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सत्यमेव जयते
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Ministry of Earth Sciences
Govt. of India

150 YEARS OF CELEBRATING THE MAHATMA

-Accounting 26 Local Sources of Emission

SAFAR-HIGH RESOLUTION EMISSION INVENTORY OF MEGA CITY DELHI - 2018

SAFAR-India

INDIAN INSTITUTE OF TROPICAL METEOROLOGY PUNE

Indian Institute of Tropical Meteorology, Pune
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SAFAR-HIGH RESOLUTION EMISSION INVENTORY OF MEGA CITY DELHI - 2018

System of Air Quality and Weather Forecasting And Research (SAFAR) - Delhi

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FOREWORD

Emission inventory is the most effective scientific tool used to identify and quantify the amount of pollutants emitted into the air. Emission inventories in our country are available either as gross estimate for a city or region, but gridded data and special distribution in high resolution is sparse.

Scientists of IITM are involved in the development of emission inventory for major metropolitan cities. This scientific report presents results of emission inventory developed not only for Delhi city area but also surrounding regions with an area of 70 x 65 km^2 using GIS based methodology. Emission inventory is a critical input for the air quality and the quality of forecast depends on the accuracy of emission estimates fed into the model.

A comprehensive study based on the scientific knowledge has been made to develop the high-resolution (0.4 km x 0.4 km) emission inventory of all major air pollutants for a domain of ~65 km×70 km (~4550 km^2 area) covering Delhi and its adjacent region in this report. Emission inventories have been developed for 8 major air pollutants namely, Particulate Matter <2.5 micron ($PM_{2.5}$); Particulate Matter <10 micron (PM_{10}); Oxides of Nitrogen (NO_X); Carbon Monoxide (CO); Black Carbon (BC); Organic Carbon (OC); Sulfur Dioxide (SO_2) and Volatile Organic Compounds (VOCs). For the development of emission inventory, a bottom up approach has been used. The emissions have been estimated for the individual sources and for that purpose; an extensive scientific field campaign has been carried out in NCR region during the past several months.

I acknowledge the effort of our scientific team at ESSO-IITM and other collaborating partners for their timely effort and to publish this emission inventory report as latest as 2018. The current emission inventory of Delhi and surrounding regions has been developed with a much higher resolution of 400 m x 400 m which is a significant advancement of earlier effort by IITM when emission estimates with a resolution of 1.67 km x 1.67 km for 2010 were prepared.

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Executive Summary

High Resolution Emission Inventory of Major Air Pollutants of Mega City DELHI for 2018 under SAFAR

Clean air is a basic necessity for human health and well-being. When the local concentrations of air pollutants exceed certain threshold limit, it can have adverse effect on the health of human beings, plants and animals. Most of the mega-cities all over the world are experiencing the deterioration of air quality, including National Capital Territory of Delhi. The pollutants are added to the environment through **emissions** of various natural as well as anthropogenic sources. The anthropogenic emission (man-made.) is on the rise. **Emission Inventory** is a comprehensive listing by local sources of air pollutant emissions and amount of air pollutants released into air as a result of a specific process in a particular geographic region during a specific time period. This is one of the most critical factors required for air pollution forecasting models along with meteorological input to forecast the air quality and frame the mitigation strategy. Quality of forecasting depends on accuracy and reliability of emission estimation. Emission inventories could also be used for air quality management and formulating environmental policy.

Development of emission inventory is a complex process due to numerous, diverse and widely dispersed emission sources in city like Delhi and its adjacent region and requires huge amount of high-resolution activity data, emission factors along with knowledge of fundamental scientific processes. A mega emission inventory campaign involving around 150 students under the supervision of group of scientists mapped all possible local sources of air pollution with around 37,500 hours of work. The main focus of the campaign was to generate missing primary data, validate some uncertain secondary data and to collect the available secondary data. The final product with 400m x 400m high-resolution emission inventory of Delhi and fringe area of eight important air pollutants (PM2.5, PM10, NO_x, CO, SO_2, BC, OC, VOCs) is prepared. Emissions are estimated for two specific regions- (a) The geographical area of Delhi city only and (b) Delhi city area along with surrounding regions measuring 70x65 km^2. Ground level activity data about emissions from as many as 26 different sources of pollution were collected. The emission inventory campaign has been led by Indian Institute of Tropical Meteorology (IITM) Pune under the Ministry of Earth Sciences along with experts and researchers from Utkal University, Bhubneshwar, School of Planning and Architecture, Environmental Information System (ENVIS) Resource Partners of MoEFCC, CPCB, IMD and DPCC.

For the development of emission inventory, a bottom up approach has been used for which a Geographical Information System (GIS) based statistical model approach has been developed by our scientists at IITM & researcher at Utkal University to prepare high-resolution gridded emission inventory. During the campaign, information related to following major/minor activities were collected:

No.	Sectors	Important Factors and data
1	Transport	• Category, Fuel Type & Quantity • Vehicle/hour/Road type/VKT
2	Slum	• Type and Fuel used Quantity for cooking
3	Brick Industry	• Type, Technology and Fuel used Quantity
4	Street Vendor	• Type and Fuel Quantity • Coal for Tandoor
5	Hotel (Dhabas)	• Type of Fuel & Quantity used for cooking
6	Construction Sites	• Type of Fuel & Quantity used for cooking activity
7	Speed Breaker	• No. of Speed Breakers per Km • Road Type
8	Major Hospitals	• Number of outdoor patients • Vehicle load and DG sets
9	Tourist places	• Tourist Load, Vehicle load
10	Shopping Malls	• No. of vehicle parked
11	Traffic Junctions	• No. of Traffic Junctions
12	Railway Stations	• Passenger load • Vehicle load in station area
13	Airport	• Vehicle No. (Delhi & Out-side vehicle No.)
14	Industry	• Type, Technology and Fuel used
15	Local Transport (Ola/Uber/Taxi)	• Km run per day and Numbers
16	Household	• Type of fuel used
17	Waste Burning	• Quantity per capita
18	Biomedical Waste	• Quantity generated
19	Power plant	• Technology used, Coal used
20	Crematorium	• Spatial locations, No. of Cases
21	Large hotels	• Fuel used for cooking
22	Large school/college	• Students no. & Travel load
23	Wind Blown Road Dust	• Road condition, vehicle load etc.
24	Diesel Generator	• Fuel used for no. of hours
25	Mobile tower	• Fuel Used & numbers
26	Routine Milk & Vegetable Van	• No of vehicle (outside)

As the vehicular density is remarkably high in NCR region, to find out the exact traffic volume the vehicle numbers were calculated by using click counters in different major and minor roads of the NCR region. Having near about 2250 kms of major roads and 31000kms of minor roads. Major vehicle dense roads contributing to pollution were identified and information were recorded.

Results and Findings: The summary of the estimated emission of all 8 pollutants for 2018 for a broader region of Delhi and surrounding areas (70x65 km2) is been given in a table below. Here, brief discussion is done on a specific pollutant $PM_{2.5}$ that would be a case study to describe the similar contribution of other pollutants in this study. The estimated total emission of $PM_{2.5}$ for Delhi-NCR domain is calculated to be around **107.786** Gg/yr in 2018. Transport sector and industrial sector are playing major role in PM2.5 emission by contributing around **42.230** Gg/yr and **24.10** Gg/yr respectively to the total emission. Windblown dust is contributing around **19.50** Gg/yr followed by residential sector **6.2** Gg/yr and thermal power plants (**3.34** Gg/yr). High emission of $PM_{2.5}$ in the range of **10-50** ton/yr is found over eastern, central, some part of southeastern part of Delhi-NCR, which includes major dense roads network and industrial and residential zones. Emission of the order of 200-1000 ton/yr is found over industrial zone next to major roads. Large Point Sources like thermal power stations and WSM plants are some of other highly emitted zone. Western and northern region of Delhi shows comparatively lower value of $PM_{2.5}$ emission in the range of 0.6-8.0 ton/yr due to large agricultural lands, less number of industries followed by low population density leading to minimum emission. ***The residential emission has reduced drastically due to penetration of LPG connection in slums (95%) and household. The MSW related pollution is emerging as new challenge to tackle air quality issue in Delhi.***

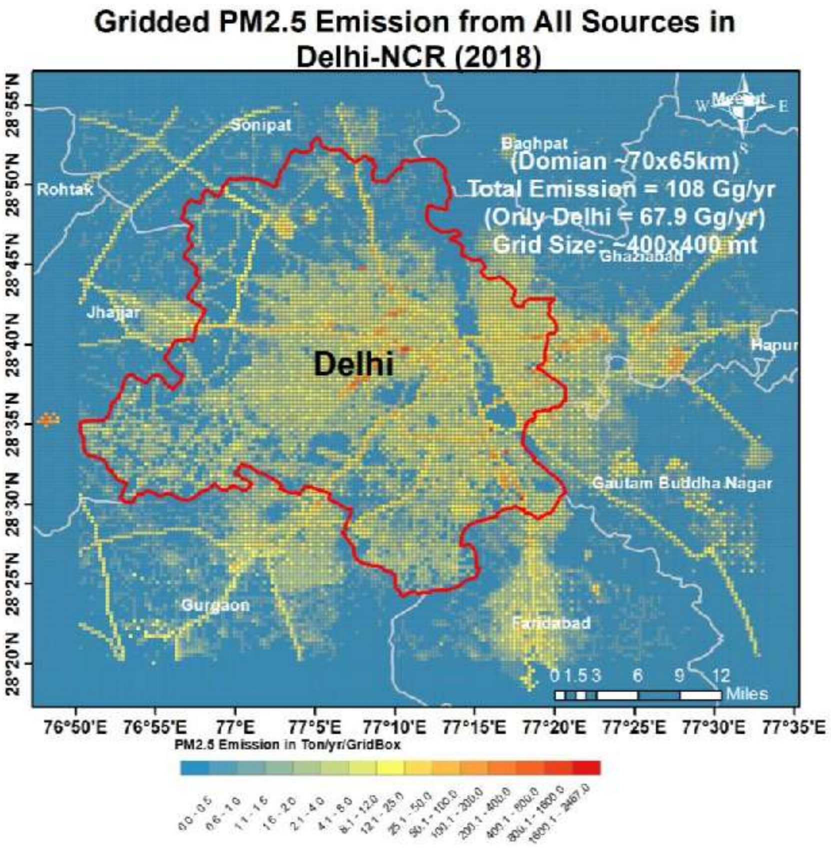
Some important observations of emissions inventory are as follows:

1. Like HCV (Heavy Commercial Vehicles), the commercial /personal four-wheeler (4W) segment has emerged as one of the major polluting sources in Delhi. The local car transport like OLA/UBER/MERU/etc. have significantly high VKT (Vehicle Kilometre Travelled) of nearly 1,45,000 km per year per car.
2. The relative contribution of other state 4W plying on different Delhi roads is found to be of the order of 25-45%. Some roads experience rising vehicle density on weekends (India Gate, Airport, Kashmiri Gate, etc.) as against usual deceasing trend.
3. Everyday vehicle load in eight different entry-point of Delhi from other states is nearly 11 lakhs. The average speed of vehicle on major roads in Delhi is just 20-30 km/hr leading to poor vehicle mileage and more emission.
4. In Slum, the penetration of LPG has touched 95% in 2018 as compared to just 35% in 2010. Although yearly wood burning consumption is 3%, it increases to 12% during winter months.
5. Preparation and burning of cow dung cakes in the outskirts of Delhi is a significant bio-fuel source of pollutants throughout the year. Brick kiln Usage of scrap rubber chapels (sleeper) as fuel in Brick kiln instead of coal is quite common.

Table: *Emissions (in Gg/yr) of various air pollutants (8) by different sectors as developed in the present work for the year 2018 in the area of approx. (65 km x 70 km) covering major parts of National capital region of Delhi*. Other includes all those sector not included in top 6 categories and mainly new one considered in 2018.

SECTORS	PM 2.5	PM 10	CO	NOx	VOC	SO_2	BC	OC
Transport	**42.2**	**43.2**	**483.1**	**257.7**	**614.5**	**77.2**	**15.5**	**26.5**
Industry	**24.1**	**43.9**	**12.1**	**100.7**	**61.0**	**400.1**	**5.1**	**8.7**
Power	**3.3**	**12.8**	**0.3**	**8.0**	**0.0**	**81.0**	**0.0**	**0.1**
Residential	**6.2**	**8.9**	**34.1**	**2.2**	**0.3**	**1.3**	**1.1**	**2.0**
Wind Blown	**19.5**	**136.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Others	**12.4**	**23.6**	**46.2**	**44.0**	**3.5**	**60.2**	**2.4**	**4.0**
TOTAL	**107.8**	**268.4**	**575.8**	**412.6**	**679.4**	**619.8**	**24.2**	**41.3**

The development of emission inventory is still in evolving stage in developing countries. Present results are not free from some amount of uncertainty but we feel that within the constraint, the emission estimates provided for Delhi are accurate with fine resolution.



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1. Introduction:

Clean air has become the most precious resources on the Earth. Air is the only thing that we all have in common all over the world. What comes to everyone's mind when we think of clean air? A basic and the most priceless thing that a person can ever have, right! However, today's scenario is somehow different. Anthropogenic activities release substances into the air, which has adverse impact on human health, plants, animals, environment and ecosystem (Akimoto et al, 2003). This is not only disturbing the natural balance of gases in the atmosphere but also has serious ecological implications. With rapid urbanization, industrialization and changing life style, air qualitygets worseday by day in most cities (Gujar et al, 2004 & Sahu et al, 2011). It is desperate situation for Government to take drastic measures to curb air pollution. A health human inhales ~14000 litres of air per day. As per recent WHO report, 9 out of 10 people worldwide breathe polluted air (WHO, 2018). Around 91% of the world's population lives in places where air quality levels exceed WHO defined limits. The same report also indicates that 4.2 million deaths occur every year because of exposure to outdoor pollution and another 3.8 million deaths occur due to household air pollution. According to WHO, "Air pollution is an invisible killer that lurks all around us, preying on young and old." In 2015, out of the 10.3 million deaths in India due to non-communicable diseases, 2.5 million were linked to pollution (WHO, 2018).

Air pollution has become a global concern. Air pollution is perceived as a modern-day curse, which is a by-product of increasing urbanization and industrialization. Rapid modernisation and progress have led to air getting more and more polluted over the years. With increase in the population, the mushrooming of industries and transport system are some of the major factors responsible for poisoning of air. As urban air quality declines, the risk of acute respiratory diseases including asthma, lung cancer, and COPD among people have increased in same magnitude. Recent WHO report depicted that 14 out of the 15 most polluted cities in terms of $PM_{2.5}$ concentrations in the world, belongs to India. Certainly, India has emerged as one of the most polluting places in the world to breathe. (Data source: Central Pollution Control Board, 2010)

1.1 Megacity Air Pollution and their Health effects:

Megacities are the metropolitan area having population more than 10 million.South Asia alone having five of these 'megacities' out of twelve in Asia. Three of them belong to India. Delhi as a megacity has led to rise in population due to two reasons. The first reason is that it is the capital of India and second reason is people migrate in large number from rural to urban areas in search of employment. It is expected that urbanization in developing countries will increase to 69% in 2050 as compared to just 45% in 2010 (Selahattin & Ulas, 2012).According to UN report, the half of world population is residing in urban areas as compared to just ~10% during industrial revolution years. This kind of development will put extra burden in cities by creating new physical, economic and social process. As the same time this will lead to uncontrolled urban sprawl and associated environmental issues due to high traffic density, irregular industry, and low quality housing in slums, etc. Megacities are highly diverse across the globe. The air pollution in Asian megacities is an emerging health and environmental problem due to rapid urbanisation, industrialisation, rising vehicles number. Most of the megacities in the world suffer from elevated concentration of atmospheric pollutants. The air pollution from megacity not only affects the people in/around a city, but also immediately affects the surrounding regions up to 200/300kms away. Capital of India, megacity Delhi has been experiencing a population boom in the last three decades. The air pollution in a megacity of country become national problem and has global linkage too. Because pollutant generated one part of the geographic region could affect other part of geographic regions.

The serious air quality problems, specifically inverse health effects, have been experienced in megacities where high population density exposed to high enough levels of certain air pollutants may experience symptoms like breathing difficulties such as asthma, irritation of eyes, and increased risk of heart attack etc. Long-term exposure to air pollution can cause cancer and damage to the immune, neurological, and reproductive and respiratory systems. In extreme cases, it can even cause death. In recent times, there has been a growing cognizance especially for particulate matter, because many global level epidemiological researches show a consistent elevate in cardiac and respiratory morbidity and mortality is due to perpetuate exposure to PM (Samet et al 2000, Brook et al 2004, Mirowsky et al 2013). It is estimated to kill more than 0.5 million people each year, (UNEP 2008) which make it a major culprit among all evils (HEI 2001).Prolonged exposures will not only create an adverse effect but also will have a noticeable change in the environment. It has been seen and stated everywhere that how air pollution is connected to numerous respiratory and cardiovascular diseases. Not only that, numerous medical literature even says, harmful effects of air pollution are noticeably higher if inhalation of these will be higher. Some of the major pollutants contributors to the degradation of environment and health hazard are particulate matter (both PM_{10} & $PM_{2.5}$), Oxide of Nitrogen (NO_x), Volatile organic compounds (VOCs), Carbon Monoxide (CO), Ozone (O_3), Sulphur dioxide (SO_2), Black Carbon (BC), Organic Carbon (OC) etc.

PM_{10} and $PM_{2.5}$ are predominant species present in the atmosphere and one of the root causes of atmospheric air pollution. These are known as inhalable particles with diameter equal to or smaller than 10μm for PM_{10} and for $PM_{2.5}$ it's equal to or smaller than 2.5μm. These are emitted directly from the source such as road dust, transport system, industries, smokestacks, construction activities etc. Larger particles can't get into the respiratory tract but smaller particles, less than 10μm can get into the tract and can get settled in the bronchi and lungs whereas particles smaller than 2.5μm pose the greatest problems, because they can get deep into our lungs, and some may even get into our bloodstream.

Apart from harmful effect on human health, air pollution can cause a variety of environmental effects like acid rain, eutrophication, haze, effects on wild life, crop and forest damage, global climate change etc.Breathing air with high concentration of NO_2 can always irritate the airways of human respiratory system. Exposures like this can produce respiratory diseases, particularly asthma, difficulty in breathing, coughing or wheezing. NO_2 along with other highly reactive oxides of nitrogen (NO_x) primarily gets in air from the burning of fossil fuels. NO_2 mainly comes from the emissions from vehicles, power plants and off-road equipment. NO_2 and NO_x together form acid rain, which affects ecosystem. The nitrate particles that results from NO_X make air hazy and difficult to see.

Being, SO_2 is another prominent pollutant generated a result of outcome of fossil fuel burning by power plants and other industrial activities. High concentration of SO_2 emission leads to the formation of other Sulphur oxides (SO_x) which reacts with compounds in the atmosphere to produce particulates. It in turn leads to particulate pollution, which may penetrate deep into the sensitive parts of lungs and affect that. Shortness of breath, difficulty in breathing for people suffering from asthma is some of the immediate effect of SO_2 exposure. It has also seen that SO_2 emission that leads to the formation of SO_x in air can generally lead to damage of trees and plants by damaging the foliage. It can also contribute to acid rain, which induces further problem in the ecosystem. The formation of acid rain is being a problem for the monuments, marble scriptures, and stone, as it tends to destroy them. As discussed above, SO_2 produces particulates, which contribute in the formation of haze reducing visibility.

Ozone is mainly known as a layer of protection for the earth to combat against the UV radiation pollution. However, the presence of ozone layer in stratosphere is protective, but in troposphere,it is generally regarded as a pollutant due to its negative impact on the atmosphere. The tropospheric ozone is not emitted directly on the air but is created by the reaction between NO_x and VOCs in the presence of sunlight. The effect of ozone on human health is effectively seen as asthma, lung cancer, decreased lung function, bronchitis, emphysema etc. It also affects sensitive vegetation and ecosystems including forests, parks and wildlife refuges. Effect of ozone can be particularly seen on plants as it tends to get into the stomata of leaf and oxidises the plant tissue during respiration.

VOC are the organic compounds that easily become vapour or gases. Along with carbon, they contain elements like hydrogen, oxygen, fluorine, chlorine, bromine, sulfur or nitrogen. Some of them are gasoline, formaldehyde, toluene etc. Some of the sources are burning fuel, paints, aerosol sprays, cleanser, disinfectants, pesticides, etc. The impact of VOC depends upon the factor that includes the time and level of exposure. The emission leads to some of the health impacts like headache, nausea, dizziness, epistaxis, damage to CNS, nose and throat discomfort.

In context of CO, it is a weak greenhouse gas, which is mainly formed by incomplete combustion of carbon. Its introduction to atmosphere can be done by motor vehicle exhaust fumes, industrial emissions, volcanoes, forest fires etc. high levels of CO has negative impact on breathing and the oxygen transport system of the body. Inhalation of CO causes the replacement of oxygen by CO and the binding of the CO in place of oxygen and forms carboxyl-haemoglobin reducing the oxygen content in the blood.Some of the air pollutants like BC, OC, have significantimpact on global radiation balance and, in turn, on the global climate change through direct and indirect radiative forcing (Bond et al, 2004).

1.2 Air quality forecasting system and role of emission inventory:

Air quality forecasting system is a state of the art modelling system which forecasts the following day's air quality. It ensures thorough and reliable monitoring of different concentrations present in ambient air, which in turn focuses on the development of emission inventories, by analysing various characteristics of the pollutants. Integral components of an effective air quality monitoring system are a) Emission Inventory, (b) Chemical Transport Model (CTM), (c) Meteorological Forecasting and d) Observation.

Emission inventory is a comprehensive listing by sources of air pollutant and amount of air pollutants released into air because of a specific anthropogenic process in a particular geographic region during a specific time period. It mainly includes surface emission data compiled from both anthropogenicand natural sources. It is one of the most critical and sensitive components of air quality forecasting system. **Meteorological** forecast is associated with prediction of condition of the atmosphere for a given location and time. WRF (Weather Research Forecast) model is widely being used meteorological model. A **chemical transport model** stimulates various physical and chemical processes that are important for understanding atmospheric trace gas and particle distribution. Chemical transport model usually rely on a meteorological model for description of atmospheric states and motion, and depends on an emission model for the description of anthropogenic or biogenic emissions. However, for model validation, robust observation network is equally important for atmospheric chemistry point of view.

Moreover, for an effective science based air quality management will help to develop robust control strategies. Emission inventories not only helps to identify the emission sources in theregion and contribution of each source to the total emission but also eventuallyguide us to set priorities for the action plan for different sources, evaluating thevarious options available to reduce the emissions from identified potential sources, formulate, and implement the appropriate action plan. It has been used as one of the important fundamentalcomponents in air quality modeling application and also for air quality managementplans to measure progress/changes over time to achieve cleaner air. Emission inventories are now regarded as indispensable tools for prevention of air pollution at national and regional/city scale. The role of the emission inventory for air quality management is depicted in Figure-1.

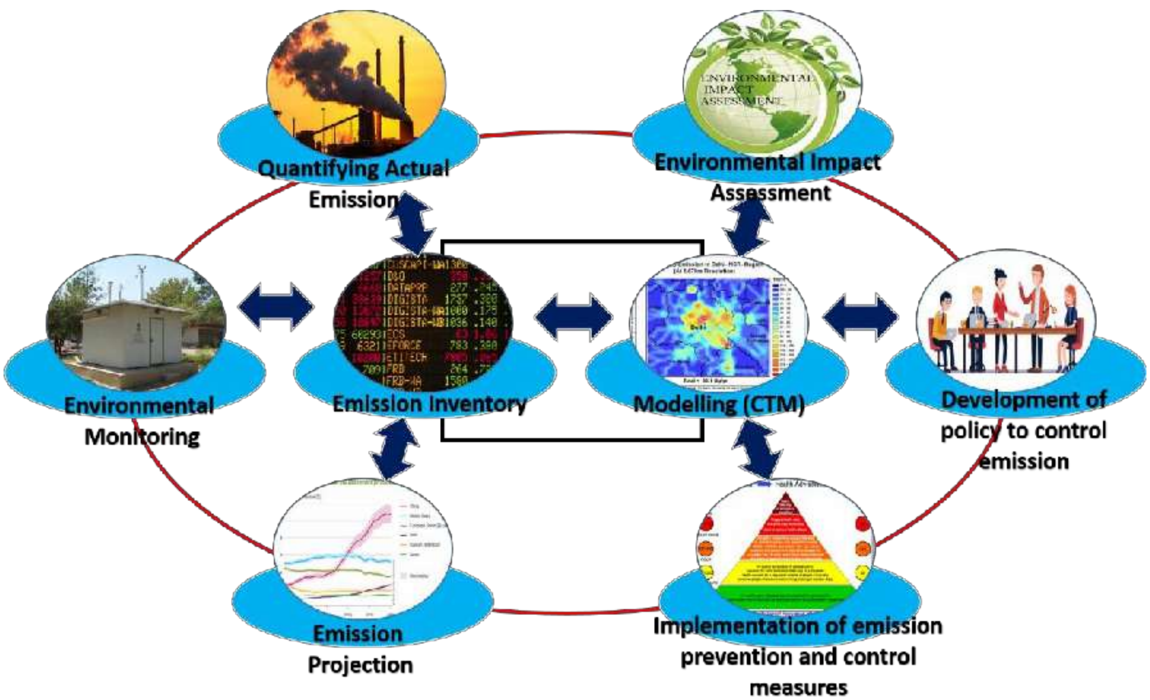


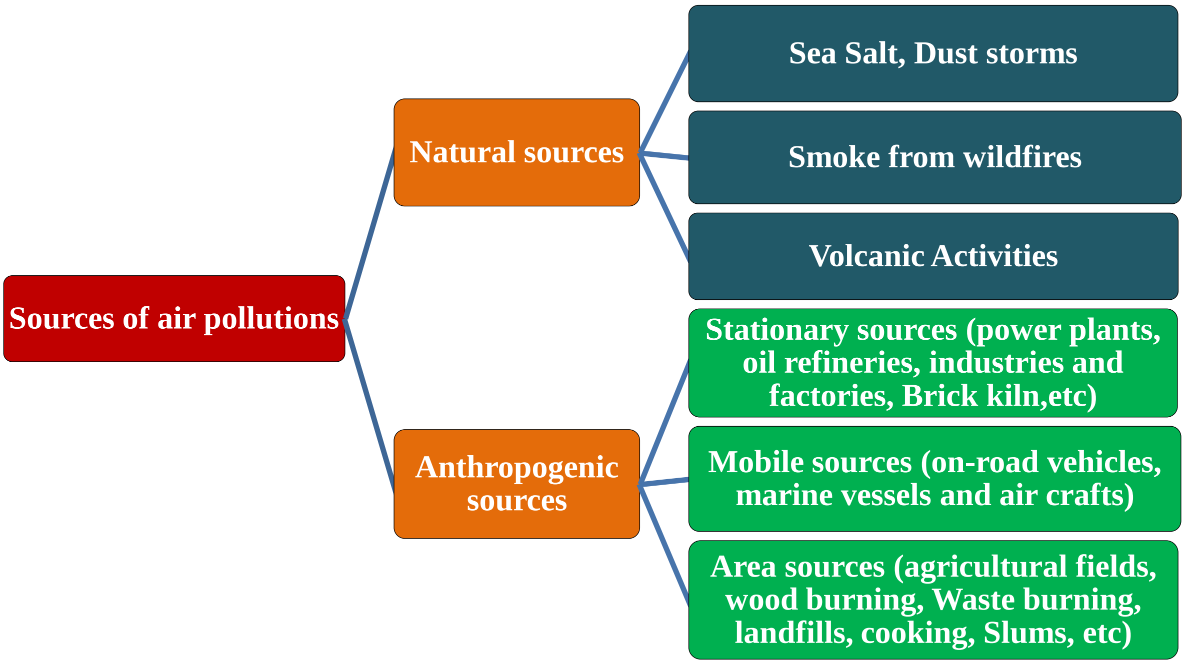
Figure 1 Roles of Emission Inventory for Air Quality Management

1.3 Present Objective:

Till date, there are couple of attempted had been made to build an robust emission inventories for Delhi by few researcher as well as institutions like Indian Institute of Tropical Meteorology (IITM, Pune), Indian Institute of Technology, Delhi, (IIT, Delhi), Central Pollution Control Board (CPCB),National Environmental Engineering Research Institute (NEERI) (Gujar et al, 2004, Sahu et al, 2011, Mukesh Sharma et al, 2017). In 2010, CPCB along with NEERI carried outsource apportionment studies in Delhi (CPCB, 2010) For modelling as well as mitigation strategy point of view, emission inventory should be as latest as possible.System of Air Quality Forecasting and weather Research" (SAFAR), a pilot project of WMO-GURME and an initiative of the Indian government, adopted an integrated modeling approach to implement the first ever air quality forecasting services during the mega international sports events held in Asia's 2nd biggest megacity Delhi in 2010. SAFAR reported first ever high resolution gridded (1.67km×1.67km) for Delhi for base year 2010 (Sahu et al, 2011). It was focused on couple of traditionally dominating sectors like transport, industries, household, slum, street vendors, thermal power plants etc. Emission sources changes with changing life style and modernization of city amenities/infrastructure. For a better understanding of ambient air quality issues in Delhi and its forecasting, an accurate estimation of rate of anthropogenic emission of the air pollutants is of great significance. It is high time again to identify all possible new minor and major emission sources and its magnitude in Delhi for a most recent base year (say 2018). In view of all the facts discussed in the section, in the present study, another attempt has been made to develop a very high resolution (0.4km×0.4km) EmissionInventory for a domain of 70km×65km covering Delhi and itsadjacent NCR region, under the Ministry of Earth Sciences (MoES) project, "System of Air Quality Forecasting and Research (SAFAR)". Unlike earlier approach, present work has targeted around 26 minor/major sectors responsible for direct/indirect emission of pollutants. The focus of the present study is on theeight air pollutants including gaseous pollutants; viz. CO, NO_x, SO_2 and VOC and particulate matters including PM_{10}, $PM_{2.5}$, BC and OC.

2. Sources of Air Pollution:

Air pollution can be formed through both natural and man-made (Anthropogenic) processes. Anthropogenic sources of air pollutants into the atmosphere depend on various human activities leading to improve the quality of life. Any kind of combustion processes are the major sources of air pollutants during the generation and use of energy. The emission depends on the fuel type used in particular technology and process activity. Some of the natural sources of air pollution are organic compounds from plants, sea salt, suspended soils and dusts. Other natural sources are released through catastrophes like forest fires and volcanic eruptions.



Pollutants are divided into two category based on its source. The primary pollutants emitted from directly from sources, whereas secondary pollutants are produced in the atmosphere as a result of chemical or physical interaction between the primary pollutants. Example of couple of primary and secondary source is provided in **Table-1**.

Table 1: Type of Pollutants and sources

Type	Definition	Pollutants	Source
Primary Pollutants	Air pollutant emitted directly from the source.	Particulate matter ($PM_{2.5}$ and PM_{10}), Sulphur dioxide (SO_2), Nitrogen oxide (NO_x), Carbon monoxide (CO)	Transportation, Industrial process, Solid Waste Disposal, Crop Burning, Cooking, etc.
Secondary Pollutants	Formed in atmosphere as a result of chemical or physical interaction between the primary pollutants.	Peroxyacetyl nitrate (PAN), Ozone (O_3), Sulphur trioxide (SO_3), Sulphuric acid (H_2SO_4), Nitric acid (HNO_3)	

2.1 Emission Sectors:

2.1.1. Vehicles:

Traditionally transport sector is the major dominating source of air pollution in India. In general vehicles are powered by internal combustion engines which operate on fossil fuel combustion. Automotive vehicles emit several pollutants depending upon the type of quality of the fuel consumed by them. There are various reasons for the increase in vehicular pollution in Indian metropolitan cities: (i) Increase in number of personal/private vehicles. (ii) Immense population with resultant huge number of vehicles. (iii) Lack of proper maintenance of vehicles. (iv) Unorganized traffic management system. (v) Poor road conditions (vi) Absence of effective, efficient public transport system. (vii) Aging vehicles on road. Rapid modernization and urbanization has alternatively geared up the increase in number of vehicles resulting in higher consumption of energy too. The major pollutants that are released from suspended particulate matter (SPM) which can cause damage to lungs, sulphur dioxide (SO_2) which can cause acid rain, damage to lungs, eyes and skin; nitrogen oxide (NO_x) which forms smog and can damage the respiratory system and cause eye irritation; carbon monoxide (CO) which is toxic and can cause blood poisoning; hydrocarbons (HC) which can cause cancer and lead (Pb) which affects the nervous system, retarding brain development.

Figure 2: Transport system in Delhi

2.1.2. Industries:

Industrialization, while important for the economic growth and development of a society, it is also harmful to the environment. Industrial units are associated with manufacturing products, which involves combustion of different kind of fuel such as diesel, LPG, kerosene, wood, coal, natural gas etc. From such industrial units verity of pollutants has been released in to the air through air vents, smokestacks, chimneys and by other means. The major air pollutant released from the industrial units is particulate matter followed by gaseous pollutants like SO_2, CO, NOx etc. Industrial activities will be more hazardous in highly populated areas mainly metro cities. The Ministry of Environment and Forests (MoEF) had identified 17 categories of polluting industries. Out of which iron and steel plants (sponge iron plants and steel re-rolling mills), brick making units, cement plants, fertilizer plants, pulp and paper, oil refineries, petrochemicals, sugar, distilleries and tanneries are some major industries which contribute more to the emissions. So far the main causes remain: (i) Lack of policies (ii) Unplanned industrial growth (iii) Use of outdated technologies (iv) Inefficient waste disposal resulting in open burning. A great deal of industrial pollution is a resultant of manufacturing products from raw materials—(1) iron and steel from ore, (2) lumber from trees, (3) gasoline and other fuels from crude oil, (4) stone from quarries (5) automobile bodies from steel, (6) furniture from lumber, (7) paint from solids and solvents, and (8) asphaltic paving from rock and oil. Each of these manufacturing processes produces a product, along with several waste products, which include number of air pollutants. The pollutants released from industries can both harm public health as well as damage the environment by contributing to global phenomena like climate change, greenhouse effect, ozone hole and increasing desertification.

2.1.3. Thermal Power Plants:

Thermal power plants are the principal generators of electricity in India. In India approximately 70% of power generation is obtained via coal based thermal power plants. Each power plant is a highly complex system in which the chemical energy stored in fossil fuel are being converted successively into thermal energy, mechanical energy and, finally, electrical energy for continuous use and distribution across other part of geography area. In India, according to the National Thermal Power Corporation (NTPC), coal base power accounts nearly 62.3% of India's electric power generation, oil and gas account for 10.2% whereas, water, nuclear, wind and other power generation methods contribute to the remaining 27.5 % usage. Large amount of SOx, NOx, CO_2, CFCs & SPM are released into air, which is also responsible for deterioration of environment, health of human beings, animals and plants as well ecosystem. Thermal Power Plant affects environmental segments of the surrounding region very badly.

Figure 3: Thermal Power Plants

2.1.4. Brick kilns:

Bricks are one of the most important building materials. India is the second largest producer of bricks in the world. However, the brick sector is unorganized but it is massive in size. Among the small scale industries, the brick kiln industry is flourishing because the demand for bricks is increasing due to rapid economic growth and urbanization. A brick can be composed of clayey soil, sandy soil, and lime or concrete materials. The most widely use technology is semi Zig-Zag in India. Coal is widely used as fuel but in many cases fuel is mixture of coal around 70%, sawdust 24% and remaining 6% wood. In certain brick kilns, low-grade carbonaceous materials such as rice husk, mustard husk (tudi), and bagasse and wood/saw dust are also used as alternative fuel. Brick kilns emission consists of mainly SPM, fine particles of coal, dust particles, organic matters and small amount of gases such as SO_2, NOx, H_2S, CO etc. The toxic substances released from brick kilns affect the air, plants, animals and people in their surroundings being hazardous for the workers over there, children and women.

Figure 4: Brick kilns in the outskirts of Delhi

2.1.5. Slums:

The informal settlement within the cities with inadequate housing and miserable living conditions defines slum. The rapid urbanization is very closely linked to the formation of slums. People from rural areas tend to migrate to urban areas which one of the reasons for formation and expansion of slum cluster across mega cities as well as other cities. Slums are prevalent characteristic of many cities. In slums, the level of air pollutants is apparently higher than the non-slum settlements due to close vicinity to industries, flow of dust from unpaved roads, poor waste disposal management, open burning of wastes and trash, heavy use of fuels like charcoal and wood. Because of this, the air in the slums is not only polluted outside but also is hazardous inside the houses. As the ventilation system of houses here is very poor, the indoor air pollution is highly noxious. This is one of the leading causes of increase in COPD (Chronic Obstructive Pulmonary Diseases). It makes hard for a normal person to breathe and gradually gets even worse over life.

Figure 5: Slum (Jhuggies) of Delhi

2.1.6. Construction Sites:

Construction activity is part of development and modernization and is very common in rapidly growing cities in India. Construction sites generate high levels of dust from concrete, cement, wood, stone, silica and this can travel large distances for a longer period. Construction activities includes various operations like land clearing, operation of diesel engines, demolition, burning, and working with toxic materials. Major source of PM_{10}at construction sites are the diesel engine exhausts of vehicles and heavy equipment called as diesel particulate matter (DPM) which readily combine with other toxins in the atmosphere and increase the risk of inhalation of those particles. Diesel is also responsible for emissions of CO, HC, NOx and CO_2. Poisonous vapours from oils, plastics, cleaners, glues, thinners, paints, treated woods, and other hazardous chemicals that are used in construction sites contribute to air pollution.

Figure 6: Construction sites of Delhi

2.1.7. Hotels & Dhabas:

Many hotels, Dhabas and restaurants, etc. use coal and wood as fuel in tandoors as well as for main fuel for cooking activity. There are approximately 9,000 hotels/restaurants in the city of Delhi where significant number use coal (mostly in tandoors). This kind of uncompleted combustion generates large amount of particulate matter along with other gaseous pollutants. It is proposed that all restaurants of sitting capacity more than 10 should not use coal and shift to electric or gas-based appliances", said the IIT study, which was commissioned by the Delhi government in 2012.

2.1.8. Household:

Nowadays, household air pollution is one of the leading causes of premature death. Burning of fuels like cow dung, wood and coal in stoves or open chulahs produces number of hazardous pollutants which includes particulate matter, methane, carbon monoxide, polyaromatic hydrocarbons (PAH) and volatile organic compounds (VOC). Burning of kerosene in simple wick lamps also emits fine particles and other pollutants. Larger particles can't get into the respiratory tract but smaller particles, less than 10µm can get into the tract and can get settled in the bronchi and lungs whereas particles smaller than 2.5µm pose the greatest problems, because they can get deep into our lungs, and some may even get into our bloodstream. Exposure to these pollutants leads to a wide range of adverse health impacts in both children and adults. Use of cleaner cooking stoves requires a multifaceted approach including: a) the introduction of cleaner technologies and fuels for cooking as well as improvised housing and its ventilation; b) initiative support of government policies; c) education and awareness for healthy environment and household management.

2.1.9. Traffic Junctions:

The rapid growth of vehicles in urban areas is a big issue not only because of locally harmful air pollution effects, but also because of their regional and global impacts. The overwhelming thing about vehicular pollution is that the vehicular emissions are emitted near ground level where we normally breathe. Due to this, the quality of air has become very poor affecting the humankind as well as the environment. The major problem that people in urban area face is the prolonged traffic congestion, which will not only reduce the avg. vehicle speed but also lead to more consumption of fuel. Many drivers don't switch off their vehicles due to slow movement of the traffic at major junction which leads to burning of a lot of fuel along with emission of harmful gases into the atmosphere. The World Health Organization estimates that "More than one million deaths each year are attributed to air pollution, of which a large proportion is caused by vehicular traffic". Traffic results in human and wildlife fatalities and economic losses. In contrary, use of different means of public transportation is environmentally friendly but it needs to be improvised and properly managed. It might help in reducing the number of private vehicles especially the cars. One of the main ways in which that could be accomplished is through innovations and implementations designed to reduce traffic.

2.1.10. Crematoriums:

According to a government census report, "Every year more than 5 million people die in India". Most of these people are cremated at open area ground, and around 50 to 60 million trees will be cut down for their pyres. Environmental threats caused by cremation are air pollution, deforestation, disposal of large quantities of ash into rivers, which pollutes the waters. In order to tackle these environmental issues evolving from these sites, the Indian government and environmental groups promoted the use of electric systems as an alternate way of cremation. However, these systems, which burn no wood and generate no smoke, have by-and-large failed, mainly due to financial and religious reasons. Traditional pyre takes six hours and burns 350-550 kilograms of wood and release hazardous air pollutants like carbon monoxide, carbon dioxide, sulphur dioxide, mercury, organo-halogens like dioxins etc.

Figure 7: Crematoriums showing traditional and electrical methods of burning

2.1.11. Wind Blown Dust:

Road dust in Indian road is an important source particulate matter in cities especially due to the bad road conditions and shoulders i.e. space between road and footpath, which are unpaved wherein most of 2W vehicles drive during traffic hours. Windblown dust consists of road dust, fly ash and soot which are generally termed as mixture of particulate matters of various size are the main contributors. Some of the factors like vehicle density, vehicle carrying capacity, vehicle weight are associated with vehicular particulate emissions. Generally, heavy commercial vehicles loaded beyond its carrying capacity deflect road dust and tyre dust (rubber dust) which results in severe particulate pollution. NCR-Delhi domain of 70x65km has minor road length of approx. 31000 km and major road length of approx. 2250 km could be large source of dust.

2.1.12. Waste burning:

Waste is a growing an environmental and social issue for all modern economies. The quality of waste depends on lifestyle and topographical background, which vary from one country to another. Wastes in fact nowadays are exceeding the economic growth imposing its impacts on every individual as well as the environment. Open burning of any type of wastes viz. Agricultural wastes, Garden wastes, Municipal Wastes or Residential wastes due to incomplete combustion release hazardous pollutants which includes PM, CO, PAH (Polycyclic Aromatic Hydrocarbons), SOx, NOx, VOC. Very high concentration of these pollutants are observed in the smoke during waste burning.

Figure 8: Waste Burning Sites

3. Area of interest

In the present study, our area of interest is domain of approx.. 70x65km covering Delhi and its adjacent industrial region, which includes districts Gurgaon, Faridabad, Sonepat, Jhajjhar in Haryana and Ghaziabad, Baghpat, Gautam Buddha Nagar in Uttar Pradesh. The emission inventories areis developed at very fine resolution of 400mt X 400mt over an area of nearly 4500 Sq km supporting approx. 28 million people as per projected census data. **Figure-9** shows the spatial extend of taken domain for present work.

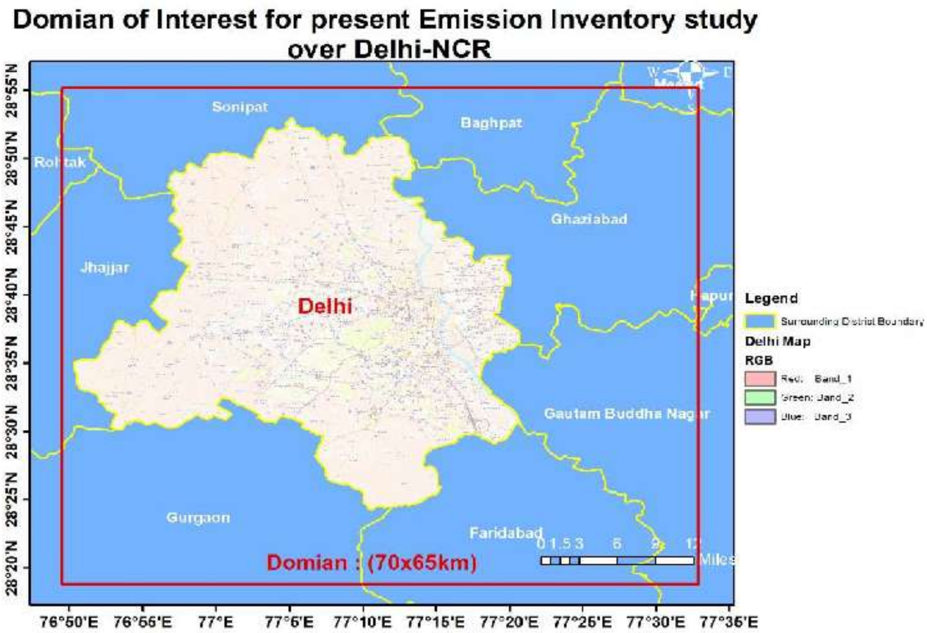


Figure 9: Area of Interest (Domain) for present Emission Inventory (70x65km)

3.1 Geographical features of Delhi:

Capital of India, megacity Delhi is located at 28.7041° N, 77.1025° E and lies in northern India. This is also known by the official name of National Capital Territory region (NCT), Delhi is having total area of 1484 km^{2}and is bordered by Uttar Pradesh in east and Haryana to the west, south and north. The overgrown population of Delhi led to the origination of National Capital Region (NCR) in 1962. The NCR is a metropolitan area of Delhi along with another 24 districts from three neighbouring states i.e. Haryana Uttar Pradesh and Rajasthan. The actual area of NCT of Delhi having an area of 58,332 km^2.

3.2 Climatology and Physiological features of Delhi:

Delhi has a semi-arid climate, mostly hot and rainfall is average supported by very cold winters. The general prevalence of continental air leads to relatively dry conditions with extremely hot summers. Mean monthly temperatures range from 14.3 °C in January (minimum 3 °C) to 34.5 °C in June (maximum 47 °C). Dust storms occur frequently during summer months. During winter, ground-based temperature inversions are a regular feature that restricts mixing height to low levels. Onset of monsoon takes place normally in the month of June. July is the wettest month in Delhi with maximum rainfall of 211 mm. Monsoon withdraws from the state by the end of the October with an annual rainfall of 715 mm. Wind speeds are typically higher in the summer and monsoon periods as compared to very calms in winter.

Physically the NCT of Delhi is divided into 3 segments:- The Yamuna flood plain, the ridge and the plain. The Yamuna flood plains are sandy, low lying, and associated with recurrent floods. The ridge is also called as the city's lungs as they maintain the environment. The ridge is mainly a part of Aravalli covered with forest. The plain region is mainly characterised by species like shisham.

4. Activity data and emission factor:

Activity data is defined as the quantitative measure of the activity that associates with the emission of air pollutants. Different kinds of activities are related with a particular source of emission and so there is a need to consider all these activities for exact quantification of the emissions.

Activity data collection:

With Delhi scenario, it is next to impossible to monitor all the sources. Hence, there were two types of data that has been collected viz. primary sources and secondary sources. Primary data are generally the on-site data and has been collected for the sectors like for transport (Vehicle Killometer Travelled (VKT), Fuel used, category specific car, Commercial car like Ola/Uber/taxis, airport and railway station parking vehicles etc.), slum, household, street vendors, brick kilns, construction site, hospitals, crematorium, small industries whereas secondary data have been collected for power plant, bio fuel, industrial stacks, airports etc. The activity data from secondary sources are also collected for couple of sectors like industry, Slum, Power plants, Malls, Municipal Solid Waste etc.

4.1 Primary Data Collection:

Primary activity data is mainly obtained from collecting the data samples from the area of interest. The main purpose of generating primary data was to check the authenticity of the existing data from secondary source as well as to fill the data gap. It is notice that there is no data for various unattended emission sources like slum sectors, street vendor, crematorium, hotel/Dhabas, commercial places etc. Activity data collection through field campaign will not only improve the accuracy and reliability of the inventory but also help to understand the emission practices happening in Delhi and surrounding regions. This will improve the spatial allocation of emission hotspots. For the collection of activity data, an extensive emission campaign (i.e. SAFAR-Delhi) was carried out in Delhi for three months (i.e. May-June) in 2018. Nearly 150 students from different colleges and universities of Delhi, IITM Pune and Utkal University, Bhubaneswar participated in this campaign to execute the emission campaign successfully. Approx. ~37,500 hrs efforts from students/volunteers were involved to cover 26 major/minor sectors across the domain. The all accounted 26 sectors are tabulated in **Table-2.**

Table 2: Showing 26 Sectors & its related activities considered for the study

Sl.no.	Sector	Activity data &Factors
1	Transport	• Category, Fuel Type & Quantity • Vehicle/hour/Road type/VKT
2	Slum	• Type and Fuel used Quantity for cooking
3	Brick Industry	• Type, Technology and Fuel used Quantity
4	Street Vendor	• Type and Fuel Quantity • Coal for Tandoor
5	Hotel (Dhabas)	• Type of Fuel & Quantity used for cooking
6	Construction Sites	• Type of Fuel & Quantity used for cooking activity
7	Speed Breaker	• No. of Speed Breakers per Km • Road Type
8	Major Hospitals	• Number of outdoor patients • Vehicle load and DG sets
9	Tourist places	• Tourist Load, Vehicle load
10	Shopping Malls	• No. of vehicle parked
11	Traffic Junctions	• No. of Traffic Junctions
12	Railway Stations	• Passenger load • Vehicle load in station area
13	Airport	• Vehicle No. (Delhi & Out-side vehicle No.)
14	Industry	• Type, Technology and Fuel used
15	Local Transport (Ola/Uber/Taxi)	• Km travelled per day and Vehicle Numbers
16	Household	• Type of fuel used
17	Waste Burning	• Quantity per capita
18	Biomedical Waste	• Quantity generated
19	Power plant	• Technology used, Coal used
20	Crematorium	• Spatial locations, No. of Cases
21	Large hotels	• Fuel used for cooking
22	Large school/college	• Students no. & Travel load
23	Wind Blown Road Dust	• Road condition, vehicle load etc.
24	Diesel Generator	• Fuel used for no. of hours
25	Mobile tower	• Fuel Used & numbers

26	Routine Milk & Vegetable Van	• No of vehicle (outside)

Sectors like street vendors, hotels, dhabas were inspected regarding the fuel usage, types of fuel etc. Different slum areas have been surveyed to understand the household utilization, fuel consumption etc. Brick kilns and small industries were surveyed for their fuel usage and production respectively. Bed capacity of hospitals, patient intake capacity, indoor and outdoor patient numbers, biomedical waste generator and its disposal were recorded. Usage of fuel (wood) in traditional and electrical burning methods of crematorium was observed and has become one of the emerging concerns. Various studies reflect that the presence of silver-amalgam in bodies emits mercury. Therefore, crematoriums play an important role in airborne emission of mercury contributing to the pollution.

Transport:

Delhi is experiencing consistent increase in number of vehicles in recent couple of decades. Delhi city is a home to approx.. 10.3 million registered vehicle (2018). The domain of interest has road network of ~2250 km of major roads and 31000 km of minor roads network across the NCR region. The spatial map of road network as well as rail/metro map is provided in Figure-10 and Figure-11 respectively.

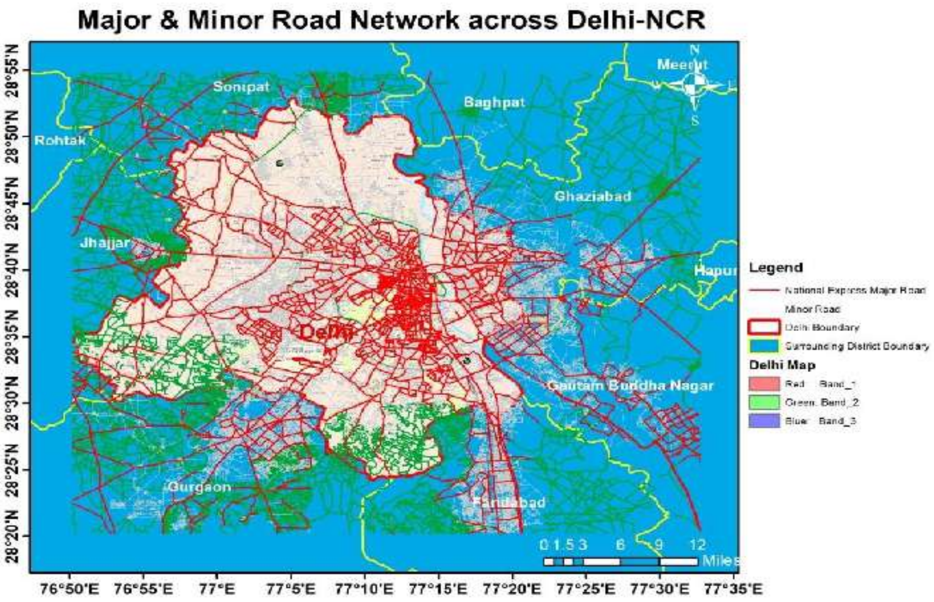


Figure 10 : Showing Major and Minor Road Network across Delhi-NCR

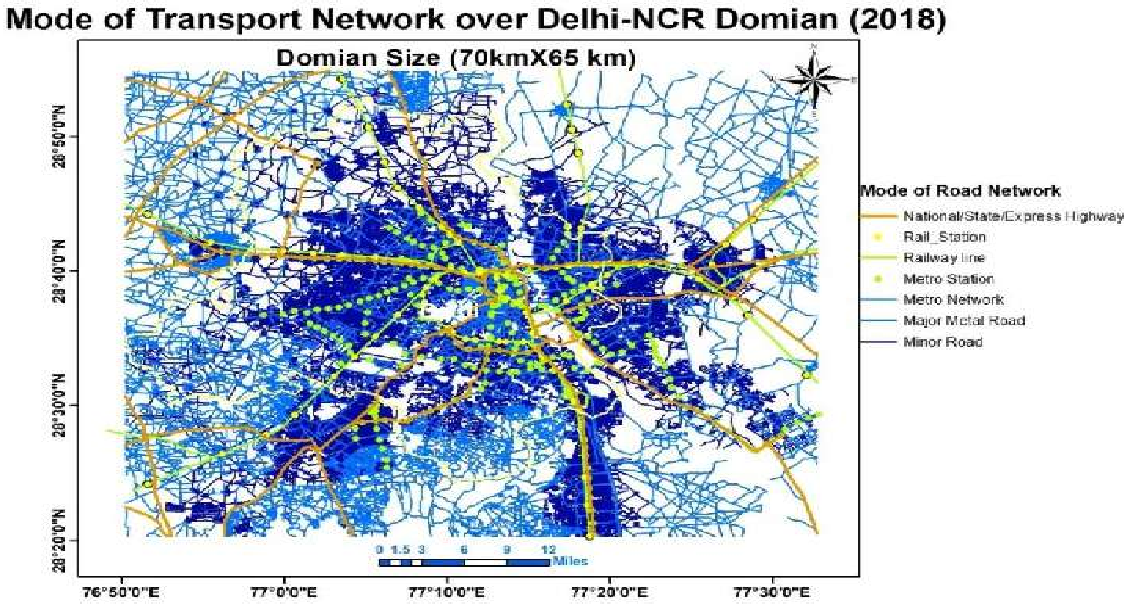


Figure 11: Showing Mode of transport network over Delhi-NCR Domain

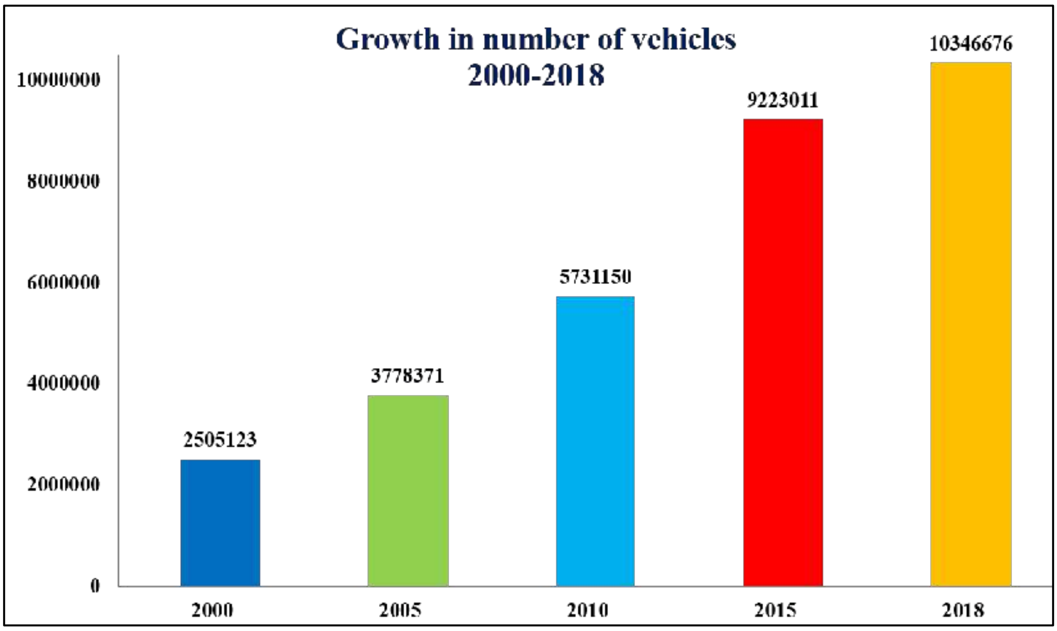


Figure 12: Growth of registered Vehicle in Delhi (2000-2018)

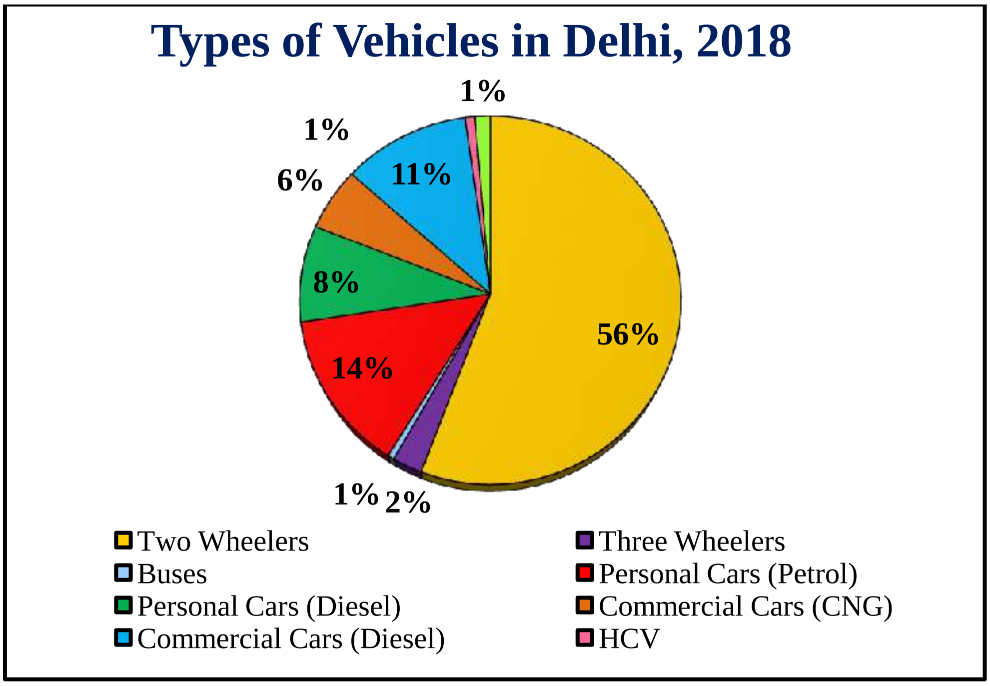


Figure 13: Relative Contribution of vehicle category in Delhi-NCR

Age/Category	2W	3W	Buses	Cars	HCV	LCV	MSLV
5 yr	1781170	54753	17735	905285	5210	5635	3515
10 yr	1594832	101406	20040	1031320	31643	87000	983
15 yr	3006030	103312	28400	1411276	63987	70776	5464

The registered vehicle growth in Delhi between 2000 to 2018 is nearly four folds and is being depicted in Figure-12. The relative contribution different vehicle categories are presented in Figure-13. As transport sector is one of most traditionally, dominating sector in Delhi-NCR has been given more emphasis to understand the driving pattern and vehicle density in different road condition/ type (i.e. major and minor roads). For primary survey, 87 major/minor roads were selected across the Delhi and it surrounding region to identify the flow of vehicle during weekday and weekend. There is a continuous digital click counter measurement carried out for 14-16 hrs per day for each side of the road. As the same time random survey are also carried out to access the driving cycle/pattern for vehicle of different category belonging to various income group or personal/ commercial issue. During random vehicle survey, ~2600 sample are collected. The selected roads for field survey are shown in **Table-3**.

Table 3: Roads selected for Vehicle Counting

Name of the Road	Name of the Road	Name of the Road
• ITO	• AIIMS	• Karampura Flyover
• Airport	• Baba Kharak Singh Marg	• Dwarka
• India_Gate	• Bapudham	• Loni Road
• Ashram_Road	• Cannought Place	• R K Puram
• DhaulaKuan	• Cariappa Marg Ashram	• Karol Bagh
• Kashmiri_Gate	• Chanakyapuri	• Kaushambhi
• Peeragarhi	• ChandniChowk	• Khan Market
• Anand_Vihar	• Civil Line	• Kirki Place
• Greater Noida Expressway	• DBG Road, PaharGanj	• Kirti Nagar
• Rohtak Road	• Delhi Cantonment	• Lajpat Nagar
• Najafgarh	• Fateh Nagar	• Laxmi Nagar
• Noida Sector 62	• Feroz shah Marg	• Maharaja Agrasen
• Sardar Patel Marg	• Ghaziabad	• Mahatma Gandhi Marg
• Delhi-Meerut Expressway	• Hapur	• Main Patel Road
• Rajouri Garden	• HarijanBasti	• Mayapuri
• Paharganj	• Jama Masjid	• Mehram Nagar
• Mathura Road	• Janakpuri	• Mother Teresa Cres.
• Jahangirpuri	• Jarak Cinema	• Moti Nagar
• GT Karnal Road	• Kamla Nagar	• New Friends Colony
• Aadarsh Nagar	• Kanjhawala Road	• New Moti Nagar
• Northern Access Road	• Sai Baba Mandir Road	• SurajDharamkanta
• Post Office, Civil Lines	• Saket Metro Station	• Tegras Garden
• Purani Delhi Railway	• Satyaniketan	• Tilak Nagar
• PWD Office	• Sewak Park, DwarkaMor	• Uttam Nagar
• Rajawi Marble Market	• Shantipath	• Vasant Kunj
• Rajdhani Park	• Shershah Road	• VishwaVidyalaya
• Rangpuri Airport	• Shivaji Marg	• Pitampura
• RML Hospital Road	• SI Hospital	•
• Root RouzGanj	• South Extension	•
• SagarunPanka Road	• Sunder Nagar	•

The new VKT generated during random survey is depicted in Table-4.The vehicular density plying over different surveyed road is shown in Figure-14. As Delhi is dominated by car from surrounding districts from three adjacent states so the relative contribution of other states car to Delhi car is crucial for emission point of view. The relative contribution of other state car to Delhi based car is depicted in **Figure-15.**Since, the impact of weekend and weekday effect is equally crucial and important to understand the load of vehicular pollution on specific roads. The weekend and weekday effect for couple of important major roads has been given in **Figure-16**.

Table 4: VKT generated during random survey

Vehicle Type	VKT (Km/day)
2W	60
3W	120
Buses	210
Personal Cars	55
Commercial Cars	210
Commercial Cars (Ola/Uber)	400
HCV	75
LCV	140
MSLV	45

where: 2W – Two Wheelers; 3W – Three Wheelers; 4W – Four Wheelers; HCV – Heavy Commercial Vehicles; LCV – Light Commercial Vehicle; MSLV – Miscellaneous

Figure 14: Total number of vehicles plying over different roads of Delhi

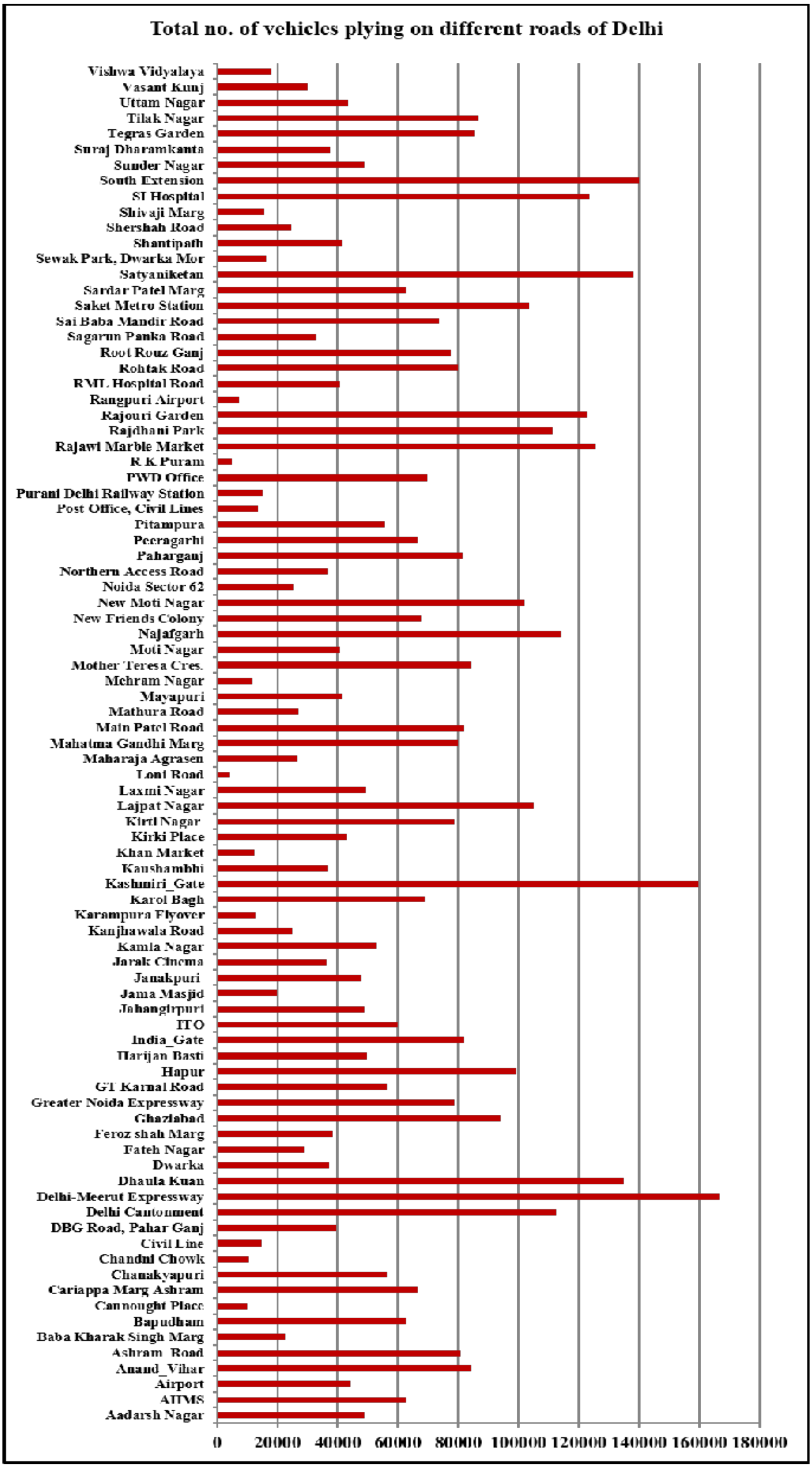
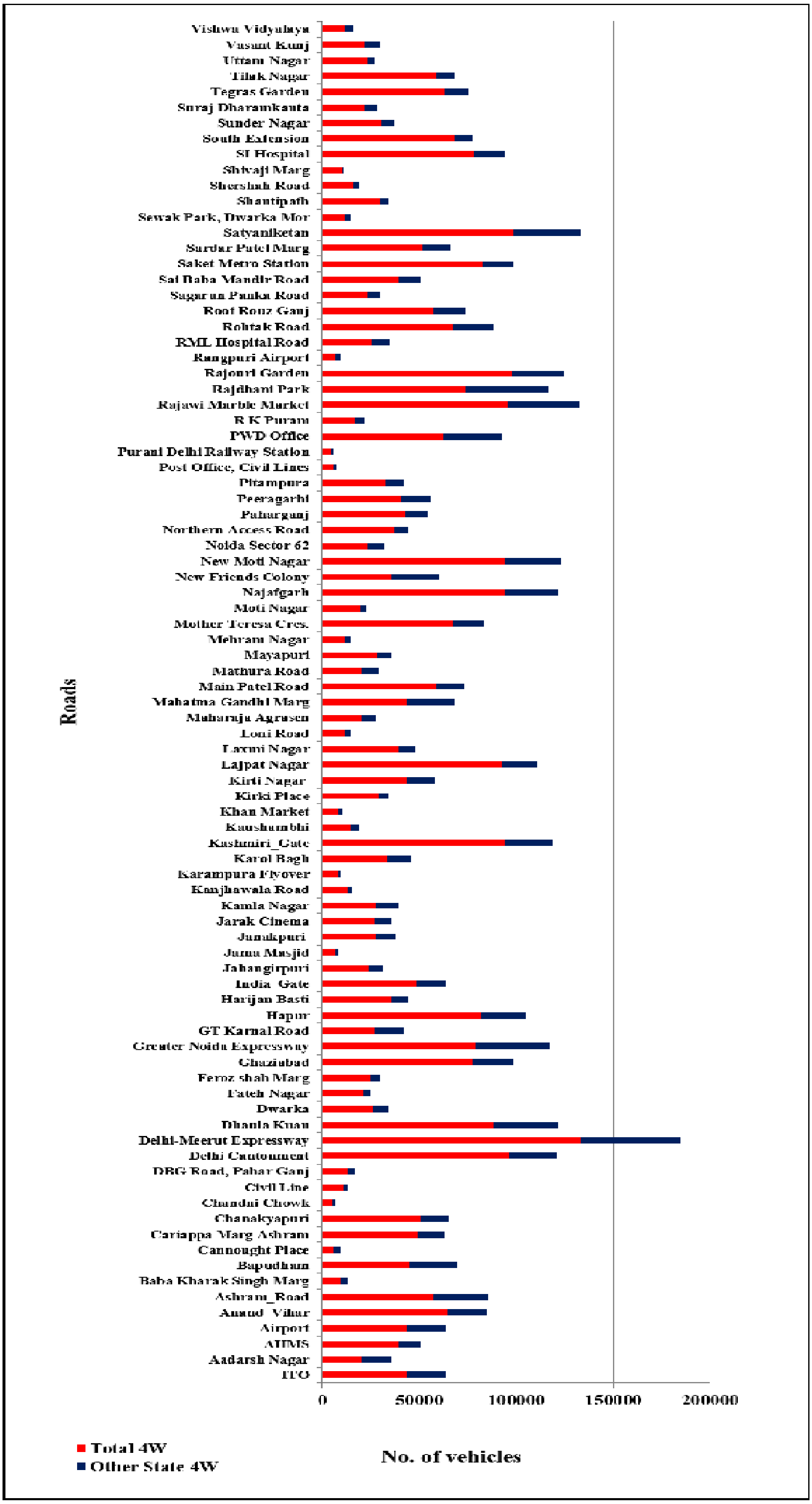


Figure 15: A graph showing relative comparison of total 4W (cars) to other state 4W (cars) plying on different roads of Delhi



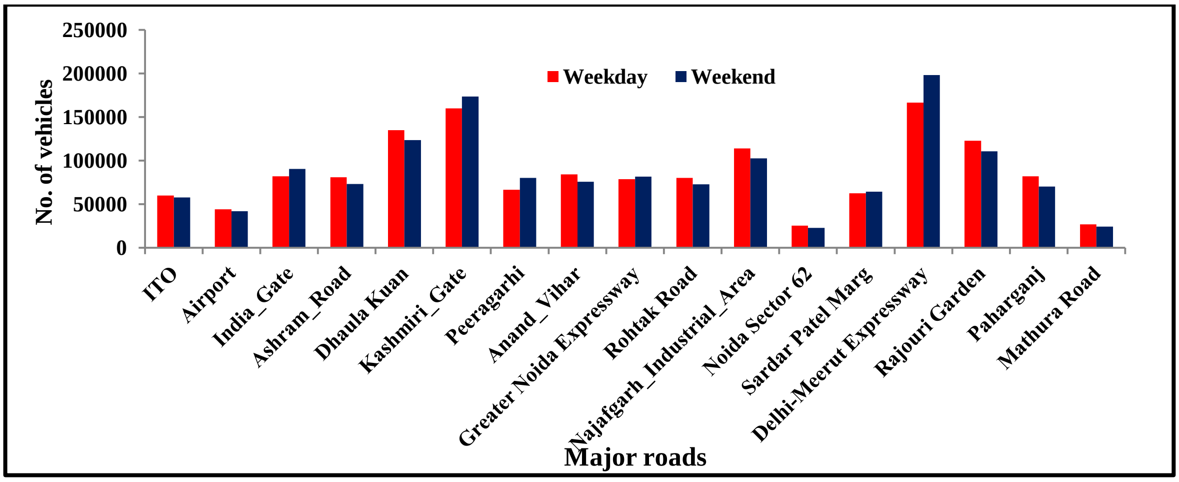


Figure 16: Graph showing flow of vehicles on Weekdays and Weekends on major roads of Delhi

Interesting Findings during Field Survey:

Transport Survey:

- High vehicular density of more than 100 thousand per day is seen in the roads like that of Delhi Meerut Expressway, Dhaula Kuan, Peeragarhi, Ashram Road, South Extension Airport Road etc.
- Vehicle density was recorded to be higher during weekdays in most of roads. However, it is observed that there is increase in vehicle number in weekend on some roads like India Gate Circle, Chandni Chowk, Lajpat Nagar etc.
- The other state car contributes as high as nearly 40-50% in majority of well-known busy roads in Delhi.
- Due to rise in vehicle numbers, the average speed of vehicles is found to be decreasing tread (i.e.18-25 km/hr) in most of major roads and 35-55 km/hr on airport roads and few more roads.

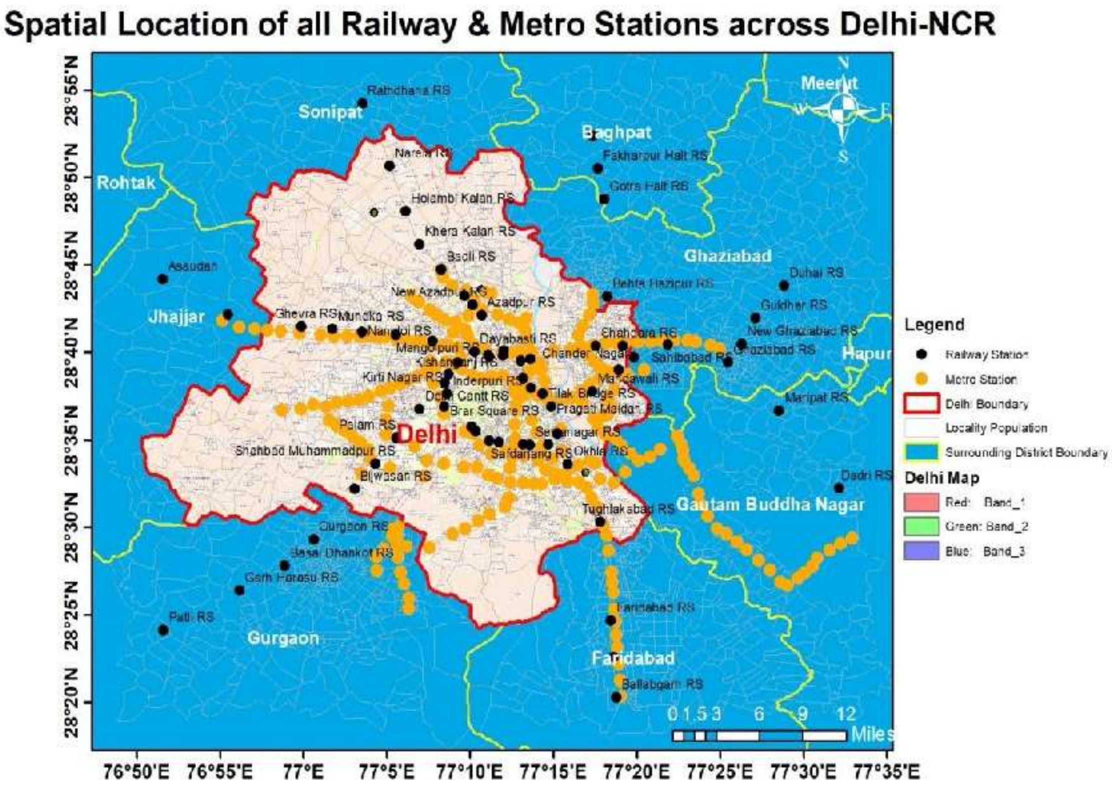


Figure 17: Showing spatial location of railway and metro stations across Delhi-NCR

Delhi metro is the 12th largest metro network in the whole world. Delhi-NCR domain comprises of 263 metro stations, and metro lines, 68 railway stations. Out of 68 railway stations New Delhi, Old Delhi, Hazrat Nizamuddin, AnandVihar Terminal, Delhi Sarai Rohilla, Delhi Shahadra junction and Delhi Cantonment etc. are some of the busiest railway stations of Delhi where the traffic congestion is major issue. Delhi Metro system carry an average of 2.6 million passengers everyday covering 160 stops over a whooping 213 kms (Figure 17). While most stations of Delhi metro are busy and crowded. The parking of vehicles around metro station is key problem and leading to act like single point emission source. These are couple of busiest metro stations around Delhi like Chandnichowk metro station, Rajiv chowk metro station, New Delhi metro station, Noida city centre metro station and Vaishali metro station.

Slum Survey:

There are around 648 slum locations pinned over Delhi, from which 87 locations were surveyed during the activity data collection (**Table 5**). Major slum clusters are confined to the central, eastern and South Eastern part of Delhi. The actual slum population data is very uncertain. The projected slum population of Delhi is approximately 4231080. During survey, nearly 3000 sample were collected over different geographic and analysed.

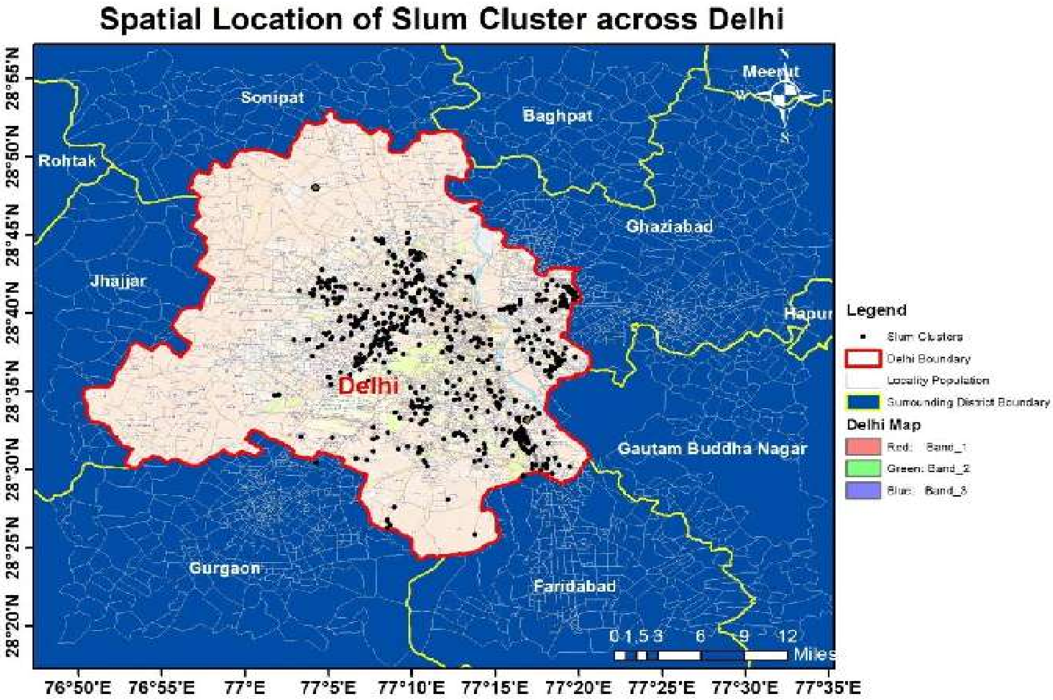


Figure 18: Showing spatial location of slum clusters across Delhi-NCR

- Unlike 2010, LPG is being widely used for cooking in slums accounts 95% followed by wood (3%) and coal (2%).
- In winters, relative contribution of wood as fuel increases during Winter months (for heating of water).

Table 5: Names of Slum Areas Surveyed

Slum Areas	Slum Areas	Slum Areas
▪ Vasant Kunj	▪ Outram Lane	▪ Prem Nagar
▪ Tughlakabad Village	▪ Mahavir Enclave	▪ Bharat Nagar
▪ Harijan Camp	▪ Lodi Colony	▪ Roshanara Club
▪ Kabeer Nagar	▪ Lal Kumbad	▪ Harkesh Nagar
▪ Jahangir Puri	▪ Nepali Camp	▪ Shakti Nagar
▪ Lodhi	▪ Bageecha Madhab	▪ GulabiBagh
▪ Jangpura	▪ Samaypur	▪ Bhalswa
▪ SaritaVihar	▪ Okhla	▪ Mangolpuri
▪ Who	▪ Wazirpur	▪ Motilal Nehru cmpus
▪ PrayogVihar	▪ Lalbagh	▪ Parwati Camp
▪ MajnuKaTila	▪ Mirdard Road, ITO	▪ Rk Puram Sector 4
▪ Chota Lal Park	▪ Rajasthani Colony	▪ Near DU
▪ H4	▪ Ratan Park	▪ Nehru Lal Jal Board
▪ HarijanColony,Tilaknagar	▪ Sankar Garden	▪ Raghubir Nagar
▪ Hy Block	▪ Satyaniketan	▪ Rajastaniday Nagar

▪ Indira Camp	▪ Sector - 8, Dwarka	▪ DDA Park
▪ J Block	▪ Sukhewender Nagar	▪ Rohila
▪ Jahangirpuri, Lakky Park	▪ Vikaspuri	▪ Anarkali Colony
▪ Kailash Park	▪ Wazirpur,Block-A,	
▪ Laxmi Garden	▪ Tilak Nagar	
▪ Gtb Nagar	▪ Badli Industrial Area	

Industries survey:

There are 3182 industries scattered over Delhi-NCR. Large number of industries are confined over East Delhi, South-East Delhi, and South-West Delhi region as shown in Figure2.2. Central Delhi has relatively very low number of industries in comparison to others part of Domain. The spatial distribution of various type of industries are depicted in **Figure-19** and it's frequency is given **Table-6.** Major industries include:- Engineering industries which carry a frequency of **546,** Machine and tools industries of **169**, Electricals **175**, Iron and Steel industries **114,** etc. Most of the information on industrial

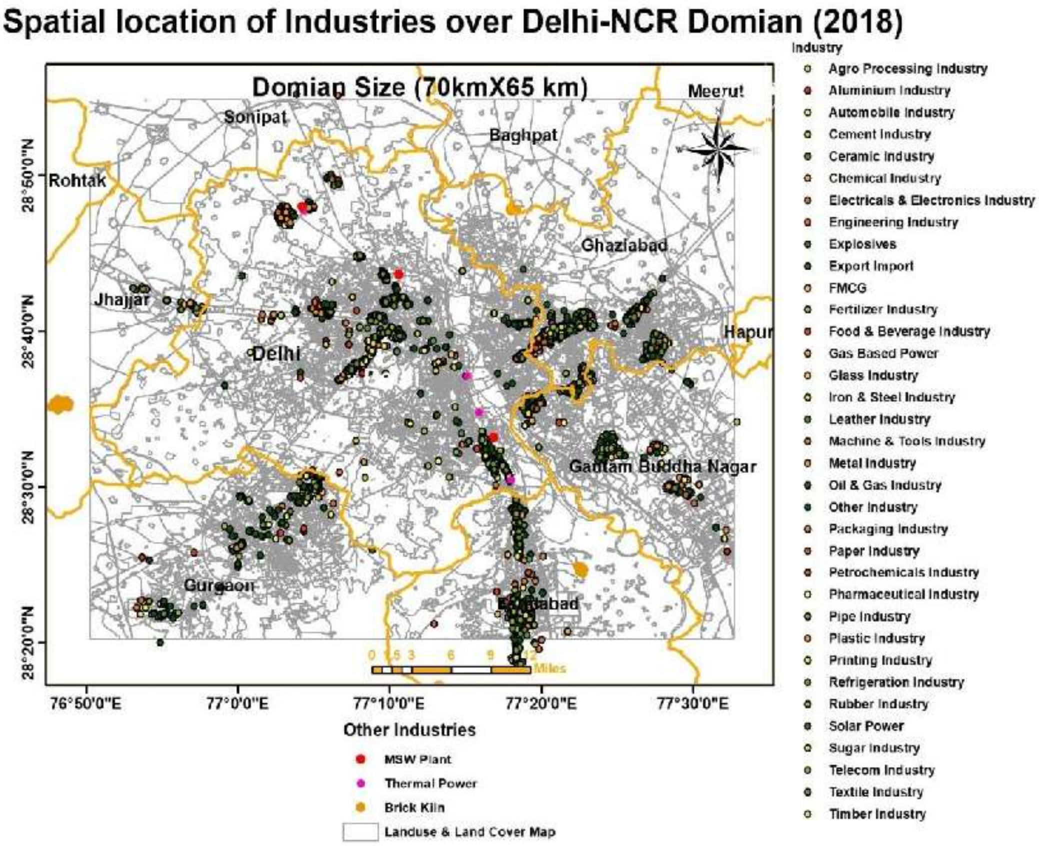


Figure 19: Showing all the spatial location of Industries over Delhi-NCR

areas, like fuel consumption, production capacity etc. have been collected from DPCC.

Table-6: Frequency of industry category in the defined Delhi-NCR Domain

Industry Type	Frequency	Industry Type	Frequency
▪ Agro Processing Industry	▪ 34	▪ Leather Industry	▪ 10
▪ Aluminium Industry	▪ 5	▪ Machine & Tools Industry	▪ 169
▪ Automobile Industry	▪ 118	▪ Metal Industry	▪ 112
▪ Cement Industry	▪ 16	▪ Oil & Gas Industry	▪ 7
▪ Ceramic Industry	▪ 18	▪ Other Industry	▪ 1054
▪ Chemical Industry	▪ 114	▪ Packaging Industry	▪ 60
▪ Electricals & Electronics Industry	▪ 175	▪ Paper Industry	▪ 19
▪ Engineering Industry	▪ 546	▪ Petrochemicals Industry	▪ 44
▪ Explosives	▪ 1	▪ Pharmaceutical Industry	▪ 41
▪ Export Import	▪ 27	▪ Pipe Industry	▪ 7
▪ Fertilizer Industry	▪ 2	▪ Plastic Industry	▪ 81
▪ FMCG	▪ 15	▪ Printing Industry	▪ 56
▪ Food & Beverage Industry	▪ 49	▪ Refrigeration Industry	▪ 16
▪ Gas Based Power	▪ 3	▪ Rubber Industry	▪ 59
▪ Gems &┬áJewellery Industry	▪ 2	▪ Solar Power	▪ 4
▪ Glass Industry	▪ 9	▪ Sugar Industry	▪ 2
▪ Industrial Estate	▪ 5	▪ Telecom Industry	▪ 20
▪ Information Technology	▪ 47	▪ Textile Industry	▪ 104
▪ Iron & Steel Industry	▪ 114	▪ Thermal Power	▪ 4
▪ Transport Industry	▪ 4	▪ Timber Industry	▪ 5

Brick kilns:

India is the second largest producer of bricks in the world. Although, the brick sector is unorganized but it is massive in size. Among the small scale industries, the brick kiln industry is flourishing because the demand for bricks is increasing due to rapid economic growth and urbanization. Approx.13 tons of biomass (Tudi) and rubber is being used as fuel to generate 1 lakh bricks in semi-ZIGZAG technology as compared to 10 tons coal for producing same number of bricks. Jajjhar Region of Haryana is one of single big source of pollutants due to 300 number of brick industries in one cluster. The industry is dominated by immigrant worker (90%). Outskirts of NCT are preoccupied with approximately 360 brick kilns majorly scattered in Jhajjar, Faridabad and Ghaziabad region (**Figure 20).**

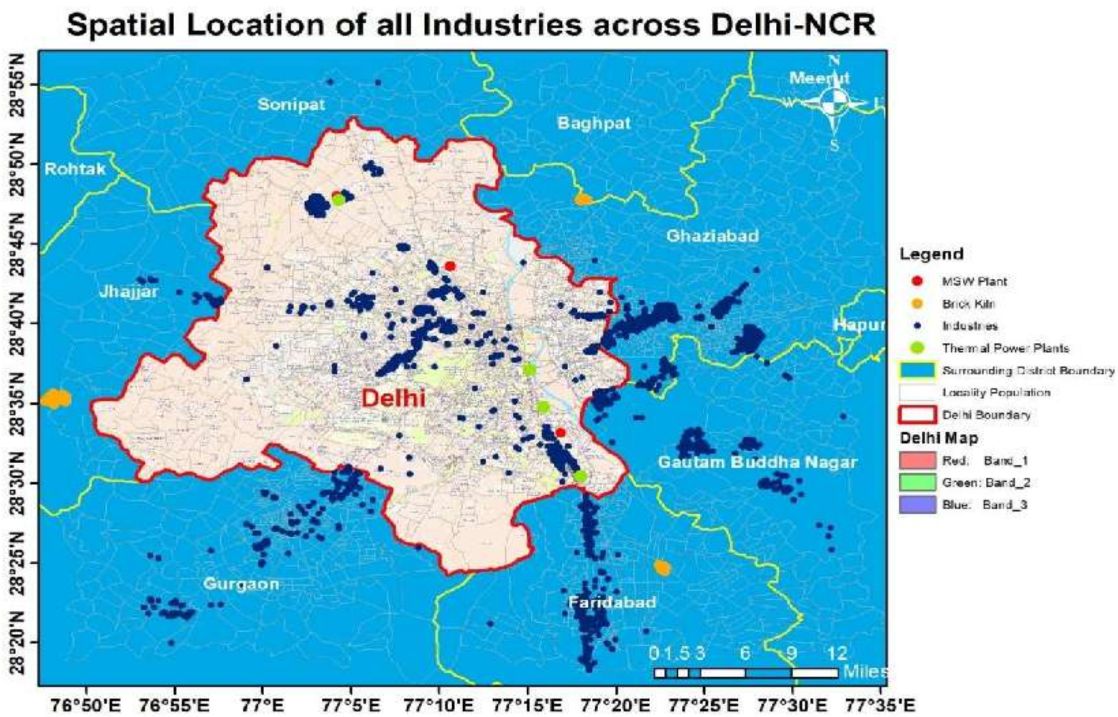


Figure 20: Showing all the spatial location of Industries over Delhi-NCR

- Outskirts of NCT are preoccupied with numerous brick kilns, which primarily use 70% of coal, 25% of tudi (mustard husk) and rest 5% uses rubber as alternative fuel along with coal as primary fuel. The total amount of coal, Tudi and rubber consumed in this sector is 125650 Tons, 71800 tons and 8975 tons in a season respectively.
- Emission from brick kiln has seasonal pattern due to peak business month starts from December to June.

Thermal Power Plants and Municipal Solid Waste Sites:

Till date, three waste-energy plants are commissioned over Delhi-NCR region which largely facilitates the treatment of incinerable Municipal Solid Waste. A total number of four thermal power plants are present over Delhi-NCR domain where two are coal based and another two are gas based. The data about the location, capacity, coal usage, and pollution control device attached, etc. has been obtained from DPCC, Govt. of NCT of Delhi, and from the official website of Northern Coalfields Limited, Govt. of India and hence treated as most authentic **(Table-7& Table-8).**

Table 7: List of Coal based Thermal Power-Plants in Delhi-NCR

Name	Installed Capacity (In MW)	Generation (In MU)	Plant Load (In %)
1. Badarpur TPS	705	1703.15	30.14
2. Indraprastha Power-plant	270	638.6	29.51

Table8: List of Municipal Solid Waste Treatment Plants in Delhi-NCR

Plant Commissioned/ Under trial	Municipal Corporation	Installed Capacity (MW)	Average Quantity MSW(tonnes/day)
1. M/s Ramky Group at Narela-Bawana, New Delhi	North Delhi Municipal Corporation	24	756
2. M/s Jindal Urban Infrastructure Pvt Ltd. at Okhla, New Delhi (Timarpur-Okhla)	South Delhi Municipal Corporation	16	1818
3. M/s IL&FS Environment Infrastructure and Services	East Delhi municipal Corporation	12	502

- Approx. 8370 tonnes of MSW is generated in Delhi every day and on an average 3240 tonnes per day is being incinerated in quantity Solid Waste Treatment plants. The rest of the 5060 tonnes are opted for land filling.

Crematorium:

There are 62 cremation sites, which are being operated in several zones of Municipal Corporation of Delhi. Out of 62 cremation sites, 56 are traditional whereas rest of the 6 are using electrical method for burning (Figure 21). The information regarding the total number of deaths in Delhi was collected from the website of Ministry of Home Affairs, Govt. of India.

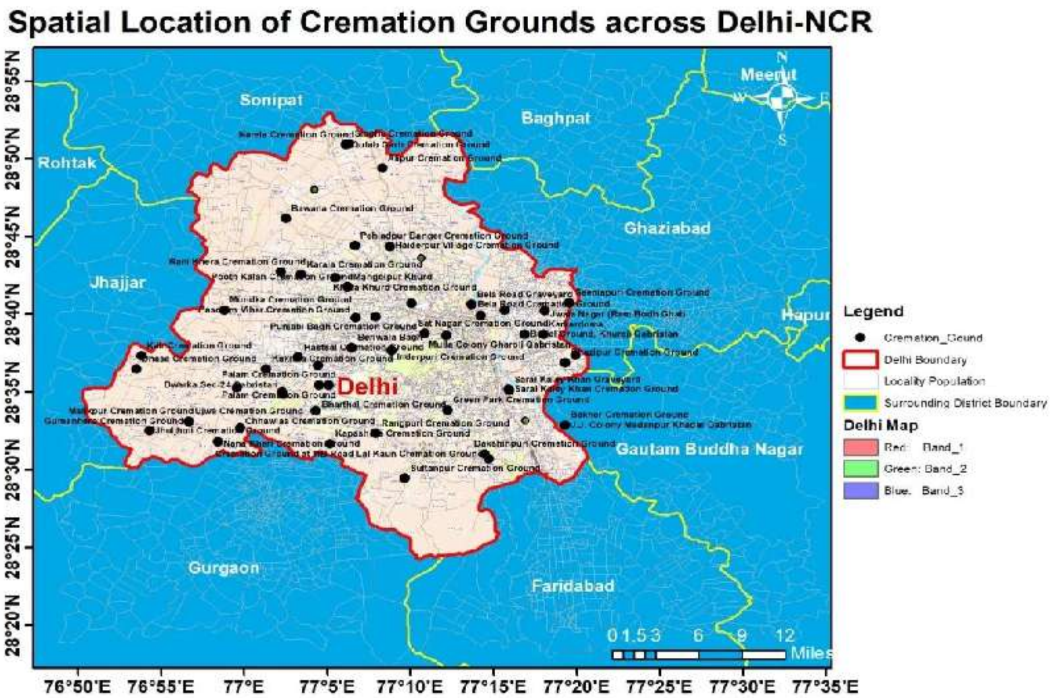


Figure 21: Showing all the spatial location of cremation over Delhi-NCR

- Still most people prefer to cremate dead body by traditional way at open field.
- Everyday approx. 350 deaths occur in Delhi and average deaths per year comes around 128148 nos. Approximately 450kgs of wood is required to burn a single body by traditional method.

Street Vendors:

- Delhi holds up a large number of street vendors well scattered all over the region. Data shows that around 50000 different types of vendors provide different sorts of fast foods. A large portion of these street vendors were authorized under the local Municipal Corporation and located at permanent places and remaining were unauthorized and kept shifting from one place to other. A large number of street vendors are found near markets, stations, metros etc. During field survey, 1653 samples were collected over 27 vending areas across the Delhi. LPG is being predominantly used as a source of fuel by the street vendors followed by coal and wood.
- It is found that 83% of street vendors are using LPG, followed by coal (15%) and wood (2%). It is noticed that coal is being used by many street vendors near

various tourist places like India gate, Jam Masjid & Jam, Lal Qila etc. Kerosene is not been in use as a source of fuel anywhere.

Figure 22: Street vending view of Delhi

Biofuel:

The use of biofuel like cow dung is still being used mostly in the peripherals of Delhi and its adjacent district of Haryana and UP. It is dried into cake like shapes and moulded by bare hands with a curvature to keep stuck to the walls. Once it isdried, they are put in a pile and used as a replacement for firewood; which in common language is said as 'Upla'. In the outskirts of Delhi, the cow dung are widely used during winter months as well as for day-to-day cooking purpose. This Dung may also be collected to produce biogas to generate electricity and heat.

Figure 23: Use of Bio fuel (cow Dung) in the outskirts of Delhi

- Preparation and storing of Cow Dung Cake across the outskirts of Delhi and Haryana /UP/Punjab is very common practices.
- A single household of size 5/6 members used approx. 30kg of cow dung per month as a source of fuel for cooking and heating of water in winter.

Hospitals & Biomedical waste:

- Couple of large hospitals in Delhi like AIIMS, Safdurjung, Ram Manohar Lohiya etc. generate approximately 109500 kg, 93075 kg, 65700 kg of biomedical waste per year respectively.
- It is found that no. of outdoor patient in AIIMS and Safdurjung are 4380000 and 3102500 respectively.

Tourist places:

- Parking of vehicles per day in tourist places like Akshardham Temple, Red Fort, QutabMinar etc. during weekdays and weekends was recorded to be approximately 2000 and 6000 respectively which contributes to the vehicle density.
- Number of tourists visit per day: ~10,000(Weekdays) and ~15,000 (Weekends)

Shopping Malls:

- During survey of 20 large malls across Delhi, it is found that average car parking capacity is ~1200 in weekdays and ~2000 in weekends. Average parking capacity was calculated to be approximately 550.

Commercial Taxi (Ola & Uber):

- Average distance travelled by Ola/Uber is found to be range between 300-600 km per days which is three time higher than other unorganized commercial taxi available in Delhi. It is observed that most of this kind of commercial taxi ply on road on double shift basic.

Aviation Sector:

- Delhi Indira Gandhi International Airport is the largest airport in India. This airport handles nearly 1176 flights per day that connect to 29 domestic destination and 34 international destination. The passenger traffic load is ~65 million (2018). Based on LTO cycle and cruise patter, the emission are estimated for various technological aircraft used. Aviation sector is large source of NOx emission followed by CO2.

Other sectors:

- During survey, there are couple of other sector like daily milk/vegetable van, speed breaker, telecom towers, diesel Set, dhabha, Incense sticks, Cooking Oil, are also contributing sectors to the rise of PM.

4.2 Secondary Data Collection:

Secondary data collection is generally collected from authentic government websites like CPCB, DPCC, census of India, etc. and some paid agencies like Indiastat. For the purpose, the secondary data for thermal power plant, industrial stack, and bio-fuel.

Table 9: Sources of Secondary Data Collection

SOURCE OF EMISSION	SOURCE OF SECONDARY DATA
Slum Cooking	Delhi Municipal Corporation, earlier studies
Hotels & Restaurants	Delhi Municipal Corporation, earlier studies
Street Vendors	Delhi Municipal Corporation, Encroachment Department
Non Industrial	Inspector of Generator, load shedding hours

Generators	(electricity board)
Industrial Generators	Delhi Pollution Control Committee
Industrial Stack	Delhi Pollution Control Committee
Thermal Power Plants	Delhi Pollution Control Committee
Transportation (mobile)	Delhi Municipal Corporation (Transport Dept., Traffic Dept.)
Paved Road Dust	AP42 &Earlier studies
Unpaved Road Dust	Earlier studies

4.3 Emission factors:

An emission factors (EFs) is an average representative value that attempts to relate the quantity of air pollutant released to atmosphere due to a particular activity associated. EFs is very sensitive parameter and highly depends on combustion type, fuel classification, fuel usage, fuel composition and efficiency of device. Generally, EF is expressed as mass of pollutants divided by a volume or weight of raw material. For the development of emission inventory, it is a necessity to have a country specified emission factor for each sectors as its one of the critical inputs to build a reliable & robust inventory. For the present study, the used information was determined as a result of valid research and justification. Most of EFs used in the present work is collected with valid scientific judgments and acceptability by global community. The sector specific EFs used given as below.

Transport Sector:

Emission Factors			2W	3W	Buses	Personal Cars (Petrol)	Personal Cars (Diesel)	Commercial Cars (CNG)	Commercial Cars (Diesel)	HCV	LCV	MSLV
Emission Factor (g/km)	5yr	CO[a]	0.4	0.69	3.72	0.84	0.06	0.6	0.06	6	3.66	6
		NOx[a]	0.25	0.19	6.21	0.09	0.28	0.53	0.28	9.3	2.12	9.3
		PM[a]	0.013	0.015	NA	0.002	0.015	0.002	0.015	0.42	0.475	0.42
		VOC[c]	2.03	0.1	0.1	0.24	0.28	0.01	0.28	0.85	0.01	0.85
	10yr	CO[a]	1.65	0.69	3.72	2.74	0.3	0.85	0.3	12.65	3.66	12.65
		NOx[a]	0.27	0.19	6.21	0.21	0.49	0.27	0.49	11.57	2.3	11.57
		PM[a]	0.025	0.015	NA	0.006	0.1025	0.0015	0.1025	3.205	0.565	3.205
		VOC[c]	4.31	0.1	0.1	1.88	0.41	0.01	0.41	1.97	0.01	1.97
	15yr	CO[a]	1.65	0.69	3.72	4.83	0.3	0.85	0.3	12.65	3.66	12.65
		NOx[a]	0.27	0.19	6.21	0.65	0.49	0.27	0.49	11.57	2.3	11.57
		PM[a]	0.025	0.015	NA	0.006	0.1025	0.0015	0.1025	3.205	0.565	3.205
		VOC[c]	4.31	0.1	0.1	1.88	0.41	0.01	0.41	1.97	0.01	1.97
		BC[d]	0.02	0.19	0.49	0.05	0.05	NA	0.05	0.34	0.19	1.24

Table 10: Emission factors for different fuel type and vehicular categories

where: 2W- Two wheelers; 3W- Three wheelers; HCV- Heavy commercial vehicles; LCV- Light commercial vehicles; MSLV- Miscellaneous vehicles

Source: [a] ARAI, Air Quality Monitoring Project-Indian Clean Air Program, 2007 report.
[b] Bond et al (2004)
[c] HEAT, ICLEI, Local Government for sustainability
[d] Cook et al (1999)

Thermal Power plants:

Table 11: Emission factors of coal used to estimate emissions from thermal Power plants

Sr. No.	Name of the TPP	Type of Fuel	Emission Factor							
			CO [a] kg/MG	NOx [a] kg/MG	SO_2 [c] ton/kt	$PM_{2.5}$ [a] kg/MG	BC [b] g/kg	OC [b] g/kg	VOC [d] Kg/GJ	PM_{10} [a] kg/MG
1	IP	Coal	0.06	1.44	22.8	0.6	0.009	0.001	0.0011	2.3
2	Badarpur Power Station	Coal	0.06	1.44	11.4	0.6	0.009	0.001	0.0011	2.3

Source: [a] AP-42 [c] Gurjar (2004)
[b] Bond (2004) [d] HEAT, ICLEI, Local Government for sustainability

Industrial Sector:

Table 12: Emission factors used for the estimation of emissions from industrial sector

Sr. No	Type of Fuel	Emission Factor							
		CO [a] kg/KL	NOx [a] kg/KL	SO_2 [a] kg/KL	$PM_{2.5}$ [b] g/kg	BC [e] g/kg	OC [c] g/kg	VOC [d] kg/GJ	PM_{10} [f] Kg/unit
1	CNG/NG	0.000272*	0.0028*	0.0000096*	0.34	0.216	0.001	0.005	0.00
2	LPG	0.19	1.45	0.00	0.31	0.0002	0.04	0.00	0.00
3	Wood	-	-	-	-	-	3.20	0.60	-
4	Diesel	0.63	2.75	31.05	0.97	0.35	1.40	0.15	0.0009
5	Coal	1#	7.5#	9.5#	1.36	1	0.90	0.001	-
6	Kerosene	-	-	-	0.34	0.03	0.04	0.90	-
7	FO	0.63	7.50	77.00	0.65	-	-	0.00	-

* kg/m3, # kg/MT
Source: [a] TERI, New Delhi [b] Reddy & Venkataraman (2002) [c] Bond et al (2004)
[d] HEAT, ICLEI, Local Government for sustainability [e] Cook et al (1999) [f] AP-42

Residential Sector:

Table 13: Selected emission factors used for calculation of residential emissions

Sr. No.	Fuel Type	Emission Factor							
		CO [d] g/kg	NOx[d] g/kg	VOCs[c] kg/GJ	$PM_{2.5}$ [a] g/kg	PM_{10}[d] g/kg	BC [b] g/kg	OC [b] g/kg	SO_2[d] g/kg
1	LPG	0.25	1.80	0.00	0.33	2.10	0.0002	0.05	0.40
2	Wood	115.40	14.00	0.60	1.50	15.30	1.1	7.80	0.20
3	Coal	24.92	3.99	0.20	12.20	20.00	2.28	4.30	13.30

Source: [a] Reddy & Venkataraman (2002) [b] Bond (2004)
[c] HEAT, ICLEI, Local Government for sustainability
[d] Source Apportionment Report, ARAI

Emission factors for aviation sector:

Emission Factors	CO_2	CH_4	N_2O	NO_x	CO	NMVOCs	SO_2
LTO (kg/LTO)	2560	0.04	0.1	11	5.3	0.4	0.8
Cruise (g/kg)	3150	0	0.1	17	5	2.7	1

*LTO=Landing and Takeoff Source: Kristin Rypdal, Aircraft Emission,

Table 14 : Calorific value for different fuel types used in the calculation

Fuel Type	Calorific Values (GJ/kg)
CNG	0.0335
LPG	0.0438
Wood	0.0176
Diesel	0.043
Coal	0.0175
Kerosene	0.0438
FO	0.041858

5. Methodology:

5.1 Establishment of Emission inventory:

To build a technological emission inventory for mega city is a complex process due to numerous, diverse and widely dispersed emission sources where the population is growing with rapid urbanization. Therefore, emission estimation efforts face enormous challenges in terms of inclusion of important sources in estimation, to develop reasonably representative and accurate emissions estimates from such a large number of diverse sources, how to keep track of changes in the number and nature of such emission sources, so that emission can be estimated for particular period. During the preparation of the complex inventory, the first step includes the recognition of sources; second step consists of distribution of emission geographically. In the current inventory development, we have followed "Bottom up" approach to improve the accuracy; reliability and uncertainty in inventory (Kalimont et al. 2002, Sahu et al, 2011 & Bond et al, 2004). The present work is being done by estimating the emissions based on activity data at grid level. Having a hope of more accuracy and reliability of data than the previous works, we have carried out our estimation for Delhi-NCR regions.

5.2 Basic mathematical calculations:

In such a scenario, preparation of authentic database with highest possible resolution is one of the most difficult tasks. Emission of a particular pollutant from a particular source category is estimated as a product of activity data, EF, application of combustion technology and removal efficiency of emission control. To calculate the total emissions of that pollutant from all the sources are summed over all sources categories. The above calculation is similar to that described by Kalimont et al. (2002) and Bond et al. (2004). Hence, the total emission can be expressed by following Equation-1 for all the pollutants unless specified otherwise;

$TE = \sum_a \sum_b FU_{a,b} \left[\sum_c EF_{a,b,c} \; U_{a,b,c} \right]$--------------------- (Equation 1)

where,

a, b, c = sector, fuel type, technology
TE= Total emission
FU= Sector and fuel specific amount
EF= Technology specific EFs
U = fraction of fuel for a sector with particular technology, where
$\sum U = 1$ for each fuel and sector.

In the presence of technology specific vehicular EFs for transport sector for India developed by ARAI, the EF using vehicular technology information is applied to the vehicle technology information and numbers. The emission from transport sector has been calculated as per the Equation -2.

$$E_t = \sum(ve\square_l \times D_l) \times EF_{l,km} \text{---------------------------------} \text{(Equation 2)}$$

where,

Et = Total Emission of compound
Veh_l =Number of Vehicle per type
D_l=Distance travelled in a year per different vehicle type
EF_l, km= emission of compound, vehicle type per driven kilometre

For Paved road dust:

$$E = [k\ (sL/2)^{0.91}\ (W)^{1.02}](1-P/4N)$$

E = particulate emission factor (having units matching the units of k),
k = particle size multiplier for particle size range and units of interest,
sL = road surface silt loading (grams per square meter) (g/m2),
W = average weight (tons) of the vehicles traveling on the road,
P = number of "wet" days with at least 0.254 mm (0.01 in) of precipitation during the averaging period,
N = number of days in the averaging period (e.g., 365 for annual, 91 for seasonal, 30 for monthly)

For Unpaved Road Dust

$$E = [(K\ (S/12)^a\ (S/30)^d)/(M/0.5)^c - C]*[(365-p)/365]$$

E = particulate emission factor (having units matching the units of k),
k = particle size multiplier for particle size range and units of interest,
sL = road surface silt loading (grams per square meter) (g/m2),
W = average weight (tons) of the vehicles traveling on the road,
P = number of "wet" days with at least 0.254 mm (0.01 in) of precipitation during the averaging period,
N = number of days in the averaging period (e.g., 365 for annual, 91 for seasonal, 30 for monthly)
And a,b,d, C are constant.

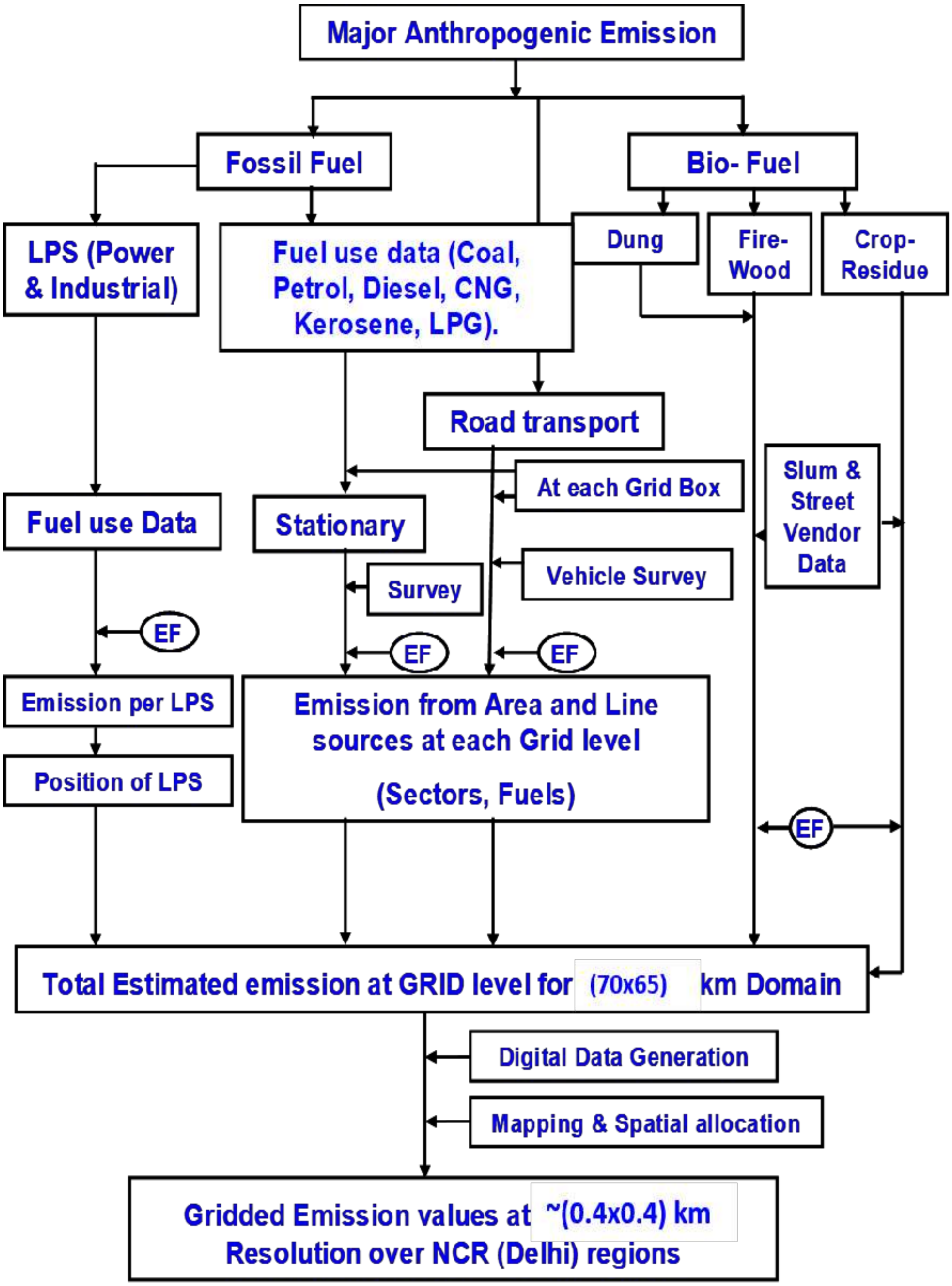


Figure 24: Schematic methodology for the development of emission for Delhi-NCR

5.3 GIS based approach:

A Geographic Information System (GIS) is a computer-based information system that enables capture, modelling, manipulation, analysis and presentation of geographically referenced data. Better organization of data being a key aspect allows GIS to become one of the most important tools for research purpose. The easy understanding feature of GIS fulfils the need of the study as well as the development of emission inventory. The GIS based statistical methodology is widely used in air quality or emission inventory related activities now a days. The ability of GIS to answer technical questions also makes GIS an excellent tool. The user friendliness of GIS is a feature that has made GIS one of the most used platforms for planning all over the world.

5.4 Digital Data & Spatial Allocation:

Prior to the incorporation of calculated emission into the GIS environment, some pre-processing tasks like geo-referencing, digitization and building of attribute database are required, because, the basic spatial objects in GIS are points, lines and polygons. As an area source can be represented as polygon, an industrial facility that emits pollutants of interest is represented by a point entity consisting of a single XY coordinate and a number of attributes. In order to map the emission from transport sector is one of the major contributors to total emission; the entire major and minor road network over the area of interest is digitized to extract the vector map of line using GIS tool. As per the recent road network over Delhi-NCR domain in the present work, we have prepared the road network of around 33250 kms. In order to prepare a gridded input for the regional atmospheric chemistry transport models, grid cells having 0.4km×0.4km resolution covering NCR-Delhi are also prepared using GIS tools.Spatial allocation (gridding) is important for model application and analysis. GIS has strong spatial overlay capabilities and is ideally suitable for deriving data in the target unit given the relevant source data. Spatial allocation of emissions can be done by overlaying the facility location layer with the grid cell layer and aggregating the facility points in each cell. It is a process to transform large and irregularly shaped emission data to uniform data using GIS tools. For the gridded data extraction, prepared geo-referenced grid cells of 0.4km×0.4km resolution covering Delhi-NCR using GIS tool is superimposed over the spatially distributed emission from different sectors. The emission value for the gridded cells based on the corresponding contribution of different sources lying inside the grid cells is calculated in GIS environment. The emission values from different sources are organized asset of thematic layers so that they can be analyzed separately.

6. Result and Discussions

Emission inventories of gaseous pollutant CO, NOx, SO_2 and VOC as well as particulate matter $PM_{2.5}$, PM_{10}, BC, OC have been developed at (0.4 km×0.4 km) resolution, which incorporated all possible major/minor sources for base year 2018. The estimations for CO, NOx, SO_2 and VOC, $PM_{2.5}$, PM_{10}, BC, OC are found to be **575.75** Gg/yr, **412.58**Gg/yr, **619.76**Gg/yr, **679.36** Gg/yr, **107.78** Gg/yr, **268.38** Gg/yr,**24.18** Gg/yr and **41.30** Gg/yr respectively. This chapter briefly discusses the spatial distribution of $PM_{2.5}$only as other pollutants follows more and less similar trend.

6.1 Spatial distribution of $PM_{2.5}$ Emission

The spatial distribution of $PM_{2.5}$ emission from all sources is shown in **Figure 25.** The emission estimation of $PM_{2.5}$ is calculated to be around **107.8** Gg/yr in 2018 where contribution from power, transport, industrial, windblown dust, residential and other source are estimated to be **3.34**Gg/yr, **42.23**Gg/yr, **24.1** Gg/yr,**19.5** Gg/yr, **6.2** Gg/yr and **12.4** Gg/yr respectively. It is observed from **Figure 25** that high emission of $PM_{2.5}$ in the range of 10-50 ton/yr is found over major area of Delhi city and its peripheral areas. Emission of the order of 100-800 ton/yr is found over some areas in Eastern, Central, some part of Southeastern part of Delhi-NCR, which includes major roads network and industrial zones. The high value of the order of 1500-2400 ton/yr found in some grid is due to presence of Large Point Sources (LPS) like thermal power stations, MSW plants and other major industrial zones. Western and northern part of Delhi shows comparatively lower value of 1-8 ton/yr of $PM_{2.5}$ emission. This is due to agricultural/green lands, less number of industries and low population density leading to lesser amount of pollution intensifying activities.

Transport sector is the most dominating sector contributing to total $PM_{2.5}$ emission. **Figure 26** shows that the estimated value for $PM_{2.5}$ in transport sector is around **42.23**Gg/yr out of which Delhi alone contributes **27.82** Gg/yr of $PM_{2.5}$ emission. Relative contribution of other state car on Delhi roads is nearly 35-50% leading to more emission of $PM_{2.5}$. Northern and western Delhi has comparatively less emission (i.e. 1-2 tons/yr) due to sparse road network and low population density. High $PM_{2.5}$emission of around 30-100 tons/yr is confined over major and busy road around industrial locations, where the traffic congestion is common problem.

Industrial sector is the second most dominating sector contributing to $PM_{2.5}$ pollution. **Figure 27** shows that the sector contributes an estimated value of **24.1** Gg/yr of $PM_{2.5}$pollution out of which Delhi's share is **12.63** Gg/yr. Central, Eastern and Southeastern zone of Delhi are preoccupied with a large number of industries contributing to a larger number of $PM_{2.5}$emisson in an order of 25-250 tons/yr. Windblown dust being the third most dominating sector for $PM_{2.5}$ emission shows an estimated value of **19.5** Gg/yr out of which Delhi was recorded with an emission of **14.6** Gg/yr. **Figure 28** shows the emission is quite high in the central region of Delhi, northwest part of Delhi and some of the eastern zone of Delhi in an order of 4-150 tons/yr.

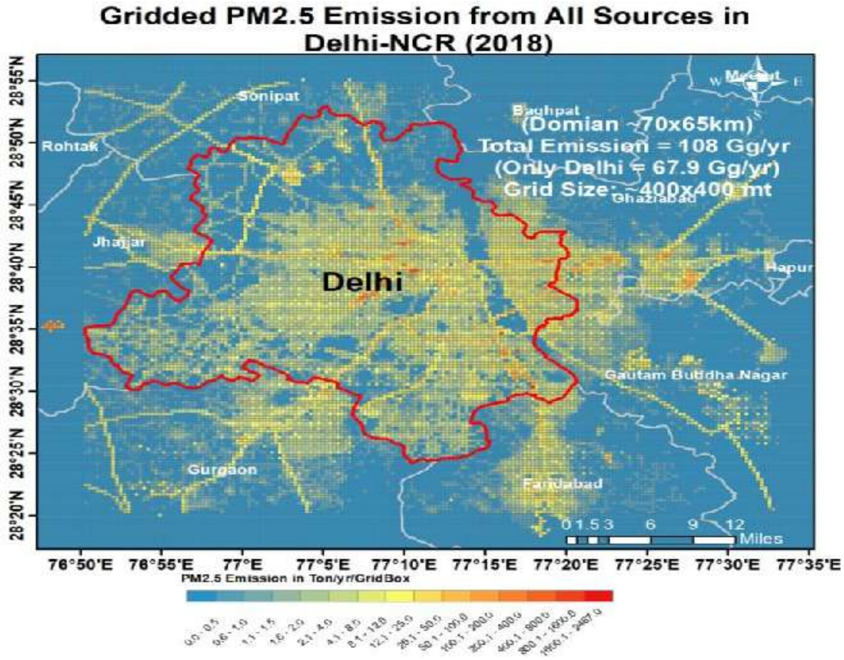


Figure 25: Gridded PM2.5 Emission from All Sources in Delhi-NCR (2018)

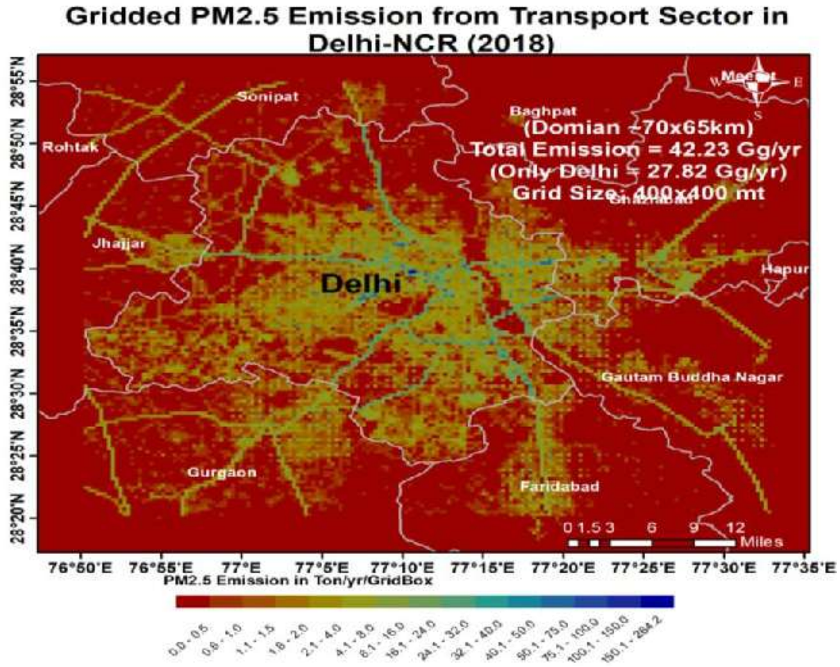


Figure 26: Gridded PM2.5 Emission from Transaport Sources in Delhi-NCR (2018)

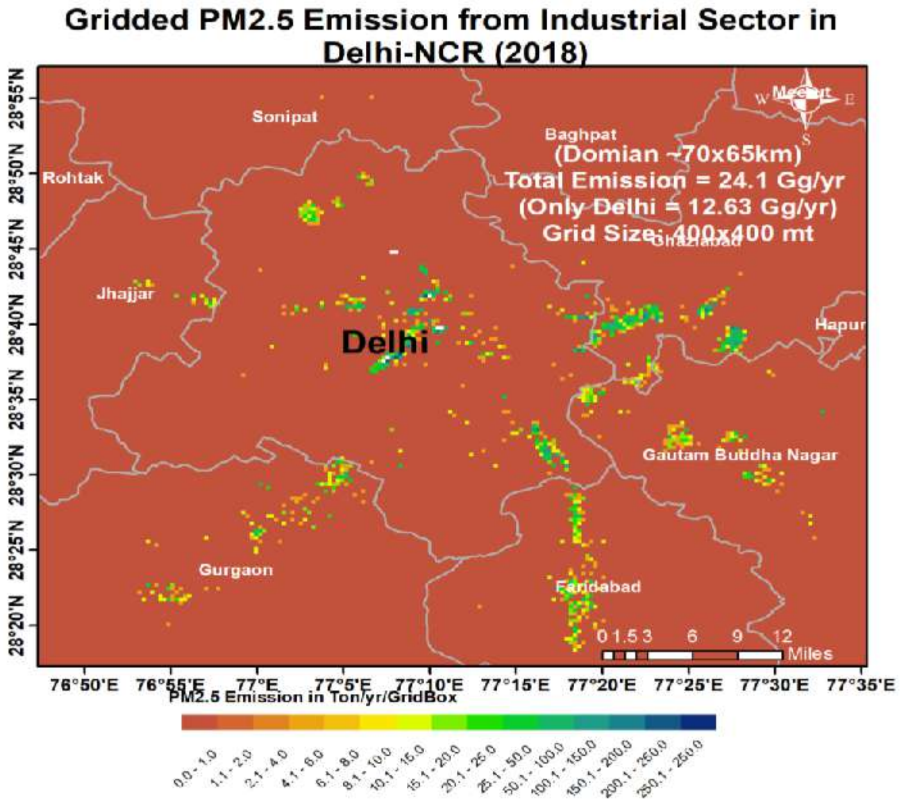


Figure 27: Gridded PM2.5 Emission from Industrial Source in Delhi-NCR (2018)

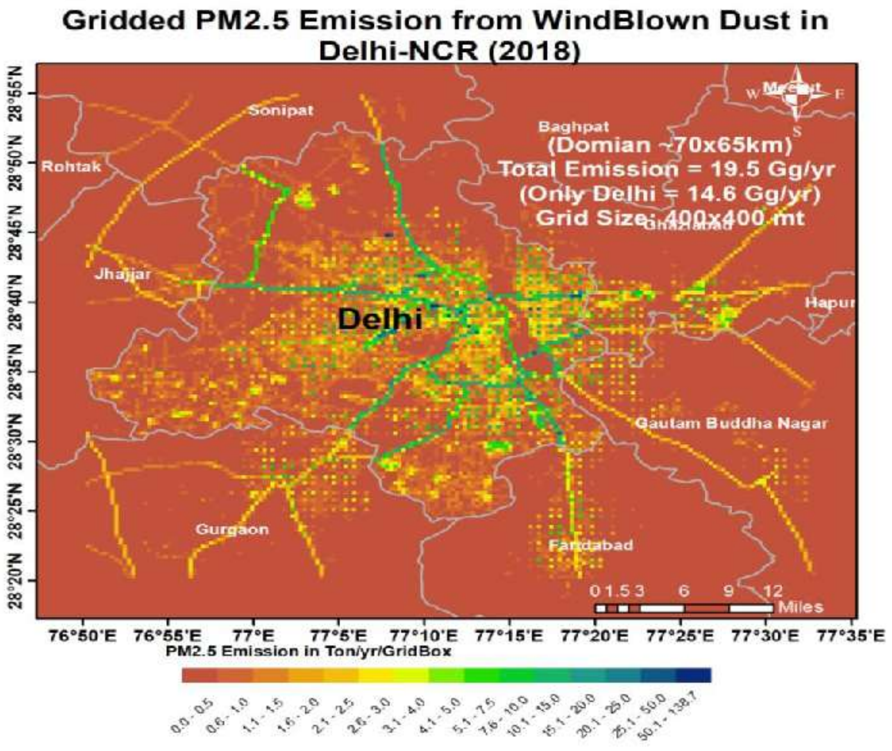


Figure 28: Gridded PM2.5 Emission from Windblown Dust in Delhi-NCR (2018)

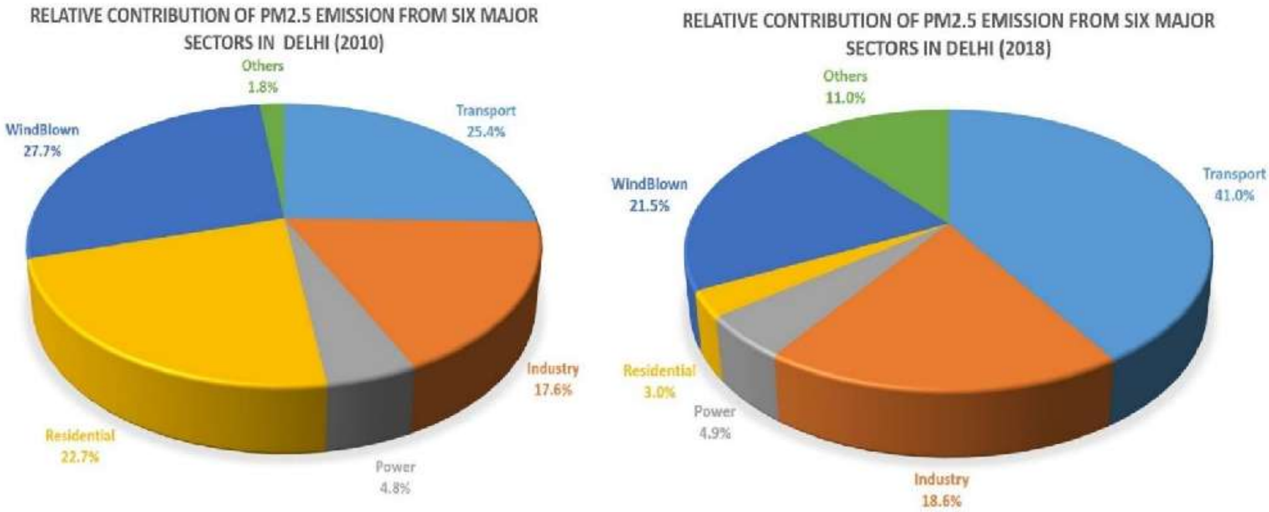


Figure 29: ***Comparison between relative contributions of $PM_{2.5}$ in 2010 and 2018 respectively in Delhi***

6.2 Inter-comparison of relative contributions of $PM_{2.5}$ in 2010 and 2018 respectively in Delhi:

Between 2010 and 2018, a significant amount of time has passed and the source of pollution might have shifted with changing life style. The present inventory is compared with previous estimation done for 2010. During these years, the sources of pollutants that has changed is crucial piece of information for policy maker as well as scientific community. Initial comparison shows remarkable difference between the emissions of both the studies.

As shown in **Figure 29** the $PM_{2.5}$ emission from **transport** sector was 25.4% in 2010 has increased to 41% in 2018. This could be due to overburden with four-wheeler car. The relative contribution of other-State car on Delhi road is approx.. 40% could be significant contributor to Delhi $PM_{2.5}$ emission. The relative contribution of residential sector has reduced from 22.7 % in 2010 to just 3% in 2018. This could be due to penetration of LPG in slum, street vendors, household, limited use of cow dung etc. Windblown dust has decreased from 27.7% to 21.5% during same time. As windblown dust load depend on vehicle speed so traffic congestion leading to decrease in avg. speed of vehicle in Delhi is one of the important factor. As far as the residential sector is concerned, there is a rapid reduction in relative contribution (i.e. 19.7% (2010) to 3% (2018). Primarily the awareness among the people led to penetration of LPG in slum areas, street vendors, household etc., which reduced the emissions by a large number.

Again, the use of cow dung as a biofuel has decreased up to a certain extent in outskirts of Delhi, which will reduced the $PM_{2.5}$ emission further. The other sector shown in the chart consists of the new emerging sectors like MSW treatment plant, MSW disposal sites, brick kilns, crematory, aviation, incense sticks etc. Emissions from these new sectors were not considered in the previous report in 2010 so the relative contribution has increased significantly. In case of whole domain, the relative contribution of residential and Windblown dust has reduced during 2010-2018 as compare to increase trend for transport and other sources (**Figure-30).** The absolute change in PM2.5 emission is just 15% in last eight years (**Table-15).**

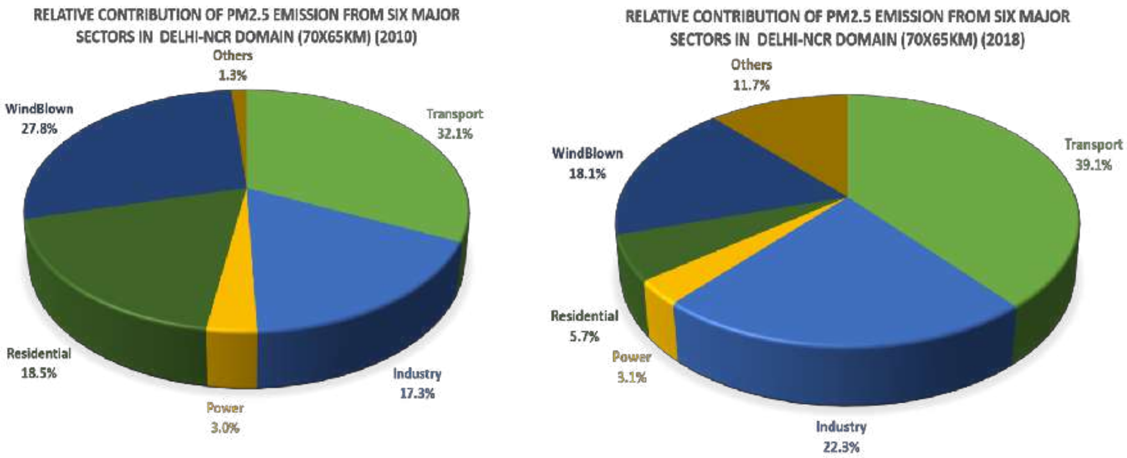


Figure 30: Comparison between relative contributions of PM2.5 in 2010 and 2018 in Delhi-NCR domain (70×65km) respectively.

Table-15: The absolute change in PM2.5 emission is just 15% in last eight years

Sector	Domain (70x65km) (Gg/yr) (2018)	Domain (70x65km) (Gg/yr) (2010)	Absolute Change in %
Transport	42.23	30.25	40
Industry	24.1	16.29	48
Power	3.34	2.87	16
Residential	6.197	17.4	-64
Wind-blown	19.5	26.2	-26
Others	12.65	1.25	912
Gross Total	108.017	94.26	15

7. Summary & Conclusion:

This study deduces the chemistry and quantity of atmospheric pollutants and remarks an accurate estimation of the rate of change in the anthropogenic emissions over the National Capital Region Delhi. Emission inventories are a critical input to chemical transport models for air quality forecasting as well as essential for the development of new mitigation strategies. A matter of concern arises in the estimations over the NCR Delhi, which requires an immediate attention for accurate forecasting. This report fulfils this lacuna and has made a significant contribution in this direction by developing the emission inventories of PM2.5, PM10, CO, NOx, VOC, SO2, BC and OC. This present piece of work adopts the bottom up approach in order to develop the accurate emission inventory with a fine resolution. Steps taken to fulfil the above goal include the following: - (i) Repository of activity data from various sources on a finer resolution; (ii) The information about EFs about which lot of uncertainty is prevailing.

This work reviews all the possible EFs used by different researchers in the past and in some cases proposed new emission factors based on the recently available information on development activities and expert judgment; (iii) Above two information needs to be integrated by developing some methodology to develop the gridded emission inventories which can then be used as input to chemistry transport models to simulate the level of air pollutants. A GIS based methodology is also formulated in order to attain the aim. This methodology is used to develop the gridded emission inventories for all the major air pollutants mentioned in this report.

Present emission inventory developed for the area of interest (70 km x 65 km) reveals that the total estimated $PM_{2.5}$, PM_{10}, CO, NOx, VOC, SO_2, BC and OC emissions are around **107.786** Gg/yr, **268.382** Gg/yr, **575.755** Gg/yr, **412.588** Gg/yr, **679.361** Gg/yr, **619.769** Gg/yr**, 24.188** Gg/yr and **41.302** Gg/yr respectively. The brief summary of estimated sector specific emission for 2018-2019 as obtained in this study has been given in the following Table:-

Table 16: Total emission (in Gg/yr) for all pollutants over Delhi-NCR Domain (2018)

SECTORS	PM 2.5	PM 10	CO	NOx	VOC	SO2	BC	OC
Transport	42.230	43.230	483.061	257.653	614.515	77.230	15.516	26.533
Industry	24.100	43.870	12.086	100.692	61.035	400.083	5.120	8.704
Power	3.340	12.806	0.334	8.018	0.006	81.020	0.043	0.072
Residential	6.207	8.886	34.085	2.222	0.270	1.256	1.143	1.950
Wind Blown	19.500	136.000	0.000	0.000	0.000	0.000	0.000	0.000
Others	12.409	23.590	46.189	44.003	3.536	60.180	2.366	4.043
TOTAL	**107.786**	**268.382**	**575.755**	**412.588**	**679.361**	**619.769**	**24.188**	**41.302**

The emission inventory developed in this work is one of the most extensive, sturdy and factual inventories as it discusses several factors, which involve detailed field survey to collect the primary and secondary data, adopted scientific methodology with proven indigenously developed GIS, based statistical model, etc. The developed emission inventories are first of its kind for Delhi-NCR for the most recent year 2018 with finest resolution. These gridded emission inventories are capable of imparting detailed information about the most emitting regions viz. emission hope spots, relative contributions of various sources and sector that can be targeted for mitigation. It improves the understanding on emission scenarios in Delhi-NCR with their possible impacts as well as this can be used in national interest for developing emission strategies. Considering everything, the high emission hotspots could be directly or indirectly amalgamated with the high vehicular density in densely populated area, high bio-fuel use along with coal, kerosene practices by slum residents, commercial cooking and street vendors in Delhi-NCR.

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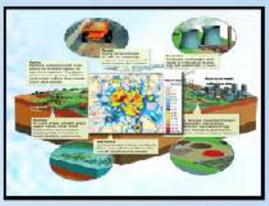

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