration in Surat city in the year 2019 during winter season. However, in 2025 and 2030 its shares decline to 8% and 4% for PM_{10} and 10% and 5% for $PM_{2.5}$, respectively mainly due to introduction of BS-VI emissions norms. In order to further reduce its share, various strategies have been tested out over and above BAU scenario. These strategies include:

- CMP do nothing base scenario
- Electrification of public and personal vehicles
- Fleet modernization
- Improved inspection and maintenance (I&M) system
- Reduced real-world emissions through congestion management
- Shifting private transport (cars and 2-w) to shared commuter vehicles.
- Use of biodiesel

The details of these strategies are given in Table 8.3. The emission reduction potential of these strategies has been assessed and is presented in the Figure 8.4.

Since transport sector emits mostly finer particles, therefore the emission reduction potential is same for both $PM_{2.5}$ and PM_{10} in this sector. Substantial reductions were observed in transport sector $PM_{2.5}$ emissions due to CMP do nothing scenario. The CMP do nothing scenario can result in 20% and 26% reduction in $PM_{2.5}$ emissions w.r.t to BAU 2025 and 2030, respectively.

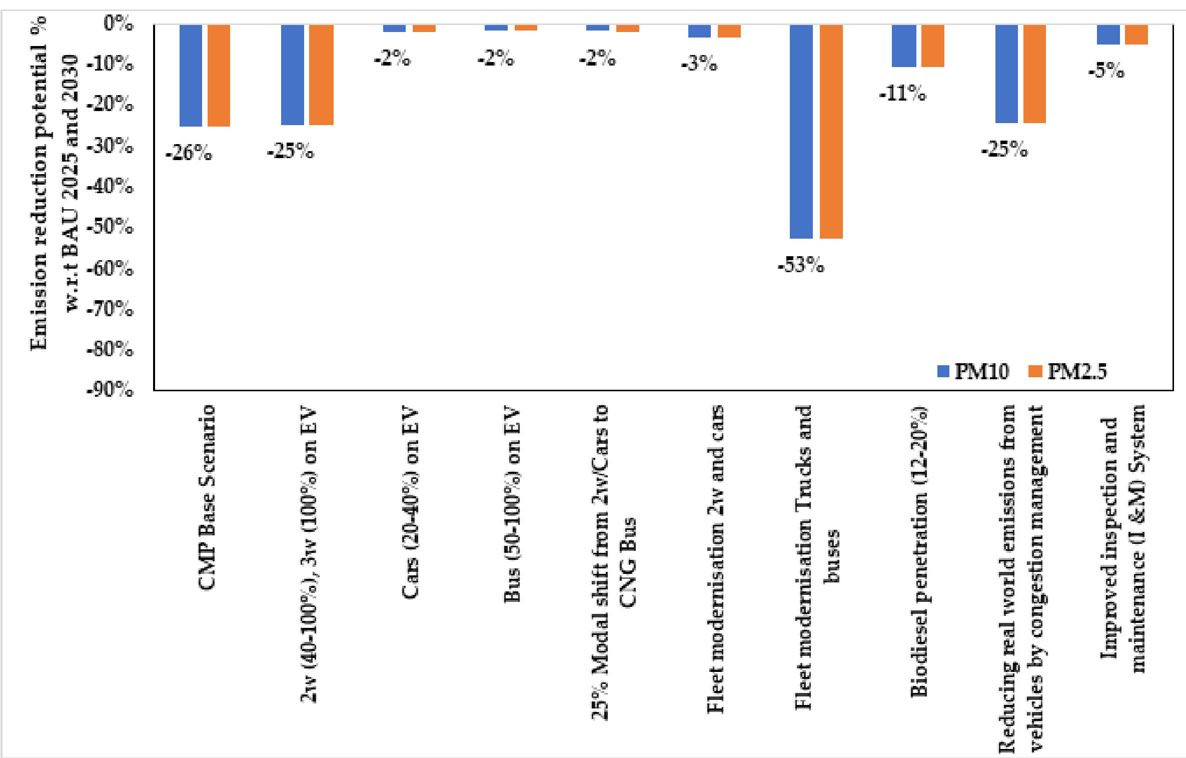


Figure 8.4 : PM_{10} and $PM_{2.5}$ emission reduction potential of various strategies with respect to BAU 2030 transport sector emissions.

Fleet modernization (replacing older vehicles with BS-VI) in trucks and buses leads to 53% reductions in PM_{10}/$PM_{2.5}$ emissions in Surat district in 2030. Decongestion of roads and 2-w and 3-w on EV will reduce the PM_{10}/$PM_{2.5}$ by 25%. Rest of the strategies have emission reduction potential in the range of 2%-11%.

After estimating emissions, these emissions were fed in to the model to estimate their concentration reduction potential for Surat City. The intervention specific concentration reduction potential for various strategies is provided in the Table 8.3. For winter season, the $PM_{2.5}$ and PM_{10} concentration reduction potential of tested strategies for the year 2030 was in the range of 0.1%-1.4% and 0.5%-0.8% w.r.t BAU, respectively. This is due to sharply reduced share of transport sector in future years. Highest reduction potential was observed for fleet modernisation of trucks and buses and least reduction potential was of the cars on Electric modes.

8.2.2 Industrial Sector

Industry is one of the significant contributors to the particulate matter concentration in Surat City. It contributed to around 25%, 31% and 36% in PM_{10} concentration in the year 2019, 2025 and 2030, respectively during winter season in BAU scenario. The contribution in $PM_{2.5}$ concentration was 27%, 36% and 43% in 2019, 2025 and 2030, respectively. The sectoral shares of industrial sector are growing in future due to growth assumed for the sector with no additional controls. Numbers of alternative strategies are proposed for industry sector for control of pollution (Table 8.3).

Switch over of industries from solid and liquid fuels to gas can result in 99.68%, 99.63%, 99.54% and 48.24% reduction in PM_{10}, $PM_{2.5}$, SO2 and NOx emissions from industrial sector, respectively in the year 2030 w.r.t BAU scenario in Surat district. Instead of switchover to gas, installation of high efficiency air pollution control devices such as wet scrubber can result in 94%, 94%, 80% and 80% reduction in PM_{10}, $PM_{2.5}$, SO2 and NOx emissions, respectively from the sector in the year 2030.

Brick kiln contributed around 3% in 2019 and 2025 and 4% in 2030 in PM_{10} concentration of Surat city during winter season. Similar contributions for $PM_{2.5}$ are observed- 3%, 5% and 5% in the year 2019, 2025 and 2030, respectively. The emission reduction potential of conversion of induced draft brick kiln to Zig-Zag technology is estimated. It is estimated that the conversion will reduce the brick kiln emissions of PM_{10} and $PM_{2.5}$ by 66% and 20% in the year 2030 with respect to BAU.

The emission reduction strategies are present in the table 2 and the reduction potential of these strategies has been assessed and is presented in the Figures 8.5.

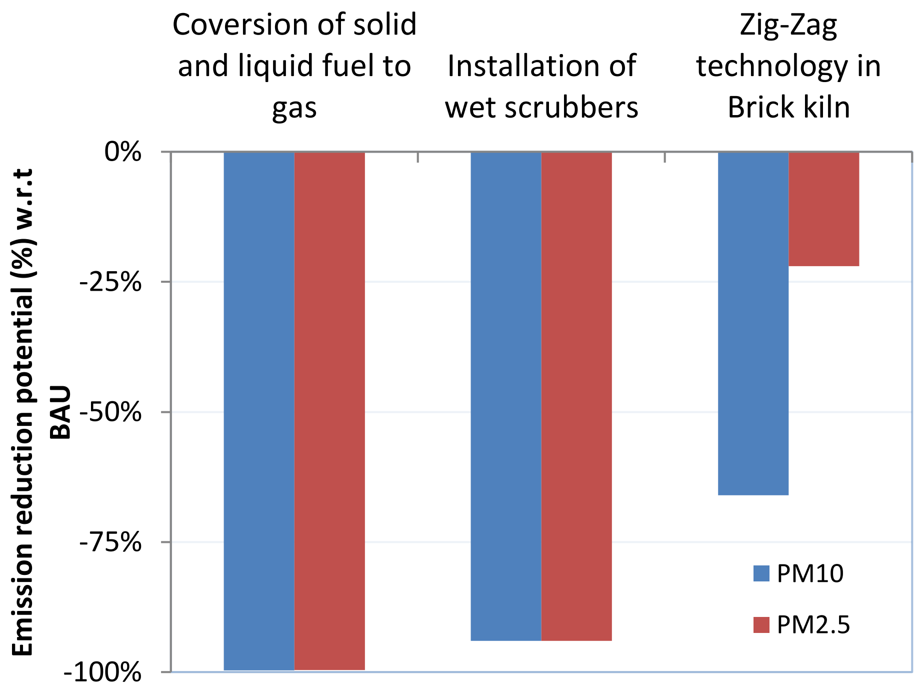


Figure 8.5: Emission reduction potential of various strategies w.r.t 2030

After estimating reduction in industrial sector emissions due to these strategies, air quality simulations were performed to estimate the corresponding concentration reduction potential of these strategies in Surat city. Details of concentration reduction potential for different strategies during summer and winter season on Surat city is provided in the Table 8.3. The conversion of solid and liquid to gaseous fuel in Surat district will reduce the PM_{10} and $PM_{2.5}$ concentration by 6.9% and 7%, respectively in the year 2030 during the winter season. The installation of wet scrubbers will result in 6.5% and 6.6% reduction in PM_{10} and $PM_{2.5}$ concentration, respectively. Despite having great emission reduction potential only 6%-7% of concentration reduction is seen due to various strategies in the sector. This is because of the significant background contribution from industries located in air shed region outside of the district boundaries. As per model estimates, outside industries contribute around 80% of PM_{10} and 83% of $PM_{2.5}$ concentrations contributed by industrial sector during winter season.

8.2.3 Biomass burning

Agriculture residue burning contributed to 3% in PM_{10} concentrations in the year 2019 in Surat city during winter season. This contribution is projected to decline slightly to 2% in the year 2030. Similarly, contribution for $PM_{2.5}$ concentrations was 3% in the base year 2019 and as well as future year 2030. As an alternative strategy, it has been assumed that the agriculture residue burning will be completely banned in future and its $PM_{2.5}$ and PM_{10} reduction potential is 100%.

Domestic sector contributed 13%, 11% and 7% in PM_{10} concentrations in the year 2019, 2025 and 2030, respectively in Surat city during winter season. Similar contributions are observed for $PM_{2.5}$ - 15%, 13% and 9% in the year 2019, 2025 and 2030, respectively. The share of domestic sector is declining in BAU due to increased penetration of LPG in the Surat district even in the

BAU scenario. This has happened as it is assumed that 100% households will be using LPG in the year 2030 in the Surat district in BAU. Therefore no further interventions have been tested for this sector.

After estimating emission reduction potential, concentration reduction potential was quantified by using air quality models and detailed results for summer and winter It is quantified that the complete ban on agriculture residue burning can reduce 2.4% and 2.8% of PM_{10} and $PM_{2.5}$ concentration in Surat city w.r.t BAU 2030 during winter season.

Dust (soil, road and construction)

Road and construction dust is estimated to contribute 16%, 21% and 22% in 2019, 2025 and 2030, respectively in PM10 concentration of Surat city during the winter season. Similar contributions for $PM_{2.5}$ are, 8%, 12% and 13% in the year 2019, 2025 and 2030, respectively.

For control of road dust emission, a strategy assuming 90% reduction in silt content of road dust in the year 2030 by taking number of measures such as plantation along road side, use of mechanized road sweeper etc. is tested. For control of PM emission from construction site, strict compliance of construction guidelines resulting in 30% and 60% reduction in emissions in the year 2025 and 2030, respectively is tested. The emission reduction potential of these two strategies is shown in the Figure 8.6. As a result, reduction in silt content of road dust will reduce 87% of PM_{10} and $PM_{2.5}$ emission from road dust sector in the year 2030. Strict compliance of guidelines will reduce 60% of particulate matter emissions from construction sector.

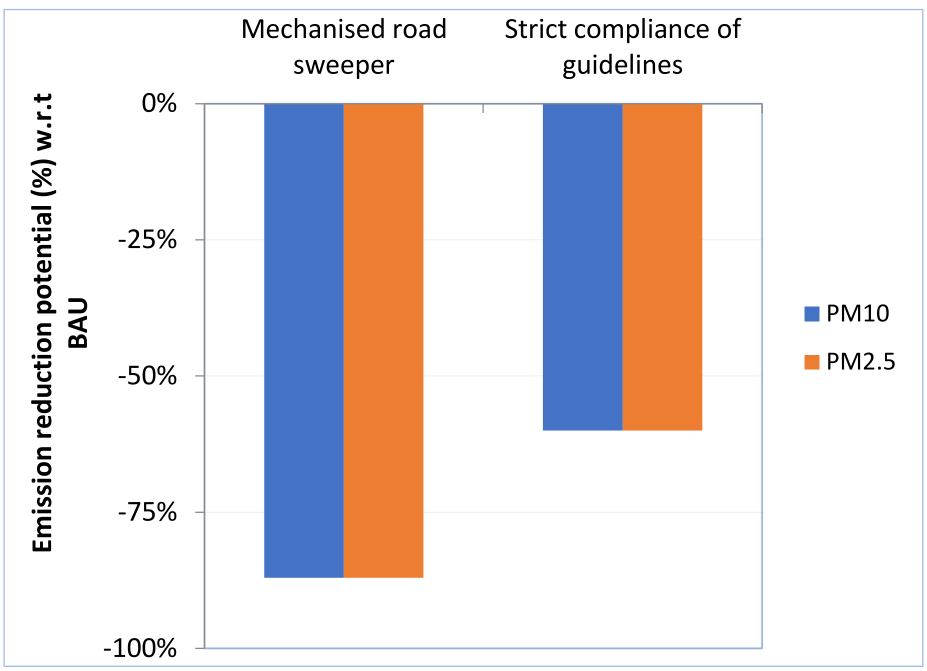


Figure 8.6: Emission reduction potential of the strategies with respect to sectoral emissions in BAU 2030.

After estimating emissions reduction potential, modeling was performed to estimate the concentration reduction potential of these strategies and detailed results are provided in the Table 8.3. Reduction of silt content of road dust will reduce 18.3% and 10.4% PM_{10} and $PM_{2.5}$ concentration, respectively in Surat city in the year 2030 during winter season. Strict compliance of construction guidelines will reduce 0.8% and 0.4% of PM_{10} and $PM_{2.5}$ concentrations, respectively in the year 2030.

8.2.4 Others

Others sector contributed 9%, 11% and 13% in the year 2019, 2025 and 2030, respectively in both PM_{10} and $PM_{2.5}$ concentrations of Surat city during winter season in BAU scenario. This sector mainly consists of emission from hotel and restaurant, landfill, aircraft, crematoria and ports. In addition to this, ammonia sensitivity is also accounted in this sector based on air quality simulations. It is estimated that secondary particulate formation due to release of ammonia from other non-air polluting sources such as live feedstock, can contribute 50% in sectoral contribution from this sector during winter season. In order to reduce the contribution of Other sector, a strategy assuming 50% and 75% reduction in Hotel and restaurants, landfill and port emissions in the year 2025 and 2030, respectively is tested. It is estimated that the tested strategy will result in 66% and 62% reduction in PM_{10} and $PM_{2.5}$ emissions, respectively from other sector in the year 2030 (Figure 8.7).

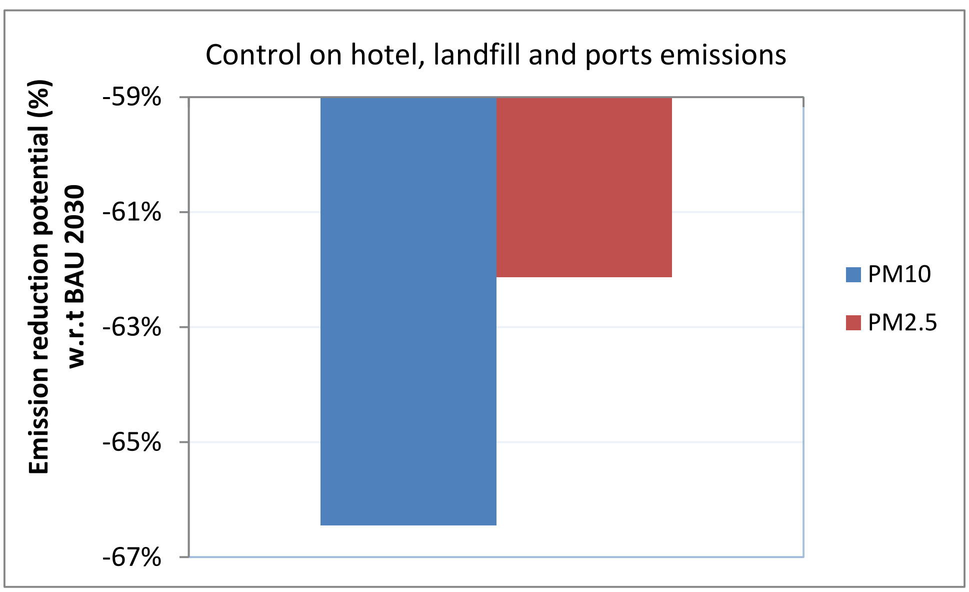


Figure 8.7: PM_{10} and $PM_{2.5}$ emission reduction potential of strategy in others sector in the year 2030.

After estimating emission reduction potential, concentration reduction potential is quantified through air quality simulations and details are provided in the Table 8.4. It is estimated that control of emissions from others sector can reduce 5.6% and 5.4% of PM_{10} and $PM_{2.5}$ concentrations, respectively in Surat city in the year 2030.

Table 8.4: Concentration reduction potential of various strategies/ interventions in Surat city during winter season.

Sector	Strategies	Intervention specific % reduction in PM concentration w.r.t BAU 2025 and 2030, respectively				Intervention specific PM reduction (µg/m³) w.r.t BAU 2025 and 2030, respectively			
		2025		2030		2025		2030	
		PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$
Domestic	**Biomass to LPG Conversion**	-0.3%	-0.3%	-0%	-0%	-0.50	-0.41	0	0
Agriculture residue burning	**Complete ban on biomass burning**	-2.6%	-3.0%	-2.4%	-2.8%	-4.35	-3.60	-4.35	-3.60
Industry	**Wet Scrubber**	-2.8%	-2.8%	-6.5%	-6.6%	-4.65	-3.32	-11.96	-8.52
	Solid and liquid to Gas fuel conversion	-2.9%	-2.9%	-6.9%	-7.0%	-4.90	-3.50	-12.68	-9.03
	Brick Kiln- Zig- Zag conversion	-0.6%	-0.7%	-0.9%	-1.1%	-0.92	-0.84	-1.59	-1.41
Transport	**2w, 3w on electric vehicle**	-0.3%	-0.5%	-0.5%	-0.7%	-0.58	-0.54	-0.90	-0.85
	Cars on electric vehicle	-0.1%	-0.1%	-0.1%	-0.1%	-0.12	-0.12	-0.17	-0.16
	Bus on electric vehicle	-0.2%	-0.3%	-0.1%	-0.2%	-0.32	-0.31	-0.23	-0.23
	Modal shift on Bus	-0.1%	-0.1%	-0.1%	-0.1%	-0.11	-0.11	-0.12	-0.12
	Fleet modernisation 2-w and cars	-0.2%	-0.2%	-0.1%	-0.1%	-0.27	-0.26	-0.16	-0.15
	Fleet modernisation Trucks and buses	-2.3%	-3.0%	-0.8%	-1.1%	-3.77	-3.51	-1.52	-1.42
	Biodiesel penetration	-0.3%	-0.4%	-0.2%	-0.2%	-0.46	-0.44	-0.33	-0.31
	Decongestion	-0.7%	-0.9%	-0.4%	-0.5%	-1.22	-1.12	-0.69	-0.64
	Strict Compliance	-0.4%	-0.5%	-0.2%	-0.3%	-0.61	-0.59	-0.38	-0.37
	CMP Do nothing scenario	-0.7%	-0.9%	-0.5%	-0.6%	-1.11	-1.03	-0.87	-0.82
Road dust	**Road dust management**	-11.9%	-6.6%	-18.3%	-10.4%	-19.91	-7.85	-33.80	-13.38
Waste burning	**Ban on refuse burning**	-0.7%	-0.5%	-0.5%	-0.3%	-1.22	-0.62	-0.88	-0.45
Construction	**Strict implementation of construction guidelines**	-0.4%	-0.2%	-0.8%	-0.4%	-0.62	-0.22	-1.43	-0.52
Other	**Control on other sector: 50% control on hotel and restaurants, landfill and ports in 2025 and 75% control in 2030**	-2.7%	-2.6%	-5.6%	-5.4%	-4.52	-3.10	-10.32	-6.96

Table 8.5. Concentration reduction potential of various strategies/ interventions in Surat city during summer season.

Sector	Strategies	Intervention specific % reduction in PM concentration w.r.t BAU 2025 and 2030, respectively				Intervention specific PM reduction (µg/m³) w.r.t BAU 2025 and 2030, respectively			
		2025		2030		2025		2030	
		PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$
Domestic	Biomass to LPG Conversion	-0.06%	-0.14%	-0.0%	-0%	-0.06	-0.06	0	0
Agriculture residue burning	Complete ban on biomass burning	0.03%	-0.11%	0.03%	-0.10%	0.033	-0.05	0.03	-0.05
Industry	Wet Scrubber	-3.27%	-5.87%	-7.87%	-13.8%	-3.21	-2.49	-8.22	-6.35
	Solid and liquid to Gas fuel conversion	-3.58%	-6.48%	-8.65%	-15.3%	-3.51	-2.75	-9.03	-7.04
	Brick Kiln- Zig- Zag conversion	-0.05%	-0.07%	-0.09%	-0.13%	-0.05	-0.03	-0.09	-0.06
Transport	2w, 3w on EV	-0.11%	-0.24%	-0.13%	-0.29%	-0.11	-0.10	-0.14	-0.13
	Cars on EV	-0.04%	-0.08%	-0.04%	-0.09%	-0.03	-0.03	-0.04	-0.04
	Bus on EV	-0.06%	-0.13%	-0.04%	-0.10%	-0.05	-0.05	-0.05	-0.04
	Modal shift on Bus	-0.04%	-0.08%	-0.04%	-0.08%	-0.04	-0.04	-0.04	-0.04
	Fleet modernisation 2-w and cars	-0.06%	-0.14%	-0.04%	-0.09%	-0.06	-0.06	-0.04	-0.04
	Fleet modernisation Trucks and buses	-0.61%	-1.33%	-0.25%	-0.53%	-0.60	-0.57	-0.26	-0.24
	Biodiesel penetration	-0.13%	-0.29%	-0.09%	-0.19%	-0.13	-0.12	-0.09	-0.09
	Decongestion	-0.26%	-0.57%	-0.14%	-0.31%	-0.26	-0.24	-0.15	-0.14
	Strict Compliance	-0.15%	-0.33%	-0.09%	-0.20%	-0.14	-0.14	-0.09	-0.09
	CMP do nothing scenario	-0.18%	-0.39%	-0.12%	-0.26%	-0.17	-0.16	-0.13	-0.12
Road dust	Road dust management	-7.89%	-7.40%	-12.6%	-11.6%	-7.74	-3.14	-13.2	-5.4
Waste burning	Ban on refuse burning	-0.08%	-0.16%	-0.06%	-0.10%	-0.08	-0.07	-0.06	-0.05
Construction	Strict implementation of construction guidelines	-0.33%	-0.26%	-0.71%	-0.56%	-0.32	-0.11	-0.74	-0.26
Other	Control on other sector: 50% control on hotel and restaurants, landfill and ports in 2025 and 75% control in 2030	-0.13%	-0.12%	-0.29%	-0.25%	-0.13	-0.05	-0.31	-0.11

8.3 Alternative scenario

Despite several interventions assumed, the BAU scenario shows increase of 23% and 15% in PM_{10} and $PM_{2.5}$, respectively between the years 2019 and 2030. Evidently, there is a need to enhance the stringency of interventions for effective control of pollution in Surat and meet the NAAQS in the worst affected winter season. Based on analysis of interventions, it emerged that there are interventions which can provide significant air quality benefits. While these interventions can provide significant benefits when implemented at the Surat level, implementation of these interventions at the airshed level (areas beyond Surat district contributing to air pollution in Surat city) can provide even larger benefits. This can bring pollutant levels close to the prescribed limits of PM_{10} and $PM_{2.5}$. The interventions which have been identified based on intervention analysis are selected for formulation of alternative air quality scenario for Surat city are listed in Table 8.6.

Table 8.6: List of interventions selected for formulation of alternative scenario for Surat city.

Sector	Intervention
Domestic	Early switchover to LPG: 100% conversion of biomass to LPG in the year 2025.
Agriculture residue and power plant	Complete ban on burning of agricultural residues.
Transport	All Buses on Electric modes
	Reduced real-world emissions through congestion management
Industries	100% fuel switch from solid and liquid to gaseous fuels in 2025 and 2030
Brick kiln	100% enforcement of Zig-Zag brick kiln technology in 2025 and 2030
Road dust	Vacuum cleaning of arterial, sub-arterial and local roads - 100% in 2025 and 2030 (leading to 90% reduction in silt loads)
Construction	100% control of dust from construction activities- barriers and fogging based controls with removal efficiency of 60% in 2030
Others	Control on hotel & restaurant; landfill and port emission- 50% in 2025 and 75% in 2030

Figure 8.8 shows the reductions in winter season PM_{10} and $PM_{2.5}$ concentration in Surat city, which are possible with implementation of all selected interventions at Surat district and at airshed levels.

In ALT Surat district scenario, the winter season PM_{10} and $PM_{2.5}$ concentrations in Surat city are expected to fall by 36% and 28%, respectively, with respect to the BAU scenario in 2030. In the ALT-Surat district scenario, the PM_{10} and $PM_{2.5}$ concentrations in Surat city are expected to be between 129-118 μg/m³ and 98-93 μg/m³, respectively in winters between 2025-2030. During the year 2030, in both PM_{10} and $PM_{2.5}$ concentrations, industry is a major contributor (46% and 50% in PM_{10} and $PM_{2.5}$, respectively) followed by residential (12% and 13%), dust blown across the international border (13% and 11%) and others sector (11% and 10%).

It is evident that despite extending the implementation of interventions to the Surat district, the PM_{10} and $PM_{2.5}$ concentration in Surat city will still be above the prescribed daily standards especially during the winter season. In order to achieve ambient air quality standards throughout the year, there is a need to implement the interventions not only in the district but in the whole airshed region (the whole region which contributes to pollution in Surat city through atmospheric transport). The PM_{10} and $PM_{2.5}$ reduction benefits of implementation at airshed region are shown as ALT-Surat air shed scenario in Figure 8.8. As seen in the Figure 8.8 & Figure 8.9, both PM_{10} and $PM_{2.5}$ concentrations in Surat city can be brought under the limits even during winter season.

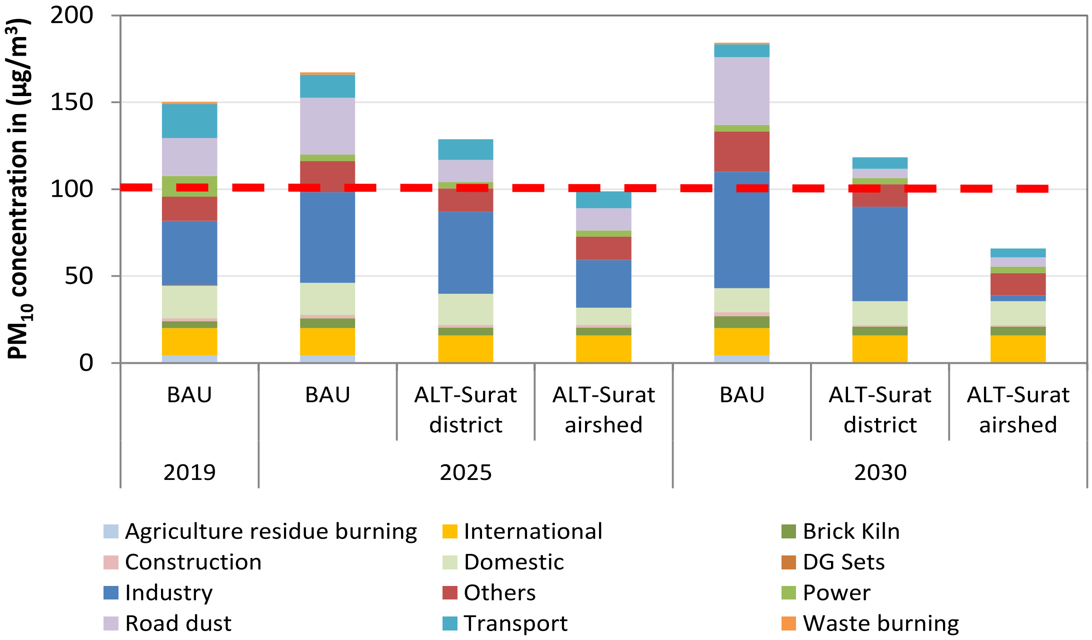


Figure 8.8: Winter season PM_{10} concentration in different scenario in the Surat city

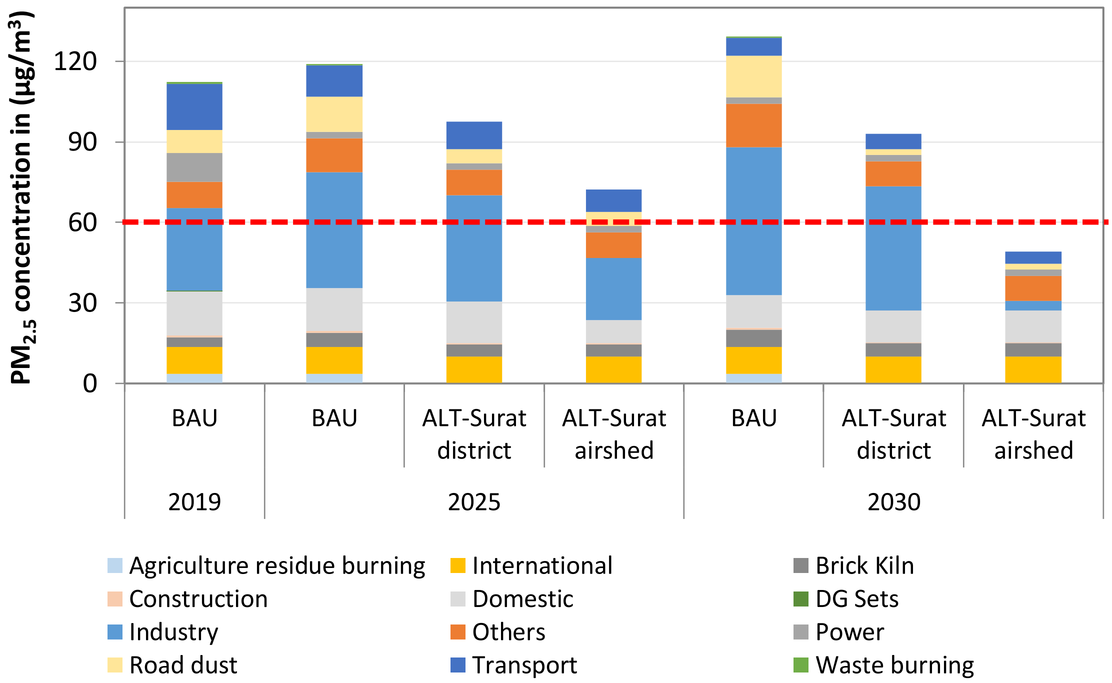


Figure 8.9: Winter season $PM_{2.5}$ concentration in different scenario in the Surat city

SUMMARY & CONCLUSION

9

Air quality is an important issue in Surat and hence it has been identified as a non-attainment city under the NCAP. This study has been carried out to strengthen the air quality management plan for city of Surat. The main objective was to carry out source apportionment of particulate matter concentration using two different scientific techniques-receptor and dispersion modelling. After a two year long assessment of air pollutant levels monitored at 7 locations in the city, chemical characterization of PM samples, emission inventory of Surat city and district, receptor and dispersion modelling, source apportionment of PM_{10} and $PM_{2.5}$ levels have been derived. Finally, the validated model has also been used to project future air quality and identify strategies which have the maximum potential for control. The broad conclusions of this study are:

- **Seasonal variations** - The results of ambient PM_{10} and $PM_{2.5}$ monitoring shows that the seasonal average concentrations exceeded the NAAQS at all locations in Surat in winter season. However, summers show much lesser concentrations than winter season and at most of the locations the levels of both PM_{10} and $PM_{2.5}$ were found to be exceeding the standard. The seasonal average $PM_{2.5}$ to PM_{10} ratio was found to be more in winter season, indicating the influence of more combustion based activities during winters.
- **AQ spatial variation in the city** – There were significant spatial variations in air quality across different locations and seasons. At all the monitoring locations, the ambient concentration of PM_{10} and $PM_{2.5}$ during winter period was higher than 24-hr average NAAQS. Commerical location and industrial location -2 showed high PM_{10} concnetration in winter season, while industrial location-2 showed higher values of $PM_{2.5}$ concentration. During summer season the average ambient concentration of $PM_{2.5}$ across different locations were recorded below the prescribed limit. PM_{10} levels at four out of seven monitoring sites during summer period were also recorded within prescribed standard. In summers, industrial location-1 showed high PM_{10} and $PM_{2.5}$ concentrations.
- **Chemical characteristics** - Elements were identified as the most abundant chemical constituents in ambient PM_{10} across all the monitoring locations during summer season. On the other side, ions were the most abundant chemical constituents in winter season depicting higher contributions of secondary particulates. This necessitates the control of gaseous pollutants like NOx, SO2 and ammonia along with PM. Ions were most dominating chemical constituents in ambient $PM_{2.5}$ samples across the monitoring locations during both summer and winter seasons. Elements were the second most dominating chemical species in ambient $PM_{2.5}$ among different monitoring locations during the summer season, while carbon was the second most dominating chemical species in ambient $PM_{2.5}$ during the winter season. Higher shares of elemental carbon in winters shows significant contributions of diesel and biomass based combustion, which are the rich sources of elemental carbon emissions.

- **Emission inventories shares** – The shares in emission inventories vary significantly with size fraction of PM and also with spatial extent (Surat district and city). At district level, major sources of PM_{10} emissions are road dust, industry, transport and thermal power plants. Industry is the major contributor to the total $PM_{2.5}$ emissions followed by road dust and transport. In case of SO_2, industry and thermal power plants are the major contributor to the total emissions. At city level, major sources of PM_{10} emissions are road dust, industry and transport. For $PM_{2.5}$ emissions, road dust, transport and industry are the major contributors. SO_2 emissions are majorly from industry followed by residential sector. NOx is majorly emitted by transport sector followed by industries

  Emission spatial distribution - Emissions of different pollutants for all the sectors are spatially distributed using and are found to be more in the areas with high population density, dependence of biomass for cooking and vehicular activity. NOx emissions are mainly concentrated at urban areas of the district and highways, mainly due to vehicular density. SO2 emissions are found to be higher at the industrial locations due to burning of coal. CO emissions are primarily driven by incomplete combustion in rural households, and hence show higher intensities in the areas outside the city.

- **Results of receptor model** – Based on receptor model, dust from road, soil and construction were major sources of ambient $PM_{2.5}$ and PM_{10} contribution at different monitoring locations in the city during summer season. It is followed by industrial contributions. In winters, industries are the major contributor to the ambient PM_{10} concentration followed by secondary particulates whereas secondary particulate are majorly contributor to ambient $PM_{2.5}$ followed by industries. Contribution from transport sector was found to be higher in winter than in summers for both PM_{10} and $PM_{2.5}$.
- **Results of dispersion model**: Dispersion model shows that in the Surat city during winter season, industry (25% and 27%), transport (15%, 13%), road dust (13%, 8%), and biomass burning (13%, 15%), are the major contributors PM_{10} and $PM_{2.5}$ concentrations, respectively. Summers were found to be more dominated by dusty sources in far off distances.
- **Geographical contributions** - The contribution to ambient PM_{10} and $PM_{2.5}$ concentration from city's own emissions in summer has been estimated to be about 24% and 26% respectively, while in winters it estimated to be 22% and 17% respectively. The contribution from outside Surat district are high in both seasons depicting regional scale pollution. Outside India contributions are higher in summers for both $PM_{2.5}$ and PM_{10} respectively, while it decreased for both the pollutants in winters. This is due to prevailing wind conditions in the summers which transports dust and other pollutants from outside the boundary of India and influence air quality of the city.
- **Receptor-dispersion combined analysis** - Both the source apportionment approaches indicate that industrial/power plants sector is the major contributor to the ambient $PM_{2.5}$ concentrations in both the seasons. In winters and summers, industry contributes dominantly to $PM_{2.5}$ as assessed from receptor and dispersion

approaches respectively. However, industrial contributions are not just form within the Surat city or district but are also from far off distances. In winters, the contribution of transport is found to be higher and significant than in summers season. Overall, the results of source apportionment from the two approaches for PM_{10} seem to be in consensus for most sectors. In summer season, dust is major contributing source followed by industrial sector as assessed from receptor and dispersion modeling respectively. Contribution to ambient PM_{10} concentrations from sea salt is also observed during summer season as derived from receptor modelling approach. These were significant in summers as the dominant wind direction (South-west) was found to be from sea-side only.

→ **Future projections**: In the BAU scenario, the winter season PM10 and $PM_{2.5}$ concentrations are expected to further increase by 23% and 15%, respectively in 2030, w.r.t BAU 2019. More stringent controls will be required to control emissions in the entire Surat district and the rest of the airshed to bring winter season PM_{10} and $PM_{2.5}$ levels down considerably. Surat district level controls can reduce winter season PM_{10} and $PM_{2.5}$ concentrations by 36% and 28% by the year 2030 w.r.t BAU. More stringent alternative scenario with airshed level controls can reduce winter season PM_{10} and $PM_{2.5}$ concentrations by 64% and 62% by the year 2030 w.r.t BAU.

Effect of regional scale pollution is pronounced in Surat's particulate matter concentrations and hence, regional level air quality planning and implementation is recommended for effective control of pollution in the entire region. Based on the intervention analysis, the major strategies suggested for control of pollution in Surat are (prioritisation to be done based on reduction potential of these strategies given in Table 8.5 and other local considerations):

- Fuel switch from solid and liquid to gaseous fuels in Surat district and other important industrial regions in the upwind regions of Gujarat.
- Public and para-transit transport on electric modes
- Reduced real-world emissions through congestion management and strengthened I&M system
- Fleet modernization of vehicles
- Enforcement of Zig-Zag brick kiln technology in 2025 and 2030
- Landscaping and vacuum cleaning of arterial, sub-arterial and local roads.
- Faster penetration of LPG in Surat district and upwind regions of Gujarat
- Control of dust from construction activities- barriers and fogging based controls
- Complete ban on burning of agricultural residues.
- Control on hotel & restaurant; landfill and port emission

References

MNRE. (2014). MNRE Annual Report. Retrieved from http://mnre.gov.in/file-manager/annual-report/2014-2015

Solar city master plan for Surat, Ministry of New and Renewable Energy, Government of India, 2013, https://www.scribd.com/document/325463133/Surat-Solar-City-Master-Plan. https://www.suratmunicipal.gov.in/Content/Documents/Departments/energyeff/EnergyEfficiencyCell.pdf

Annexure –I- Methodology for chemical analysis of PM samples

The quantitative analysis of elements in PM samples collected on Teflon filters was carried out using Energy Dispersive X-ray Fluorescence Spectrometer (ED-XRF). As XRF analysis is a non-destructive technique this paper was used for subsequent analysis of water-soluble inorganic ions using Ion Chromatograph. PM samples collected on quartz filters were subjected to OC and EC analysis using the Thermal/Optical Carbon Analyzer. Details of the sample analysis are given below:

Energy Dispersive X-Ray Fluorescence (ED-XRF) spectrometry (EDX 7000, Shimadzu, Japan) was used to determine the concentrations of elements including Al, Si, K, Ca, Ti, V, Fe, Co, Ni, Cu, Zn, As, Se, Zr, Mo, Pd, Cd, Ce, and Pb, on the Teflon filters. Calibration standards, in the form of filter paper, of Micromatter Inc. for various elements were used for calibration of equipment. Measurements were also made on the blank filter and correction in the intensities was made for the loaded filters. Data acquisition and quantitative analysis were carried out by using equipment software.

The water-soluble inorganic ionic components in PM collected on Teflon filters were determined using ion chromatography method. Each sample was ultrasonically extracted using 50 mL of deionized water for 90 minutes. The extract was filtered through a 0.22 µm nylon membrane syringe filters to remove insoluble matter and then analysed using an ion chromatography (IC) system (ICS Aquion, ThermoFisher Scientific). Concentration of cations (Na+, K+, Mg+, NH4+, Ca2+) were determined using a IonPac CS16, 5mm analytical column and its CDRS600, 4mm guard column, 3.8 mM Methanesulfonic Acid was used as eluent while the concentrations of anions (Cl-, F-, Br-, NO3-, SO42-) were determined using a separation analytical column IonPac AS23; 4mm and guard column ADRS600, 4mm), and 4.3 mM carbonate and 0.8mM bicarbonate as eluent. The blank filters were also analysed for the cations and anions.

A 0.495 cm2 punch from a quarter of each quartz filter sample was used for the analysis of organic carbon (OC) and elemental carbon (EC) using a Thermal/Optical Carbon Analyzer (DRI Model 2001A; Desert Research Institute, USA) following IMROVE_A protocol. The four OC fractions i.e. OC1, OC2, OC, and OC4 are produced in a step-wise manner at 140, 280, 480, and 580 0C temperatures, respectively in a pure Helium (100% He) atmosphere. This analysis was further continued for three more temperatures i.e. 580, 740 and 840 0C for determination of three EC fractions i.e. EC1, EC2, and EC3, respectively in 98% helium and 2% oxygen containing atmosphere. The pyrolyzed carbon fraction (OP) is also determined when the reflected laser signal returns to its initial value after oxygen is added to the Helium atmosphere. The IMPROVE protocol defined OC as OC1+OC2+OC3+OC4+OP and EC as EC1+EC2 +EC3-OP. Each filter and blank filters were analyzed to get the representative estimation of OC and EC concentrations.

About TERI

A unique developing country institution, TERI is deeply committed to every aspect of sustainable development. From providing environment-friendly solutions to rural energy problems to helping shape the development of the Indian oil and gas sector; from tackling global climate change issues across many continents to enhancing forest conservation efforts among local communities; from advancing solutions to growing urban transport and air pollution problems to promoting energy efficiency in the Indian industry, the emphasis has always been on finding innovative solutions to make the world a better place to live in. However, while TERI's vision is global, its roots are firmly entrenched in Indian soil. All activities in TERI move from formulating local- and national-level strategies to suggesting global solutions to critical energy and environment-related issues. TERI has grown to establish a presence in not only different corners and regions of India, but is perhaps the only developing country institution to have established a presence in North America and Europe and on the Asian continent in Japan, Malaysia, and the Gulf.

TERI possesses rich and varied experience in the electricity/energy sector in India and abroad, and has been providing assistance on a range of activities to public, private, and international clients. It offers invaluable expertise in the fields of power, coal and hydrocarbons and has extensive experience on regulatory and tariff issues, policy and institutional issues. TERI has been at the forefront in providing expertise and professional services to national and international clients. TERI has been closely working with utilities, regulatory commissions, government, bilateral and multilateral organizations (The World Bank, ADB, JBIC, DFID, and USAID, among many others) in the past. This has been possible since TERI has multidisciplinary expertise comprising of economist, technical, social, environmental, and management.

teri
The Energy and Resources Institute
www. teriin.org