Evaluation of Economic, Environmental and Health Impacts of Vehicular Exhaust Emission Standards for India

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By

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DECLARATION

I, Prachi Singh, Scholar No.16554008 hereby declare that the dissertation titled "Evaluation of Economic, Environmental and Health Impacts of Vehicular Exhaust Emission Standards for India", submitted by me in partial fulfillment for the award of Master of Technology in Infrastructure Systems, at Indian Institute of Technology Roorkee, India, is a record of bonafide work carried out by me. The matter/result embodied in this dissertation has not been submitted to any other University or Institute for the award of any degree or diploma.

Prachi Singh

Date: -06-18

CERTIFICATE

This is to certify that the declaration of Prachi Singh (16554008) is true to the best of my knowledge and that the student has worked under my guidance for one year in preparing this report.

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ABSTRACT

Motorized road vehicles overwhelmingly dominate the markets for passenger and freight transport throughout the world owing to their versatility, flexibility, and low initial cost. In the developing nations, economic growth has triggered a boom in the number and usage of motorised vehicles. Although a balanced mix of transport modes has been brought about—including non-motorized transport for small-scale applications and rail in high-volume corridors—motorized road vehicles still retain their overwhelming dominance in the transport sector for the upcoming future. Owing to rapidly increasing numbers of cars and limited use of exhaust emission control technologies in motor vehicles ,they are becoming as the largest source of urban air pollution in the world. Air pollution is a significant and alarming public health concern in India. Pollution levels in Indian cities such as New Delhi, Mumbai, Bengaluru, Kolkata, Gwalior, Patna, Allahabad and Raipur exceed those in any city in the industrialized and developed nations. Tens of thousands of excess deaths hev been accounted in developing nations owing to the rising air pollution as the epidemiological studies state and billions of dollars in medical costs and lost productivity every year. Continously rising levels of the air pollution and their repercussions forced the authorities in the nation to look for solutions to the prevalent problem. It is in the wake of these concerns that vehicular emission norms namely **Bharat Stage Standards** were formulated to curb emissions at their source. This report brings a comprehensive picture of the present scenario of vehicular emission norms adopted by India i.e, Bharat Stage Standards to tackle the alarming levels of the air pollutants released by motor driven vehicles. It throws light on the evolution of these standards and whether they have been successful in lowering the pollution rates and evaluates the human health impacts and environmental impacts owing to the prevalent air pollutants borne by vehicular exhaust and vehicular non-exhaust. This study analyses the emission trend of the various pollutants borne by the vehicular fleet in Delhi for the period 2001-2015 which have endured four generations of Bharat Stage standards for vehicular emissions in India i.e., BS-I, BS-II, BS-III and BS-IV. The total yearly emissions given out by the vehicles are then transformed into the corresponding ambient concentrations which are utilized for the impact assessment of the human health and ecology using various techniques.

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CHAPTER 1 : INTRODUCTION

1.1 PRE-BHARAT STAGE SCENARIO IN INDIA

The Air (Prevention and Control of Pollution) Act, India was enforced in 1981 and amended in 1987 to provide for the prevention, control and moderation of air pollution in India. Beginning in 1987, India's Central Pollution Control Board (CPCB) began compiling readings of Nitrogen Dioxide (NO_2), Sulfur Dioxide (SO_2), and particulate matter with aerodynamic diameter less than 100μm (PM). The data were collected as a part of the National Air Quality Monitoring Program (NAMP), a program initiated by the CPCB to help identify, assess and prioritize the pollution control needs in various sectors, as well as to aid in identifying and regulating potential hazards and pollution sources. As per CPCB, Particulate matter (PM) is a general indicator of pollution, receiving key contributions from fossil fuel burning and vehicular exhaust. Whereas SO_2 emissions, predominantly in 1990s were products of fossil fuel use. NO_2 is regarded by the CPCB as an indicator of vehicular pollution, though it is contributed by almost all combustion reactions and not just vehicle engines. India has almost surpassed China in pollution index and everyone else in having the dubious distinction of having the world's most polluted air. Air in some Indian cities has particulate matter (PM) levels 5 times above safety limits**.** The PM levels are the major cause of health concern in urban areas**.** Exceptionally higher PM10 levels are found in northern Indian cities with continuous increase in Delhi, Faridabad, Lucknow, Bangalore and Mumbai(Hosamane and Desai 2007). Research and studies have shown that the advanced emission controls can reduce hydrocarbon and carbon monoxide emissions by more than 95% and emissions of nitrogen oxides by 80% or more when compared with uncontrolled emission vehicles.(Asif et al. 1996). While these emission norms help in lowering down the air pollution levels, they invariably result in increased automobile cost due to the improved and advanced technology for lower emissions & greater fuel prices.

The Government of India instituted the Bharat Stage Vehicular Emission standards to regulate the emission of air pollutants from internal combustion engines and spark-ignition engines equipment, including motor vehicles. The standards and the timeline for implementation are set by the Central Pollution Control Board under the Ministry of Environment & Forests and climate change. The Bharat Stage standards, based on European vehicular emission regulations were first implemented in 2000. Progressively stringent norms have been rolled out since then and all new vehicles manufactured after the implementation of the norms have to be compliant with these regulations.

1.2 IMPLEMENTATION OF BHARAT STAGE STANDARDS IN INDIA

- The first emission norms were introduced in India in 1991 for petrol and in 1992 for diesel vehicles. These were followed by making the Catalytic converter mandatory for petrol vehicles and the introduction of unleaded petrol in the market.

- On 29 April 1999, the Supreme Court of India announced a two important rulings. First was to make all vehicles in India compliant to Euro I or India 2000 norms by 1 June 1999 and secondly, Euro II was made to be made compulsory in the National Capital Region by April 2000. However, automobile makers were not ready for this sudden transition and hence in a subsequent judgement the implementation date for Euro II could not be enforced.
- Next year in 2002, the Mashelkar committee submitted the the report Indian government. The committee proposed a road map for the phase-wise roll out of Euro based vehicular emission norms for India. It also recommended a phased implementation of future norms in major cities first and then a gradual extension to the rest of the country in a few years.
- Finally, based on the recommendations of the committee, in 2003 ,the National Auto Fuel policy was officially announced and a roadmap for implementation of the Bharat Stage norms were laid out till 2010. The policy also created guidelines for auto fuels, reduction of pollution from older vehicles and R&D for air quality data creation and health administration.

Table-1.1: Emission norms for passenger cars(CPCB 2016)

Norms	CO	HC+NOx
1991 norms	14.3-27.1	2.0(ONLY HC)
1996 norms	8.68-12.40	3.00-4.36
1998 norms	4.34-6.20	1.50-2.18
India stage 2000 norms	2.72	0.97
Bharat stage-II	2.2	0.5
Bharat stage-III	2.3	0.35
Bharat stage-IV	1.0	0.18

Table-1.2: Emission norms for Heavy Diesel vehicles(CPCB 2016)

NORMS	CO(g/kmhr)	HC(g/kmhr)	NOx(g/kmhr)	PM(g/kmhr)
1991 Norms	14	3.5	18	-
1996 Norms	11.2	2.4	14.4	-
India stage 2000 Norms	4.5	1.1	8.0	0.36
Bharat Stage-II	4.0	1.1	7.0	0.15
Bharat stage-III	2.1	1.6	5.0	0.10
Bharat stage-IV	1.5	0.96	3.5	0.02

Table-1.3: Emission norms for 2/3 wheelers(CPCB 2016)

Norms	CO(g/km)	HC+NOx(g/km)

1991 Norms	12-30	8-12(only HC)
1996 Norms	4.5	3.6
India stage 2000 norms	2.0	2.0
Bharat stage-II	1.6	1.5
Bharat stage-III	1.0	1.0

The timeline below shows the phased-roll out of Bharat Stage standards in India and the reduction in emissions incorporated with each modified standard.

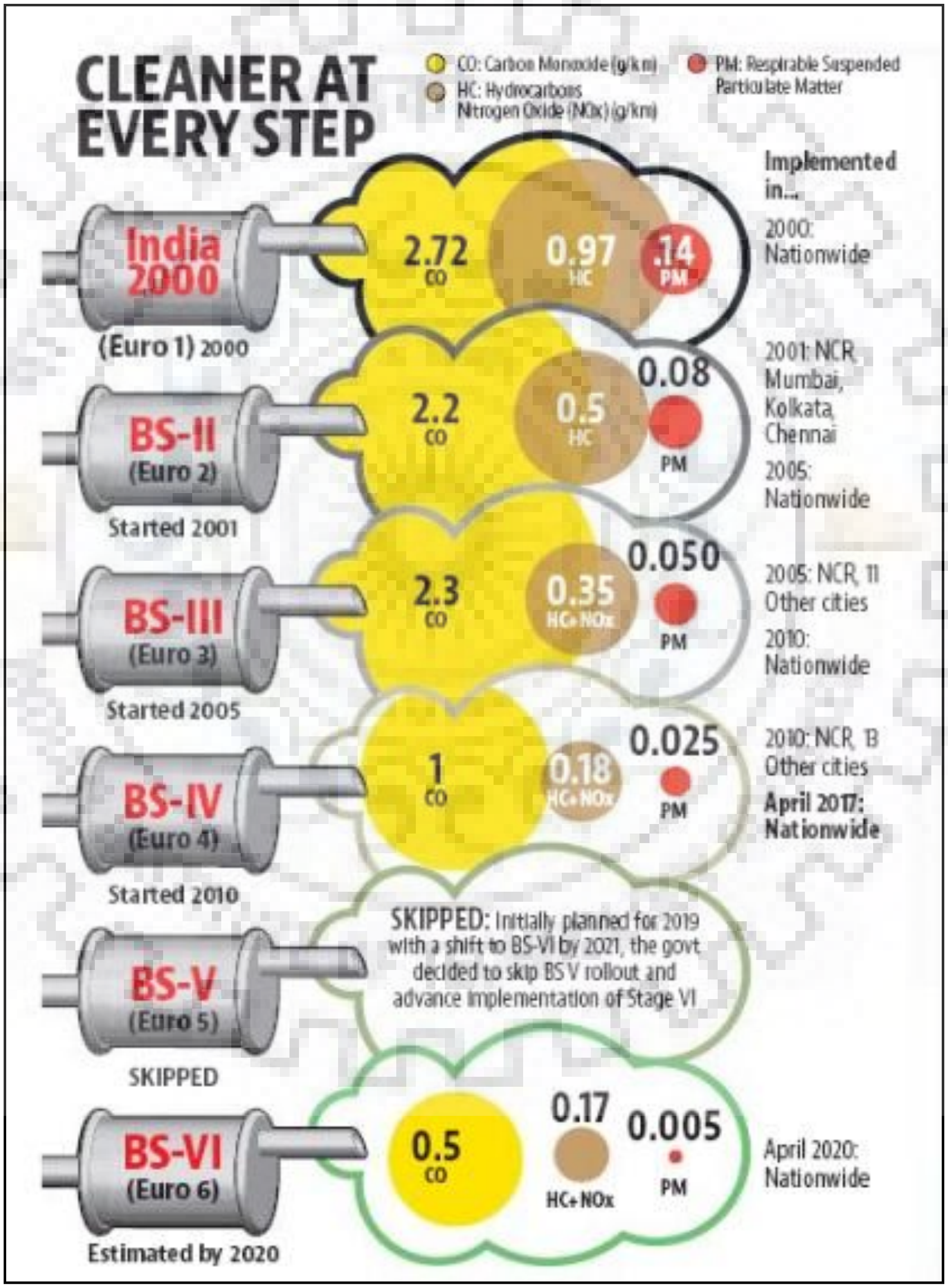


Fig-1.1: Timeline for Bharat Stage Emission Standards roll out in India

1.3 IMPACTS OF AIR POLLUTANTS REGULATED BY BHARAT STAGE EMISSION NORMS

1.3.1 IMPACTS ON HUMAN HEALTH

❖ **Presence of NOx in air:**

- NOx mainly influence respiratory conditions causing inflammation of the airways at high levels. Exposure to it for longer times can cause lung function disruption,aggravate the risk of respiratory conditions and increase the sensitivity to allergens. NOx also takes part in the formation of fine particles (PM) and ground level ozone, both of which are known to induce adverse health effects.

❖ **Presence of Particulate matter in air:**

- Particulate matter perhaps the most characteristic of diesel emissions, is the reason for the black smoke traditionally known to be associated with diesel-run vehicles. Researchers estimate that for every rise of 5μg/m³ in PM2.5 exposure content throughout pregnancy, the risk of low birth weight in infants rises by 18% (Lancet, 2013). Respirable particles whose size is lesser than 2.5 micrometres are among the most dangerous of particulates matter because they can be inhaled into the lungs, thus severely damaging the respiratory tissues (Kampa and Castanas n.d.).
- As stated by the American Lung Association (2013), people that are most vulnerable to particulate matter are infants, people who work and are active outdoors, people with heart disease or diabetes, children and teens, people over 65 years old, people suffering from lung disease (asthma, chronic pulmonary disease, chronic bronchitis and emphysema).

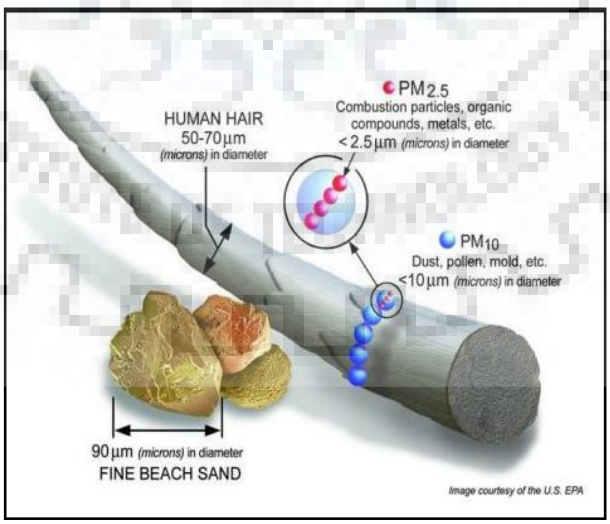


Fig-1.2: Size of particulate matter (source: American Lung Association(2013))

- Particle pollution is confirmed to cause respiratory harm that will force the asthma, COPD(Chronic obstructive pulmonary disease) and inflammation getting worse. This deadly air pollutant is alos cancerogenic and can induce reproductive and developmental harm (Kampa and Castanas n.d.).
- It has also been estimated that $PM_{2.5}$ exposure led to about 570,000 premature mortalities(Ghude et al. 2016) in 2011. Even the slightest increase in airborne fine particulate matter PM2.5, tiny pollution-causing particles could lead to acute lower respiratory infection (ALRI) in young children.

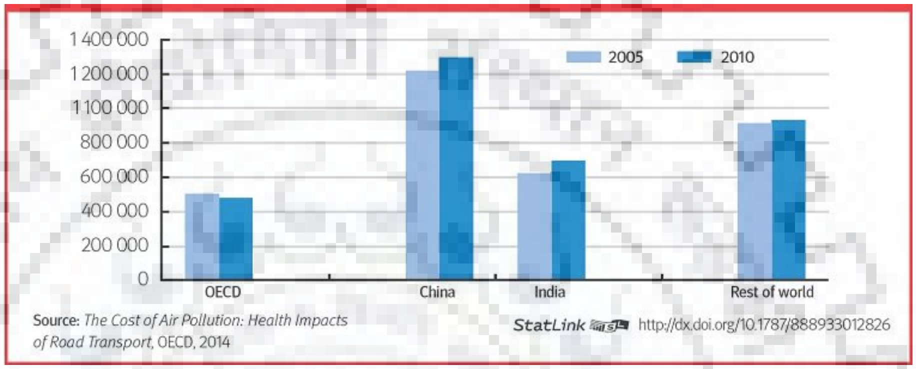


Fig-1.3: Annual mortalities from ambient PM and ozone pollution, 2005 & 2010

❖ **Presence of Carbon-mono-oxide in air:**

- Inhaling high concentrations of Carbon-mono-oxide leads to decreased oxygen (O_2) transport through haemoglobin as it has more affinity to dissolve in haemoglobin than oxygen. It induces headaches, great risk of chest pain for persons experiencing heart disease, and in some cases impairs reaction timing.(Sandilands and Bateman 2016)
- Daily rise in Carbon-monoxide ambient concentrations are associated with statistically significant increase in the numbers of hospital admissions for heart disease and congestive heart failure and with increase in deaths from cardiopulmonary illnesses(Sandilands and Bateman 2016).

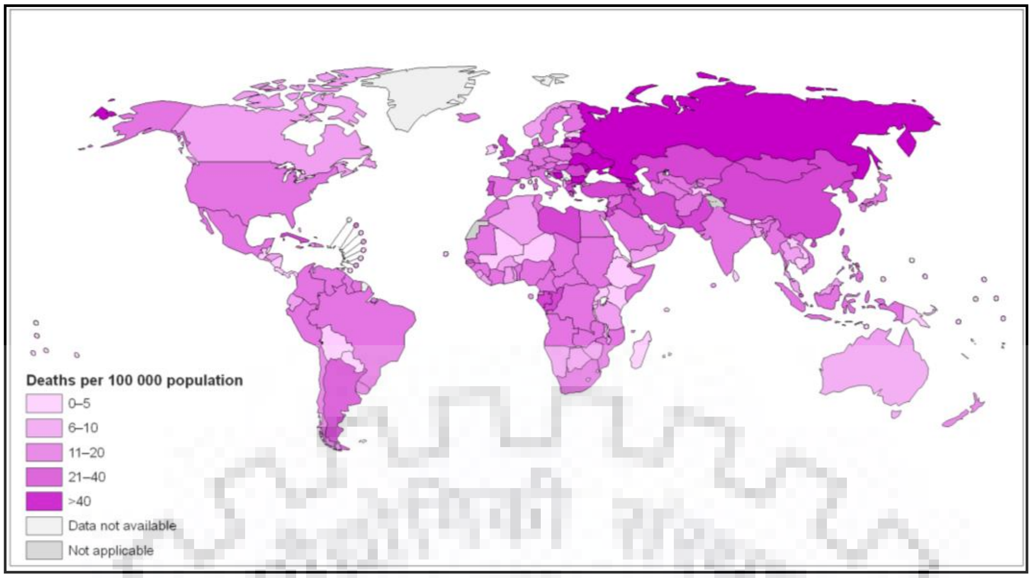


Fig 1.4: Deaths attributable to outdoor air pollution **source: WHO, 2011**

- **Presence of Hydrocarbons in air:**
  - Vehicular hydrocarbons are a combination of number of organic compounds. The Hydrocarbons in air by themselves alone cause no harmful effects. They have been shown to produce eye and minor respiratory irritations(Wulf et al. 2002). They can chemically react in air again to produce nitrous oxide, which can affect bone marrow and possibly cause neurological effects for which nitrous oxide is termed to be quite toxic.

- **Presence of Carbon-di-oxide in air:**
  - India ranks the third-highest carbon dioxide generator in the world in 2015 after USA and China, according to the International Energy Agency, a Paris-based energy policy advisor to 29 nations globally speaking for clean energy. The study titled 'Carbon-di-oxide Emissions from Fuel Combustion (Highlights) 2017' released estimated Carbon-di-oxide emission loads from combustion increase in India from 181 million tonnes (MT) in 1971 to 2,066 MT in 2015, a whooping increase of 1,041%. Excluding China, alone India's emissions accounted for 46% of total net emissions for whole Asia.
  - Carbon dioxide is essential for the survival of animals. Oxygen is carried to body tissue during breathing and carbon dioxide is released. The gas guards the pH level of blood. If carbon dioxide is confined, it can reduce the amount of oxygen reaching the body(Raub et al. 2000). Any disruption or excess in the quantity of carbon dioxide reaching the body can cause kidney failure or coma.

1.3.2 IMPACTS ON ECOLOGY

❖ **Presence of Particulate matter in air:**

- PM can turn streams and lakes acidic upon settlement. It disrupts the nutrient balance in coastal waters and river basins, depleting the nutrients in soil. It damages sensitive forests and farm crops, affecting the diversity of ecosystems. PM deposition can stain, damage and corrode the stone and other materials, thus adversely affecting the infrastructures including culturally important objects such as statues and monuments.

❖ **Presence of Hydrocarbons in air:**

- HC emissions have been assumed to present a relatively low toxicity threat, and, the main concern is their significant role as precursors for the formation of secondary pollutant which is ozone (O_3) and its build-up at a tropospheric level along with other hazardous secondary pollutants(Hickey et al. 2014).

❖ **Presence of NOx in air:**

- NOx emissions also contribute to a number of year-round ecological problems,ranging from acid rain in the mountaineous regions to eutrophication thus ultimately depleting oxygen that invariably results in water quality degradation and harms fish. Deposited loads of acidity and nitrogen can be attributed most closely to annual average ambient concentrations of sulphur and nitrogen contents in air. Enhanced nutrient supply to an natural ecosystem may result via foliar uptake of nitrogen oxides, nitric acid and ammonia, and via wet and dry deposition of nitrates, nitrites and ammonia to soils. NOx emissions also leads to haze air pollution in flora-fauna sanctuaries and wilderness areas(Selden and Song 1994).
- Eutrophication can worsen water quality along with subsequent impacts including changes in species composition , dominance, reduced biodiversity and toxicity effects. Deposition of acidifying substances and eutrophication in a number of cases still exceeds the critical loads prescribed for the ecosystems. However, although increasing supply of nitrogen can enhance growth (potentially desirable), but its excess can bring about undesirable alterations in the exposed species turning their helpful relationships competitive.
- NOx emissions leads to the production of fine particulates and ozone smog that cost society billions of dollars annually from avoidable illnesses and deaths. It also leads to the generation of secondary particulate aerosols and tropospheric ozone (O_3) in the atmosphere

both are important air pollutants due to their negative effects on human health(Frost et al. 2006).

- ❖ **Presence of Carbon-di-oxide in air:**
  - Carbon dioxide in the atmosphere is vital for the survival of plants and animals. Excess , however, can cause all life on Earth to end. Carbon dioxide plays a key role in plant life and helps keep the earth warm. Soaring levels of carbon dioxide in the atmosphere, though, are associated to global warming. Carbon dioxide is a naturally occurring greenhouse gas. Others include water vapor, methane and nitrous oxide. These gases help keep the Earth warm by absorbing the sun's energy and by reverting energy back to the Earth's surface. An increase in the amount of carbon dioxide creates an overabundance of greenhouse gases that trap additional heat(Idso et al. 1980). This trapped heat causes ice caps to melt and raise ocean levels, which may turn to flooding.
  - Because of the effects of CO_2 and other Green House Gases , such as methane and nitrous oxide, result in more than just rising temperatures, a more appropriate term is "climate change," which better conveys that other changes such as sea-level rise from thermal expansion and ocean acidification from increased absorption of CO2(Idso et al. 1980) are occuring too.

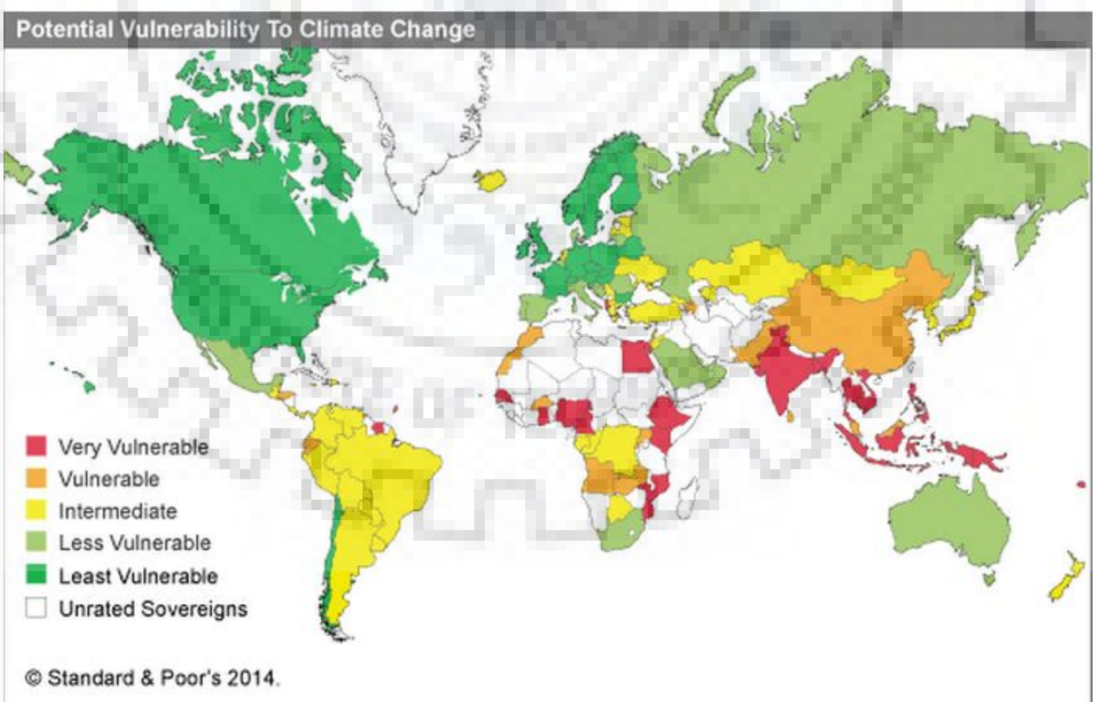


Fig-1.5: Potential vulnerability to climate change

- **Presence of carbon-mono-oxide in air:**
  - When carbon monoxide is released into the atmosphere it affects the amount of greenhouse gases, which are associated to potential global warming and climate change. This means that land and sea temperature gets altered, altering the ecosystems, increasing rate of storm activity and causing other extreme weather events.
  - It reacts with varied pollutants in the air to form hazardous ground level ozone. This occurs close to the site of emission. It does not signify environmental effects at a global level.

CHAPTER 2 : LITERATURE REVIEW

2.1 BACKGROUND OF THE VEHICULAR AIR POLLUTION

Energy, the engine of growth for any economy plays a vital role in the socio-economic development of a nation(Umang 2016). Since decades, fossil fuels have been dominant sources of energy that generate electricity and run transportation systems and hence "fuel" the economy(Umang 2016). India is the fourth largest consumer of fuel in the world. And our consumption has always outpaced the overall production(see fig-5).

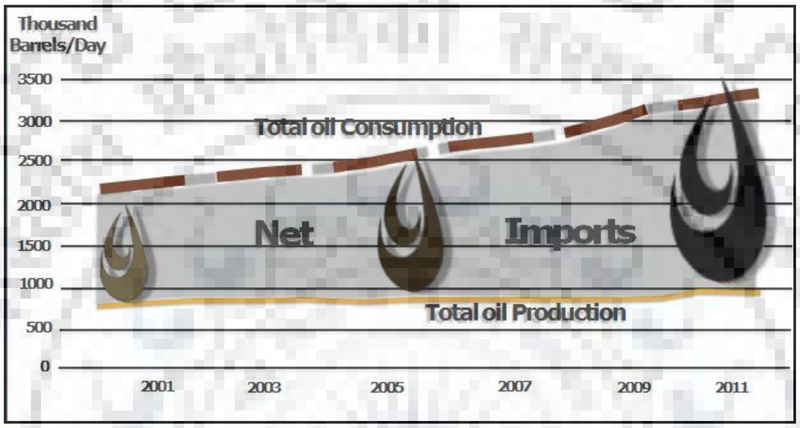


Fig-2.1: Oil production and consumption in India source: EIA

In the developing nations like India, economic growth has triggered a boom in the number and usage of motorised vehicles. Although a balanced mix of transport modes has been brought about including non-motorized transport for small-scale applications and rail in high-volume corridors, motorized road vehicles still retain their overwhelming dominance in the transport sector for the upcoming future. Owing to ever-rising numbers of auto-mobiles and limited use of exhaust emission control technologies in motor vehicles, they are becoming the largest source of urban air pollution in the world(Asif et al. 1996). Air pollution has been a matter of concern since industrial revolution around the world.

Megacities around the world are facing a multitude of ecological challenges including soaring air pollution emissions. Fast paced economic growth in Asia has resulted in unprecedented increase of new vehicle sales in recent years, predominantly motorized two- and three-wheelers and this rapid expansion of vehicles has put extra stress on air quality,surrounding ecosystem and public health(Posada et al. 2011). Transportation has been a major source of air pollutants that degrade the air quality and hence cause several human health impacts and environmental impacts. This has also been justified by the Auto fuel policy report that presented a source apportionment statistics for the polluting agents in Delhi and Mumbai.

Table-2.1: Source apportionment for various air pollutants in Delhi region as published in Auto Fuel Policy report

S.no	Parameter	Transport	Industrial	Domestic and other sources
1	CO	76-90%	37-13%	10-16.3%
2	NOx	66-74%	13-29%	1-2%
3	SO2	5-12%	84-95%	0-4%
4	PM	3-22%	74-16%	2-4%

Vehicular exhaust or tailpipe emissions lone are not the contributor for the air pollution but non-exhaust emissions have also been altering the air quality(Alistair Thorpe and Roy M. Harrison 2008; Amato et al. 2014; Ketzel et al. 2007) Several studies have been done to evaluate the effects of the traffic brone air pollutants(Amato et al. 2014; Asif et al. 1996; Ingle et al. 2005; Kittelson 1998; Kumar et al. 2014). In all these studies health impact estimation is done by considering the air quality near by the traffic intersections or along the roads. For example, in (Ingle et al. 2005) ambient air quality monitoring was carried during the May 2003 to April 2004 along the NH-6 passing through Jalgaon city, Maharashtra. The average concentrations of sulphur oxides 64 µg/m3, Nitrogen oxides 58 µg/ m3, particulate matter (>10 µ) 515 µg/m3 and respirable dust particulates 224 µg/m3 were reported at Prabhat during the study period . This location represents the major highway crossings in the study area. They presented investigations on the health status survey and lung function of traffic policemen exposed to the inferior air quality as recorded along the highway crossings. The spirometric analysis of traffic policemen presented significant variation in Peak Expiratory Flow Rate , Forced Expiratory Volume in one second and Forced Vital Capacity. The mentioned parameters were significantly affected in the traffic policemen as against the control group of population which is actually a group of adult population working in offices that remained unexposed to the traffic pollution for longer hours of the day. It revealed significant respiratory impairments in the traffic policemen due to exposure to vehicular pollution. Motor vehicle emissions can be controlled most effectively by designing vehicles to have low emissions from the beginning(Asif et al. 1996). Advanced emission controls can reduce hydrocarbons and carbon monoxide emissions by more than 95 percent and emissions of nitrogen oxides by 80 percent or more(Asif et al. 1996) as compared to uncontrolled emission levels.

Since number of studies revealed the rising rate of casualties and future detoriaiting conditions, vehicular emission norms were brought about. They were already existing in developed countries and we formally adopted them in 2001 as Bharat stage standards. The standards, based on European regulations were first introduced in 2000. Progressively stringent norms have been rolled out since then. All new vehicles manufactured after the implementation of the norms have to be compliant with these emission regulations.

Even after the implementation of the Bharat stage standards, air quality has been degrading in many cities and the reason for the same is being attributed to the rising vehicle fleet along with other factors. The national capital of India, Delhi makes a perfect case for this. The urban air database released by the World Health Organization in September 2011 reported that Delhi has exceeded the maximum PM10 limit by almost 10-times at 198 μg/m3. Industrial activities and traffic emissions were found to be associated with outdoor as well as indoor air pollution in Delhi. Studies on air pollution and related mortality from Delhi found that morbidity and all-natural-cause mortality rose with increased air pollution(Rizwan et al. 2013). Delhi authorities took several steps to lower the level of air pollution in the city during the last decade. However, that has not been satisfactory and more still needs to be done to further lower down the levels of air pollution.

2.2 IMPACT ASSESSEMENT OF URBAN AIR QUALITY

Numerous studies have been done regarding the risk assessment and impact assessment of the air pollution on human health and simultaneously on the environment. All these studies mainly focus on the evaluation of the impacts of the detoriated air quality owing to the increased anthroprogenic activities such as industrialization, energy generation, domestic fuel use, transportation etc(CPCB 2010; Guttikunda and Jawahar 2014; Leduc et al. 2016; Maji et al. 2016; Nagpure et al. 2010; Parikh et al. n.d.). For example, in (Nagpure et al. 2010) the spreadsheet model, Risk of Mortality/ Morbidity due to Air Pollution (Ri-MAP) was used to evaluate the direct health impacts of various criteria air pollutants present in urban airsheds. They applied Ri-MAP in a case study to assess health impacts of air pollution in the megacity Delhi during the period 1998 to 2005 .They also used Ri-MAP to rank the most and/or least polluted megacities, based on the number of annual excess deaths and illnessess due to air pollutants.

Similiarly in (Maji et al. 2016), for air quality health impact assessment, WHO developed AirQ+ software is used to evaluate the direct health impacts of various critical air pollutants in 10 cities of Maharashtra for the period 2004–2013. This case study focuses on quantitative assessment of HHR(Human Health Risk), like cardio-vascular mortality (CM), respiratory mortality(RM), chronic obstructive pulmonary disease (COPD), total mortality (TM), hospital admissions due to respiratory disease (HARD), and hospital admissions due to cardiovascular disease (HACD), due to exposure to three critical pollutants (SO_2, PM10, and NO_2) in 10 urban areas namely, Mumbai, Thane, Nashik, Solapur, Pune, Nagpur , Navi-Mumbai, Kolhapur, Aurangabad, and Chandrapur in Maharashtra from 2004 to 2013.

The result shows that excess number of morbidity and mortality in Chandrapur, Thane, Kolhapur, Aurangabad and Nagpur is in rising trend, while cities like Solapur and Mumbai are in decreasing trend, and other cities as Pune, Navi-Mumbai and Nashik are in a steady-state condition. Cities having highest annual average excess number of total mortality, cardiovascular mortality, and respiratory motility in one million population are Mumbai ,Chandrapur Navi-Mumbai and Pune in decreasing order. Cities having highest annual average of hospital admission due to respiratory disease and cardiovascular disease among one million population are in decreasing order: Mumbai , Chandrapur, Navi-Mumbai, Pune, and Solapur. In all these studies, the air quality data collected by the monitoring stations has been ustilised to carry out the evaluation of health impacts and results were complied to establish the fatality of the worsening air quality. But the air quality utilized here is the combined air quality of the region i.e., the air composed of the pollutants added concurrently by industry emissions, traffic exhaust emission, construction activities emissions, farm residue burning emissions, domestic fuel burning emissions, thermal power plants emissions, etc. Thus the estimated health impacts are actually a combined result of all polluting activities and individual source apportionment has not been performed here that would have brought out a clear pictue of the major emitter of the pollutants and the real culprit for the rising hospital admissions and incidences of illnesses.

Transportation being one of the major sources that aided the air pollution in Delhi has been dealt with various precautionary steps ranging from replacement of public transport fleet with CNG vehicles(Product Life Institute n.d.) to implementation of Bharat stage standards(CPCB 2016) and also phasing out of the vehicles that have already attained their serviceable age. But did all these steps to curb the traffic air pollution have yielded any significant results??? Not many studies have dealt with this query instead they go for the bigger picture where they resort to evaluating the effects of overall air pollution(Bhati et al. n.d.; COMEAP 2016; Du et al. 2016; Ghude et al. 2016; Hooper et al. n.d.; Hosamane and Desai 2007; Kampa and Castanas n.d.; Maji et al. 2016; Mészáros et al. 1992; Schwartz n.d.; Stevenson et al. 2000). When it comes to evaluation of the individual impact or risk assessement, researchers go for evaluation of the individual pollutants like impact assessement of particulate matter(Du et al. 2016; Ghude et al. 2016; Hoek et al. 2012; Mészáros et al. 1992), risk assessment of nitrous oxide(Borken-Kleefeld et al. n.d.; Obbink et al. 2010; Sutton et al. 2014) and like wise for other pollutants. But for curbing the overall pollution, all of its contributing sources need to be controlled and for their better efficiency, regular assessment is the highly necessary. Monitoring of the air quality and putting restrictions on the polluting souces without carrying out proper assessment of their role in the degrading air quality will not give productive results.

2.3 ESTIMATION OF VEHICULAR EMISSIONS AND CORRESPONDING AMBIENT CONCENTRATIONS

For estimation of the contribution of motorized vehicle transportation to air pollution, various emission models are available. Many of the popular models include: MOBILE, MOVES, EMFAC, COPERT, CMEM etc(Mathew V. Tom 2014). MOBILE model was proposed by the Environmental Protection Agency of the

United States. The MOBILE model provide estimates for emission rates from on-road fuel-driven vehicles. The outputs of the model are emissions per unit time or distance of a fleet or vehicle type (i.e. grams/hour or grams/mile) of NOx, CO2, PM,HC, CO, NH3, SO2 and five other toxic air contaminants such as lead. It estimates emissions of both exhaust and evaporative emissions, as well as particulate emissions from tire and brake wear. MOBILE model , as described in (Perkinson and Dresser 2001) does not apply the vehicle operation such as number of starts and distance travelled. The model is also capable of predicting emission rates from a future vehicular count to comprehend how emissions will change over time(Mathew V. Tom 2014). This model also considers aggregate driving cycles. MOBILE 6.2 is the current version of the model. MOVES is an abbreviation for "Motor Vehicle Emission Simulator", also a product of EPA. This model was proposed as a replacement to their MOBILE model. The MOVES unlike MOBILE model ,contains fine scale information, such as driving behaviour and second by second resolution emissions (Mathew V. Tom 2014) that can be gathered with the help of on-board instrumentation. The "Emission Factors" model is developed by the California Air Resources Board. The model is similar to the MOBILE model, but it is applicable to California only. California vehicular emission norms are different from rest of the USA. This model is developed by the European Environmental Agency. COPERT stands for "Computer Program to calculate Emissions from Road Transport". COPERT 5 is the current version of this model("Emisia SA" n.d.). It classifies vehicles into various age groups and size as well as categories for highway, rural and urban driving situations. The "Comprehensive Modal Emissions Model", or CMEM, was designed at the University of California, Riverside and generate predictions for fine-scale emissions. CMEM 2.0 is its latest version. The model predicts emissions based, on the average speed of the vehicles, power of the and vehicles fuel consumption (Barth et al. 2004).

The only concern with these models is that these have been developed keeping in view the road conditions of developed nations like Europe and USA and require extensive datasets to estimate emission inventories. In developed countries, such datasets are available due to good number of regular studies but in developing countries like that in Asia and Africa, availability of such kind of informative datasets is very low and confined to only megacities. Hence these models couldn't be used in Indian conditions or they may wrongly estimate the the emissions. Thus, to overcome these limitations, a new model was developed that is actually a spreadsheet model. This model is known as VAPI(Vehicular Air Pollution Inventory) model created by (Nagpure and Gurjar 2012) . It is an excel spreadsheet model, which estimates on-road vehicle emissions for Indian cities. It is a type of emission model that is commonly used to provide traffic emission information for the prediction and management of air pollution levels near roadways. The best feature of the VAPI model is related to its simplicity with respect to requirements of data. Contrary to models developed in advanced countries that need exhaustive input datasets, the VAPI model considers country specific emission factors and requires only the types of data that are actually available in India. The term "emission factor" may be defined as the ratio of average amount of pollutant discharged to the total amount of the fuel used up(ARAI 2007). It is expressed in kg of particulates/metric ton of fuel. The proposed VAPI model is based on a simple approach incorporating emission factors and correction factors. This model can be used for estimating emissions for exhaust, evaporative and non-exhaust conditions in Indian cities. The temporal trend of emission estimates generated by the VAPI model depict reasonable agreement with ambient air concentrations monitored at locations significantly influenced by vehicular activity.

The basis of exhaust emission calculation process in VAPI model is to apply a base emission rate i.e., emission factor with geographical (e.g., altitude) and climatic (e.g., temperature, humidity) correction factors. It estimates the adjusted emission rate of pollutants for various vehicle categories by multiplying the basic emission rate with the correction factors such as Altitude, Temperature and Humidity. It estimates the emissions of various pollutants from different vehicle categories by adjusted emission rate, vehicle population and distance travel. Country based emission factors developed by ARAI (Automotive Research Association of India, Pune) have been used in VAPI model. Emission factors were developed using the existing condition of Indian vehicles. According to (ARAI (Automotive Research Association of India) 2007) , suggested emission factors were analyzed with regard to maintenance effect ,fuel effect, and model effect after the test. (ARAI (Automotive Research Association of India) 2007) has given emission factors for 40 vehicle categories and subcategories according to their model. Because it is difficult to get vehicle population data according to emissions factors, vehicle categories have been categorized according to possible data availability i.e., broad and fine category of vehicles. The model requires number of input datasets for the result generation such as registered vehicular number, yearly population, yearly GDP and per capita income, phasing out age of vehicles, annual mean temperature, humidity, and average vehicle kilometer travelled by the vehicle category. It takes ARAI suggested emission factors for vehicles as default emission factors and also works with user defined emission factors if they are available for a particular region or a city. For the future projection of vehicle emissions, VAPI uses econometrics model called Gompertz equation(Nagpure n.d.). The Gompertz equation needs vehicle population/1000 people saturation level to predict the future vehicle population. After feeding the required values in the model and using desired emission factors into it, it generates results for the yearly emissions of the prescribed pollutants for the various vehicle categories in the terms of Gigagrams or Megagrams and Kilograms depending upon the precision. The results obtained can then be used for the further analysis as per the objective of the study.
There are certain limitations of the proposed VAPI model(Nagpure and Gurjar 2012), for instance, Speed related correction factor is not used in the model. Model needs cumulative registered vehicle population for calculation. Only two climatic and one geographical correction factor is considered in the model. Less number of vehicle categories is available in the model, which restricts its use at the international level. If

vehicle population data are not provided in cumulative format then model might give erroneous results. After providing the cumulative vehicle population, model is able to calculate the on-road vehicle population and

their age wise composition in each time period for more accurate emissions calculation. For the risk assessment of the vehicular emissions either emissions or the corresponding ambient concentrations can be used but as a convenient case would be to use concentrations as a parameter because a number of assessment models or softwares make use of ambient concentrations for the evaluation of the prevalent risks and potential impacts on the subject of concern. Thus for the conversion of vehicular emissions, a number of models were considered that have been already used for the estimation of the pollutant concentrations in various studies. For instance, AERMOD model(Bhati et al. n.d.) , SIM-air modeling tool(Guttikunda 2010) , Markov Chain Monte Carlo Model(Almbauer and Sturm 2003) and Gaussian Plume model(Mathew V. Tom 2014) etc. But these models mainly work on air quality estimation due to plume emissions i.e point and area sources. Though in some studies they were also used for line sources i.e vehicle tail pipes, but that require altogether different data sets. Whereas, in (Kumar et al. 2011), an altogether different approach was tried which is that of a modified box model. The simplified model derived for a street canyon had been used for the deriving the ToN concentrations in megacity Delhi. Formulation of the box model assumes that the whole city acts as a control volume and that the air in the box is well mixed and uniform in concentration and there is a uniform wind velocity flowing along the *x*–direction, and an exchange wind velocity in the *z*–direction(Kumar et al. 2011).

It has been assumed that the city acts like a closed box of some width and extends up to the city mixing height and that there is background pollution being advected (vertically and horizontally) in and out of the box and that the vehicles in the box are the only uniformly distributed line source that generates *Q* (particle number flux) $cm^2\ s^{-1}$;also total particle numbers in the box are assumed to be conserved. Also, the removal due to deposition and gravitational settling are assumed to be negligible. This box model works on a mathematical equation that utilises number of parameters related to the dispersion scenario of the city or region under consideration to estimate the concentrations of the pollutants. This simplified model derived for a street canyon had already been used for the deriving the ToN concentrations in megacity Delhi. Parameters used by the model included: gaseous flux out of the city system(g/m^2 sec), Length of the city when whole city is considered a cuboidal box of some control volume (m), Mixing length of the city based on metrological data(m) and uniform wind velocity flowing along the *x*–direction (m/s). The final concentrations obtained by this model approach are in terms of $\mu g/m^3$.

2.4 IMPACT ASSESSMENT OF AMBIENT POLLUTANT CONCENTRATIONS

All the pollutants given out by traffic , industries , factories , thermal power plants and domestic fuel use have potential fatal impacts on human health and environment and evidence for this can be found in numerous studies done around the world(Guttikunda and Jawahar 2014; Kampa and Castanas n.d.; Maji et al. 2016; Miller et al. 2017; Pope and Dockery 1992; Ramachandra et al. 2015; Selden and Song 1994).

Major pollutants of the vehicular emissions are CO, PM10 and PM2.5, NOx, CO_2, hydrocarbons, benzene, PAHs, etc(Delphi 2013; Larsen 1966; Matsuo n.d.). Many researchers have tried to study the impacts of these major air pollutants. Most of the studies exist for PM10, PM2.5 , NOx and CO_2. Other pollutants individually dont prove to be harmful but in conjuction with other pollutants can be highly dangerous for instance, NOx , CO, VOC and PM during winters mixes with fog in the presence of sunlight to form photochemical smog, etc. Now, for the impact assessment of air pollution on human health in Indian cities, Ri-Map assessment tool is widely used and yields satisfactory results(Maji et al. 2016; Nagpure et al. 2010). A new software, AirQ+, developed by WHO is also widely used nowadays for the assessment of the human health impacts. Ri-Map assessment tool also works on the same principle that is the core of the AirQ+ software but they are still very distinct from each other owing to limitations and advantages.

Many studies have made use of the AirQ+ assessment tool(Johansson et al. n.d.; Mishra and Kumar 2017; Olstrup et al. n.d.; Pierpaolo 2016) for estimating the health impacts of the air pollutants. The AirQ+ software uses WHO specified input values of Relative Risk(R_r) values (per 10 μg/m^3 rise in concentration of hazardous pollutants) and corresponding baseline incidences (per 100000 population under observation) for different air pollutants like particulate matter(PM10), Ozone(O_3), Blackcarbon (BC), sulfur dioxide (SO_2), and nitrogen dioxide (NO_2), , etc., as well as types of diseases (e.g. cardiovascular, respiratory and chronic obstructive pulmonary diseases) associated with input concentration values(Maji et al. 2016). In epidemiology, the relative risk (R_R) is the probability of developing an illness caused by the exposure to various pollutants(Nagpure et al. 2010).
It can deal with the accompanying mortality and morbidity of various air pollutants like PM2.5, PM10, NO_2, O_3 and black carbon (BC) with software approaches to evaluate the impacts of long term and short term exposure in ambient or indoor air for the targeted population of a specific area. It works with logarithmical functions, statistical functions and matrix calculations (at least 40,000 matrix elements). AirQ+ is usefull for any region/city/country if pollution related health impacts are to be estimated. AirQ+ software tool is developed by World Health Organization (WHO), 18th May 2016 and it is a open sources software . There is some limitation, like other health risk assessment (HRA) tools, It considers ambient air pollution monitoring data as a proxy indicator of population exposure, AirQ+ calculations do not account for multiple exposure cases or multipollutant scenarios. And its morbidity estimates present low reliability due to difficult conformity in the assessment of health outcomes related to hospital admissions(Mishra and Kumar 2017).
For the environmental or ecological impact assessment, a good number of specific tools doesn’t exist but individual studies have been done incorporating the factors that might help in the evaluation in the potential impacts for the air pollution on the surrounding ecosystem. For example, critical loads have been estimated

for the deposition of polluting compounds or as well as acid deposition(Nagel 2004; Obbink et al. 2010; Stevenson et al. 2000; Sutton et al. 2014), and this has been done to compare them wid the existing deposited loads in the study areas or regions to quantify the difference and assess the gravity of risks.

CHAPTER 3 : AIM AND OBJECTIVES OF THE THESIS

From the presented case studies in the literarture review , one can decipher that several studies have alreay been done on the state of the air quality of the cities and related health and environmental impacts have also been estimated. But in all the whole discussion, it has been clealy stated that all these studies considered the total air quality which is the end result of several polluting sources that exist in the region under study and hence end impacts were estimated considering all of these factors. But this study focuses on only one major source of air pollution, i.e., Traffic emissions. Also their potential impacts are already known to the policy makers and thus they have formulated the regulatory policies in the name of **Vehicular Emissions Standards** that are designed and implemented by various nations across the world whether developed or in developing phase. But these standards are revised after regular interval of 4-5 years and new standards are brought about to tackle rising pollution owing to the sole reason of increasing vehicular count. Similiarly, in India we have Bharat Stage Emissions standards to beat the rising vehicular pollution which are revised over the years many times and this study actually evaluates the efficiency of these standards in combating the rising air pollution and hence human health , ecological and economic impacts are assessed to support the study. Such kind of studies are often carried in developed countries for assessing the efficiency of the adopted standards but the story is altogether different when developing nations are concerned. India is considered to be most polluting nation after USA and China. Many cities of India find place in the annual reports of the United Nations that are concerned with issues of air pollution for instance, Delhi, Mumbai, Kolkata, Chennai, Pune, etc. And these mentioned cities are the ones where these emissions standards were rolled out in priority phase but still these cities are counted among the polluting megacities of India. Obviously, other pollution sources are also responsible but traffic emissions is also one of them which cant be put aside simply because limiting standards already exist for vehicles. Thus in this study I have tried to analyse the impacts of vehicular emissions standards adopted by India and for the analysis the study region has been chosen as Delhi City.

The aim of this thesis work is to evaluate the health, environmental and economic impacts of the Bharat Stage Emissions standards in India with the following broad objectives.

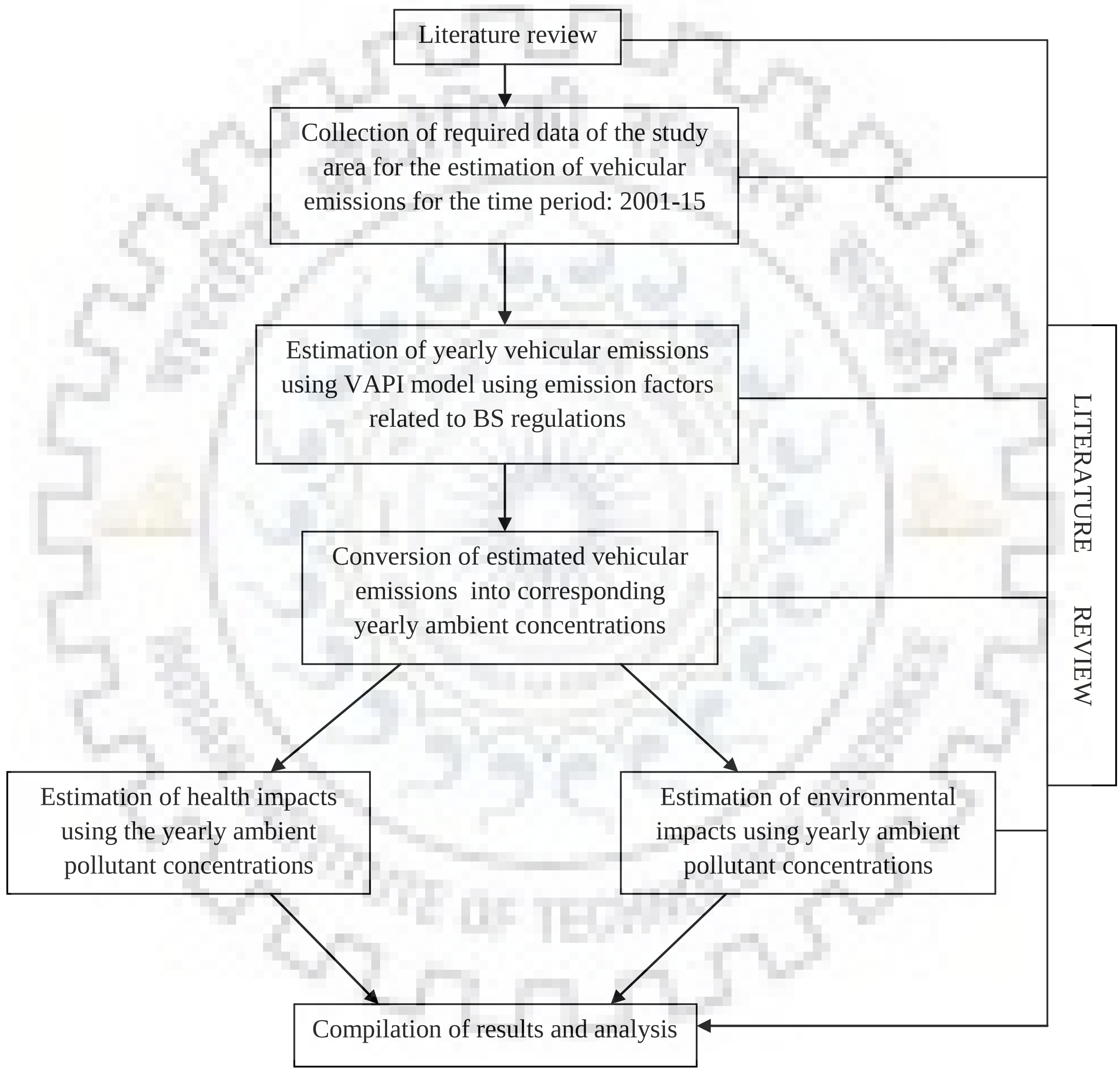
1. To analyse the impacts of the vehicular emissions standards BS-I to BS-IV adopted by India during the period 2001-2015 for the Delhi City region, in the following dimensions:
    - **Health impacts**: mortality and morbidity cases related to rising concentrations of regulated pollutants emitted ib vehicular emissions.

- **Environmental impacts**: pollutants deposition and acid deposition owing to the prevalent content of pollutants in the atmosphere. These include crop damage, rapid climate change, ground level ozone pollution, acid rain, eutrophication, etc.

- **Economic impacts**: Rising costs of vehicles, advancement of refineries, rising cost of cleaner fuel, etc.

2. To suggest possible solutions so as to curb the negative impacts.

CHAPTER 4 : METHODLOGY ADOPTED



CHAPTER 5: EMISSION INVENTORY AND DETERMINATION OF AMBIENT CONCENTRATIONS

❖ EMISSION INVENTORY

Vehicular exhaust emissions for Delhi city have been estimated using VAPI model for the time period of 2001-15. The Vehicular Air Pollution Emission Inventory (VAPI) model is a spreadsheet model that estimates the vehicular emissions for Indian cities(Nagpure and Gurjar 2012) using the following parameters:

1. Cumulative vehicle population for each year for different categories of the vehicles plying in the city.
2. Phasing out age of the vehicle categories.
3. Population of the city for the each year.
4. Yealy GDP and per capita income of the region.
5. Yearly recorded Humidity and mean temperature.
6. Vehicle kilometer travelled per day by each vehicle.

Before the initiation of feeding the data parameters in to the model, the model asks the user for emission factors to calculate the emissions for each year. ARAI(Automotive Research Association of India) provides the emission factors for each type of vehicle(CPCB 2011) (ARAI 2007). The emission factor is predominantly a function of vehicle technology used, quality of the fuel used and age of the vehicle. The VAPI model uses the emission factors provided by ARAI(CPCB 2011) (ARAI 2007) as default factors. Though provision has been made in the model to manually enter the emission factors different from the default ones in the factors spreadsheet. Although for the current research, only default factors have been used as incorporation of these emission factors can estimate the emissions for each year owing to their relativity to the Bharat stage standards implemented for vehicles.

Sources referred for input data values used in VAPI model for generation of vehicular emission inventory are provided below:

- ✓ ("Statistical Abstract of Delhi" 2016) provides cumulative category wise vehicle population for Delhi city for a period of 1991-2016.
- ✓ Economic survey of Delhi 2016-2017 provides population data for 2001-2015.
- ✓ Monthly mean temperature and humidity data was taken from Statistical Abstract of Delhi, 2016.

- ✓ GDP and per capita income values for the period 2001-2015 were taken from Economic survey of Delhi, 2016.
- ✓ Vehicle kilometer travelled by vehicles taken from (Nagpure and Gurjar 2012).
- ✓ Phasing out age of the vehicle categories taken from(Nagpure and Gurjar 2012).

Data values prescribed by the mentioned sources are entered as input values in the VAPI model and emission factors prescribed by ARAI were marked as default emission factors to be used for the output value generation. The model was run three times as vehicular emissions have been estimated for three seasons of Delhi i.e., winters , monsoon and summers, to assess any possible seasonal variation in the traffic emissions. This has been achieved by considering the mean temperature and humidity values on a seasonal basis. A particular season lasts for a set of months and the seasonal mean temperature and humidity is computed as the average of the meterological values of corresponding set of months for each season. Thus November-February, March-June and July-october set of months were considered for winters, summers and monsoon season respectively. Season-wise emissions are tabulated in the analysis portion of the air pollutants discussed in the report. Thus season-wise emissions loads are obtained for various pollutants in Gigagrams, Megagrams and Kilograms for the period 2001-2015. All of these are converted to one common unit i.e., Tonnes.

❖ **DETERMINATION OF POLLUTANT AMBIENT CONCENTRATIONS**

The emissions loads could not be utilized for risk and impact assessment as it is and thus needs to be converted into a more uniform form and thus they are finally converted into ambient concentrations. For this simplified box model initially derived for a street canyon and later modified for implementation in Delhi city(Kumar et al. 2011) has been incorporated. Formulation of the box model assumes that the whole city acts as a control volume and that the air in the box is well mixed and uniform in concentration and there is a uniform wind velocity flowing along the *x*–direction, and an exchange wind velocity in the *z*–direction(Kumar et al. 2011).

It has been assumed that the city acts like a closed box of some width and extends up to the city mixing height and that there is background pollution being advected (vertically and horizontally) in and out of the box and that the vehicles in the box are the only uniformly distributed line source that generates Q (particle number flux) $cm^2\ s^{-1}$. Also, the removal due to deposition and gravitational settling are assumed to be negligible. This box model works on a mathematical equation that utilises number of parameters related to the dispersion scenario of the city or region under consideration to estimate the concentrations of the pollutants. Parameters used by the model included: gaseous flux out of the city system(g/m^2 sec), Length of the city when whole city is considered a cuboidal box of some control volume (m), Mixing length of the city based on metrological data(m) and uniform wind velocity flowing along the *x*–direction (m/s). The final concentrations obtained by this model approach are in µg/m^3. The research paper makes use of the equation given below:

$$C = \frac{Q}{H_m \left[\frac{U_r}{L} \right]}$$

Here,

C = Concentration of the pollutant , g/m^3

Q = gaseous flux out of the city system , g/m^2 sec

L= Length of the city when whole city is considered a cuboidal box of some control volume, m

H_m = Mixing length of the city based on metrological data, m

U_r = uniform wind velocity flowing along the *x*–direction, m/s

Values of the above parameters have been referred from(Kumar et al. 2011)

Q = emission load in g/s per unit equivalent area of city , g/m^2 sec

Equivalent area of city= 1483 km^2

L= 47.53 km

H_m = 200.66 m

U_r = 2.14 m/s

After putting these values in the equation above we obtain a relation,

C= 0.0023667 X (Emission load in tonnes)

Thus all emissions loads were multiplied with the above computed factor to get annual ambient concentrations. The concentrations obtained are in the units of µg/m^3.

CHAPTER 6: IMPACT ANALYSIS OF NOX AMBIENT CONCENTRATIONS

In atmospheric chemistry, **NO_x** is a general term for the nitrogen oxides that are most relevant for air pollution, namely Nitrogen dioxide (NO_2), nitrous oxide (N_2O) and Nitric oxide (NO) (Obbink et al. 2010). These gases contribute to the formation of smog, acid rain, as well as tropospheric ozone. NO_x gases are generally formed from the reaction among oxygen and nitrogen during combustion of fuels, such as hydrocarbons in air; especially at high temperatures, such as those occuring in motor vehicle engines. The term NO_x is chemistry shorthand for molecules containing one nitrogen and one or more oxygen atom. It is generally meant to include nitrous oxide (N_2O), a fairly inert oxide of nitrogen that has many uses as an oxidizer for rockets to car engines, an anesthetic, to a propellant for aerosol sprays to whipped cream. Nitrous oxide plays hardly any role in air pollution, although it may have a significant impact on the ozone layer, and is a significant greenhouse gas.

In older, naturally aspirated diesel engines, nitrogen oxides were composed of approximately 95% of nitric oxide and almost around 5% of the Nitrogen dioxide. One of the NO sinks is the transformation of NO to NO_2 in the atmosphere(Yao et al. 2005). At low NO concentrations on the order of a few ppm which can be representative of exposures to engine emissions a good number of days may be required to achieve a significant level of conversion rate of NO_2. Further production of NO_2 occurs spontaneously albeit at a slower rate in the NO-air mixture after exhaust gases are discharged into the atmosphere. These conversions can be achieved through the any of the following reactions occurring in the atmosphere once these emissions are discharged into air:

$2NO + O_2 \rightarrow 2NO_2$

$NO + O_3 \rightarrow NO_2 + O$

$NO + HO_2 \rightarrow NO_2 + OH$

$NO + RO_2 \rightarrow NO_2 + RO$

The proportion of NO_2 in total NOx in turbocharged diesel engines (without aftertreatment) is typically higher, reaching up to about 15%. According to British data, the fraction of NO_2 in vehicle NOx emissions (all fuels) increased from around 5-7% in 1996 to 15-16% in 2009. But NO_2/NOx ratios of 70-80% are still possible at temperatures typical for diesel engine exhaust. The average NO_2/NOx ratio in US 2007 heavy-duty truck engines (with catalytic aftertreatment) tested and presented by the ACES study was 68%("CRC Report" 2009). NO_2 from diesel cars has increased from around 10-15% for Euro 3 and older technologies up to an average of almost 30% for Euro 4/5 technologies(Rhys-Tyler 2013). Furthermore, it is found that diesel cars emit increased emissions of NOx with increasing vehicle specific power for Euro 3 to Euro 5. It is also found that larger engine capacity (>2.0L) diesel cars emit more of their NOx in the form of NO_2; typically between 40% (Euro 3) to 60% (Euro 4/5) more (Rhys-Tyler 2013).

6.1 EMISSON INVENTORY AND PRELIMINARY ANALYSIS

The annual average vehicular emissions and ambient concentrations estimated by VAPI model for the period 2001-2015 have been tabulated here. These concentrations are generated on seasonal basis i.e summers, winters to monsoon as these 3 are the extreme climates faced by Delhi city each year.

Table -6.1: NOx annual average emissions(Tonnes) and ambient concentrations in winters

year	2W	3W	CARS	BUSES	GOODS VEHICLES	TOTAL EMISSIONS	AMBIENT CONC. (µg/m3)
2001	1374.03	687.61	12854.94	18974.31	21097.61	54988.51	130.14
2002	1896.64	748.20	13481.20	8413.10	16852.65	41391.80	97.96
2003	2482.01	827.64	14169.06	10453.97	17301.23	45233.92	107.06
2004	2649.62	881.85	13812.97	13871.52	18451.63	49667.60	117.55
2005	2915.51	973.49	14033.19	21506.08	19764.78	59193.04	140.09
2006	3343.60	924.40	14832.01	22736.51	19897.85	61734.37	146.11
2007	3889.89	887.57	15487.05	24722.79	20094.37	65081.68	154.03
2008	4462.32	1001.91	15999.09	24770.93	20378.28	66612.53	157.65
2009	4880.90	993.34	16909.94	27391.06	20740.92	70916.16	167.84
2010	5319.90	963.73	16930.89	32627.14	21054.20	76895.86	181.99
2011	5985.87	904.18	17377.81	35293.69	21443.48	81005.02	191.71
2012	6813.63	811.61	16776.48	22843.87	18303.86	65549.46	155.14
2013	7079.41	824.94	16694.99	27452.03	17280.09	69331.46	164.09
2014	7234.18	534.89	16102.52	21017.77	16287.25	61176.62	144.79
2015	7512.47	668.98	15836.25	26411.87	16911.45	67341.01	159.38
	5403.43	862.64	16089.11	26070.34	19286.96		

Table -6.2: NOx annual average emissions(Tonnes) and ambient concentrations in summers

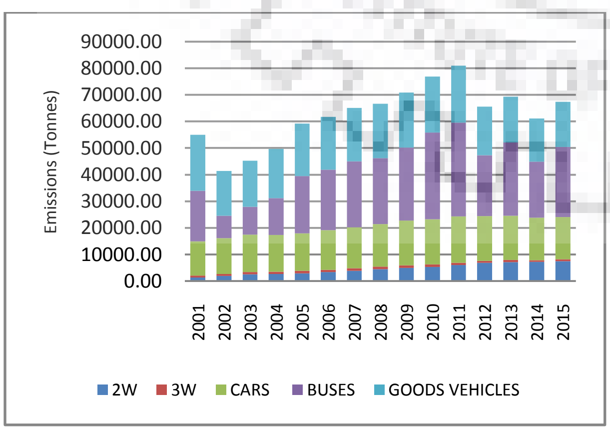
Year	2W	3W	CARS	BUSES	GOODS VEHICLES	TOTAL EMISSIONS	AMBIENT CONC. (µg/m3)
2001	2070.03	417.61	14447.94	20364.31	21097.61	58397.51	138.21
2002	2522.64	588.20	15011.20	10823.10	16852.65	45797.80	108.39
2003	2961.01	717.64	15339.06	12033.97	17301.23	48352.92	114.44
2004	3442.62	647.85	14712.97	15461.52	18451.63	52716.60	124.76
2005	3426.05	881.71	16363.70	23526.07	19764.78	63962.30	151.38
2006	3821.64	820.02	16971.74	24736.54	19897.85	66247.79	156.79
2007	4392.98	768.95	17929.86	26723.89	20094.37	69910.05	165.46
2008	4944.54	880.65	18129.32	26370.93	20378.28	70703.71	167.33

2009	5371.42	866.93	18858.16	30391.17	21040.92	76528.60	181.12
2010	5863.47	863.52	19302.30	34648.13	21654.20	82331.62	194.85
2011	6228.74	781.79	19949.42	37793.69	21443.48	86197.11	204.00
2012	7318.23	719.15	18109.81	23943.87	18503.86	68594.92	162.34
2013	7582.49	733.65	17520.50	29392.10	17280.09	72508.82	171.61
2014	7888.66	477.94	18026.56	23217.75	16287.25	65898.15	155.96
2015	8352.55	587.50	17393.31	27511.87	16911.45	70756.67	167.46

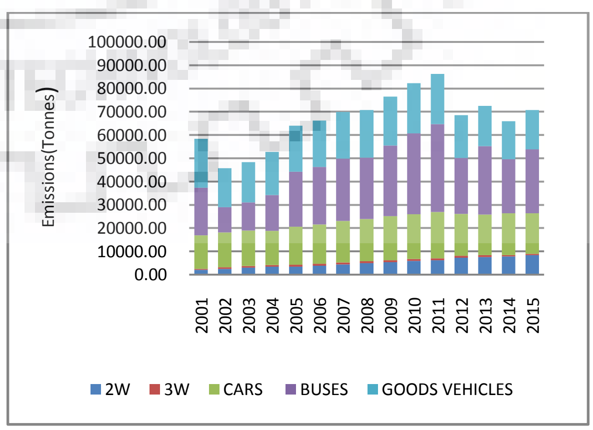
Table -6.3: NOx annual average emissions(Tonnes) and ambient concentrations in monsoon

Year	2W	3W	CARS	BUSES	GOODS VEHICLES	TOTAL EMISSIONS	AMBIENT CONC. (µg/m3)
2001	1255.03	368.61	11947.94	19854.31	21097.61	54523.51	129.04
2002	1843.64	524.20	13741.20	9113.10	16852.65	42074.80	99.58
2003	2160.01	653.64	12769.06	10963.97	17301.23	43847.92	103.77
2004	2831.62	608.85	11162.97	13851.52	18451.63	46906.60	111.01
2005	2726.05	775.40	13363.70	20526.07	19764.78	57155.99	135.27
2006	3230.64	741.35	13971.74	22736.54	19897.85	60578.12	143.37
2007	3692.98	708.33	14829.86	23723.89	20094.37	63049.42	149.22
2008	4142.54	807.64	15129.32	23370.93	20378.28	63828.70	151.06
2009	4671.42	786.01	15758.16	27391.17	20740.92	69347.68	164.13
2010	5161.57	768.60	16402.30	31648.13	21054.20	75034.80	177.58
2011	5519.74	720.13	16849.42	33793.69	21443.48	78326.45	185.38
2012	6518.33	648.02	15109.81	30376.19	18303.86	70956.21	167.93
2013	6882.49	671.03	16120.50	26392.10	17280.09	67346.20	159.39
2014	7178.56	444.40	15126.56	21217.75	16287.25	60254.52	142.60
2015	7560.55	551.18	15393.31	12430.86	16911.45	52847.34	125.07

❖ **Observations drawn from the above VAPI model generated data:**



(a)



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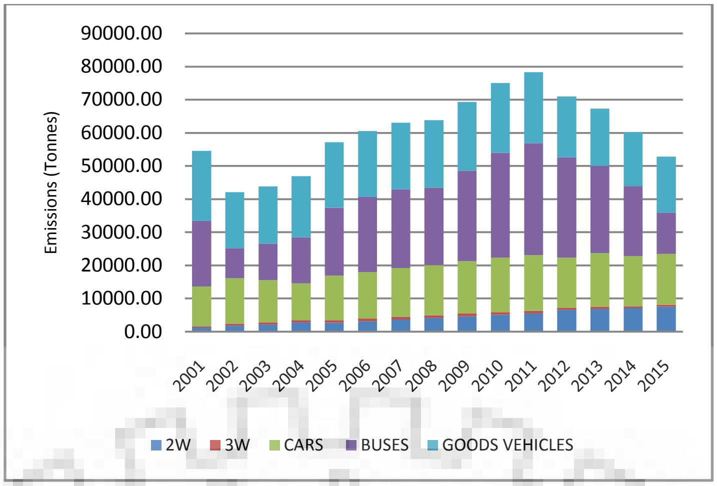


(c)

Fig-6.1: Estimated annual average emissions in tonnes for period 2001-2015 (a) winters (b)summers (c) monsoon

- **Buses have been the highest emitter of NOx gases but after 2011 their NOx emissions have reduced significantly.** Before 2001 buses were driven by diesel only most accessible means of cheap public transportation. Diesel had always been the fuel favoured by the government. It was first subsidized, than less taxed than gasoline. In 2000, despite the 1998 order of the Supreme Court order, the government still allowed 6000 new diesel buses to take up service(Product Life Institute n.d.). However due to rising levels of air pollution, rulings were passed by Supreme court to convert the diesel driven bus fleet to CNG driven. Eventually the reduction was observed when Delhi government's adherence to strict rulings of SC led to disappearance of diesel driven buses from the road to their subsequent replacement with CNG buses after 2002. Again in 2011 significant reduction in NOx content emission factor of buses was achieved when phasing out of old buses was carried out for Delhi city.
- **Three wheelers as well as cars have been consistent emitters of NOx gases and three-wheelers are the least emitters.** The after-treatment technologies for motorcycles are not as efficient as those for cars(Ana-Marija 2006) and comparison of mean unit emissions shows that motorcycles exceed cars in NOx emissions which is owing to the fact that gasoline-powered two wheelers and diesel run cars have been increasing with an alarming rate and two wheelers are exactly double the number of cars running in Delhi (see fig-6.2), whereas three wheelers have been running on CNG since 2000 and hence, are the least emitter of NOx gases.

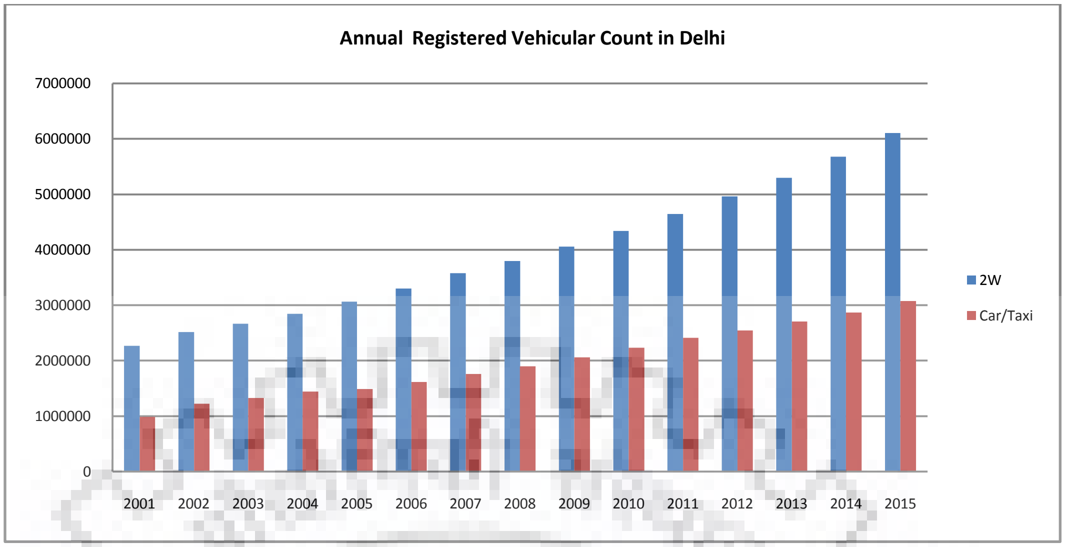


Fig-6.2: Registered number of two-wheelers to cars/taxis vehicular in Delhi (Source:Statistical Report of Delhi, 2016)

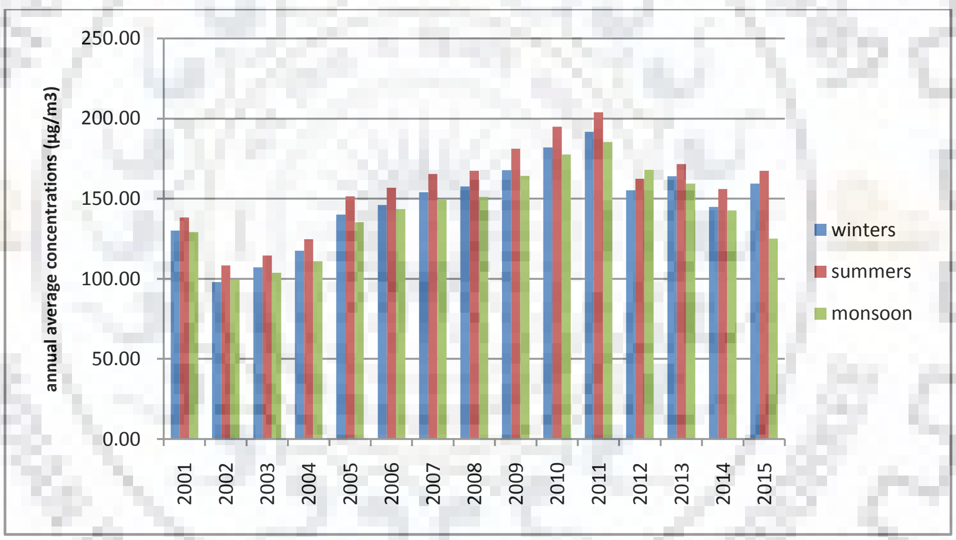


Fig-6.3: Estimated annual average NOx ambient concentrations for period 2001-2015

- **Inference 1**: Estimated NOx Concentrations for winters and monsoon do not seem to be much affected by climatic changes but concentrations in summers apparently have a wider gap than that of winter emissions implying that these are somehow affected by humidity and temperature conditions. It can be easily inferred that improved BS standards can be put in place to control the NOx emissions but climatic conditions still remains an influencing factor for the NOx vehicular emissions and these emissions increase with increase in temperature.
- **Inference 2**: Three BS standards have been rolled out during the period 2000-2010 but they failed to reduce the NOx concentrations by any amount as they have been on a rise

continuously and the only reduction witnessed in 2001 was due to removal of diesel buses from the Delhi roads after the Supreme court ruling. But that reduction was short lived and emissions continued rising. Only after the implementation of stringent BS IV standards in 2010 and phasing out of buses in 2012 leading to a decrease in the number of the buses brought out significant reductions in the NOx ambient concentrations and the decreasing trend has been since maintained.

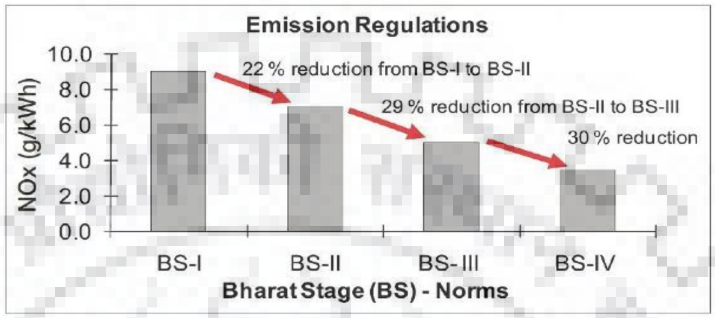


Fig-6.4: Emission regulations reduction through subsequent BS standards

6.2 HEALTH IMPACT ASSESSMENT

WHO AIRQ+ software has been used here to determine the health impacts of the NOx emissions on the human beings. But AirQ+ makes use of only NO_2 concentrations to estimate the casualties or cases of affected persons in a region. Thus NO_2 concentrations are estimated assuming the NO_2/NOx ratio to be around 40% for period 2001-2010 to 60% for period 2011-2015 for the Delhi region accordingly as per the discussion and facts stated in the introduction part. Since, it has already been stated that NO gets converted into NOx at a slow rate depending on the presence of other NO_2 precursors in the Delhi atmosphere, while only 15% of NO_2 is given out directly through vehicular emissions. With the estimated NO_2 concentrations for each year, health impacts due to its long-term exposure have been quantified as excess number of attributable cases which are estimated considering the threshold values for NO_2 ambient content to be 10 $\mu g/m^3$ which is the lowest level at which total mortality(all causes) have been shown to increase with more than 95% confidence in response to long-term exposure to NO_2(Mudu et al. 2016). The values in the *'Lower'* and *'Upper'* points correspond to the estimates calculated with, respectively, lower and upper confidence interval limits of the RR. The interval between the lower and upper values represents a part of the uncertainty associated with the estimation.

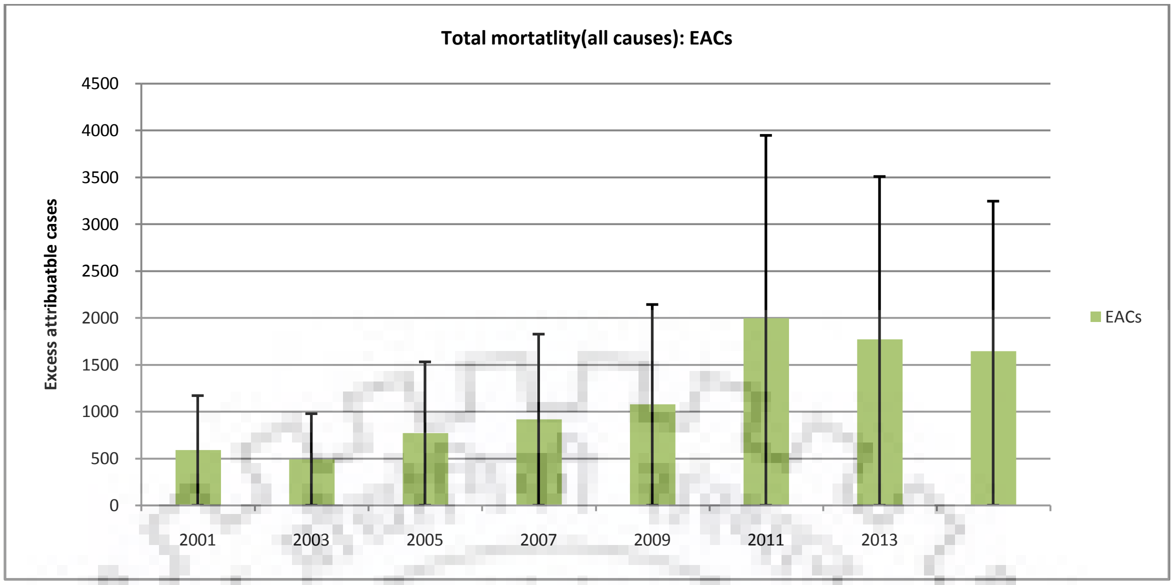


Fig-6.5: Bar-graph depicting excess number of attributable cases of mortatilty due to long term exposure of NO2 concentartions computed from WHO AirQ+ with central or close estimates shown by thick bars and thin vertical lines depict high and low estimates.

Inferences drawn

- The results above indicate that excess number of cases caused by long term exposure to NO_2 could have been "avoided" if concentration of NO_2 would not have exceeded 10 µg/m3, which happens to be the threshold recommendation by the WHO Air Quality Guidelines (2005). For example, the excess number of deaths due to long term exposure of NO_2 pollutant in the atmosphere estimated for the year 2015-2016 is1646(3300-0), whereas these EACs was only 919(1800-0) approximately just half of the EACs estimated for the year 2007-2008. All these EACs for the corresponding NO_2 ambient concentrations have been estimated from AirQ+, a WHO software, which considers 10 $\mu g/m^3$ as threshold value for NO_2 concentrations for causing any possible fatal impacts on human health.
- The trend-line for excess number of cases follows the variation of NO_2 emissions trendline implying that mortality cases are directly affected by any significant increase/decrease in the ambient NO_2 content. For instance , NO_2 emissions increased by 58.14% during the period 2003 to 2009 and corresponding to this estimated rise in ambient NO_2 , the estimated excess number of attributable cases rose by almost 20.57% for the period in consideration. Subsequently, when ambient NO_2 content reduced by 22.28% for the observed period 2011-2015, the corresponding fall in excess number of cases was computed to be around 17.57%.

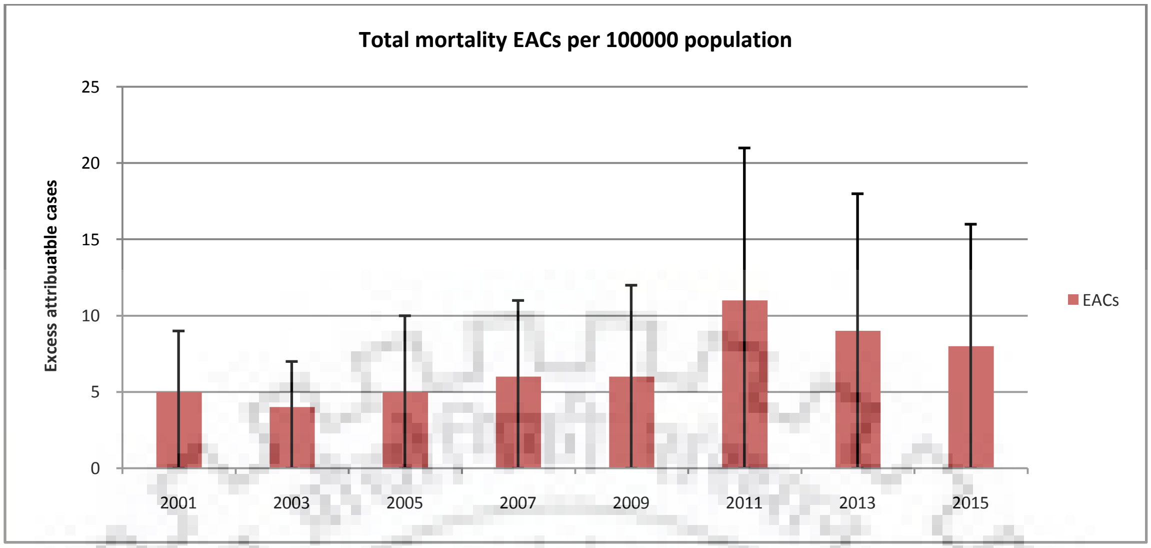


Fig-6.6: Bar-graph depicting incidence of total mortality per 100000 population due to long term exposure of NO_2 concentrations computed from WHO AirQ+ with central or close estimates shown by thick bars and thin vertical lines depict high and low estimates.

The bar-graph above depicts incidence of total mortality per 100000 population due to long term exposure of NO_2 concentrations computed from WHO AirQ+ where the incidence of mortality has reduced from 11(21-0) to 8(16-0) after the implementation of BS IV standards.

Discussion: The EACs estimated for 2011-2015 are much greater than that estimated during 2001-2010 and this unusual trend can be attributed to the fact that the percentage of NO_2 in the NOx emissions has risen significantly over the years thus making the residers more exposed to the toxic fumes of NO_2. Thus, it can be said that strict implementation of stringent steps aimed at controlling NOx emissions from the diesel vehicles that gives out less proportion of NO_2, can make a larger positive impact on the health and the lives of the Delhi residents. CPCB, the implementing agency for the BS standards is well aware of this fact as there have been several studies published highlighting the repercussions of the usage of diesel in vehicles(Borken-Kleefeld et al. n.d.; Chossière et al. 2017) and to restrict the emissions of the NOx revised BS standards have been rolled out and in subsequent standards effective reduction of NOx pollutants has been practiced.

The BS standards for NOx as prescribed by CPCB are as follows:

Table-6.4:Emission norms for passenger cars

Norms	HC+NOx
1991 norms	2.0(ONLY HC)

Table-6.5:Emission norms for Heavy Diesel vehicles

NORMS	NOx(g/kmhr)
1991 Norms	18

1996 norms	3.00-4.36
1998 norms	1.50-2.18
India stage 2000 norms	0.97
Bharat stage-II	0.50
Bharat stage-III	0.35
Bharat stage-IV	0.18

1996 Norms	14.4
India stage 2000 Norms	8.0
Bharat Stage-II	7.0
Bharat stage-III	5.0
Bharat stage-IV	3.5

Table-6.6: Emission norms for 2/3 wheelers

Norms	HC+NOx)(g/km)
1991 Norms	8-12(only HC)
1996 Norms	3.6
India stage 2000 norms	2.0
Bharat stage-II	1.5
Bharat stage-III	1.0

With each subsequent standard, stringent control has been established over the NOx emissions in vehicular exhaust so as to achieve possible reduction in the NOx ambient content.

Conclusion: Even though the vehicular exhaust emission limits have been made stricter in every subsequent phase , corresponding decrease in emission factors could not be achieved as evident from the vehicular emission trends. And this trend can be attributed to the rapidly increasing number of vehicles on the Delhi roads. Thus implementing strict emissions norms alone is not suffice to achieve the anticipated emission factors, instead vehicular count needs to be regulated in the city especially the number of two-wheelers to diesel run SUVs. An IIT Kanpur study has shown that diesel cars are 25% of total car fleet in Delhi**,** the SUV segment is the fastest growing to the most polluting segment in passenger vehicle category currently in India(ICAT 2017). Centre for Science to Environment has drawn attention to tests carried out in Delhi-NCR which show alarmingly high emissions from diesel cars to SUVs. The results show that adding one diesel SUV to the city fleet is equal to adding 25 to 65 small petrol cars in terms of nitrogen oxide emissions. Bharat Stage IV (BS-IV) diesel cars emit at least 1000 times more ultrafine particles than a BS-VI vehicle. While the future PM emissions norms under Euro V to Euro VI will close gap with the more stringent US emission standards, the NOx norms will continue to remain comparatively lax(CSE n.d.). This is because meeting equally stringent NOx to PM levels to tight fuel efficiency target present a difficult engineering challenge in diesel engines.

6.3 ENVIRONMENTAL IMPACT ASSESSMENT

Importance of green areas in urban or metro ecosystems has been widely acknowledged from time to time. Urban forests in the name of parks and gardens in Delhi have acquired an essential place in the dynamical ecosystem of the city. There are more than 18000 parks and gardens in national capital territory spread across 8000 ha in various locations throughout Delhi contributing towards environmental sanity(Tripathi and Joshi 2015). They play a vital role in controlling CO_2. As per data of ("Delhi Ridge" n.d.) the capital city of Delhi is sprawled across a dry deciduous forest known as Delhi Ridge, a part of the Aravalli hills, one of the earliest mountain systems of the world. This small forest tract has been termed as the 'green lung' for more than 12 million residers of Delhi and has played a crucial role in groundwater recharge, pollution absorption, and environmental amelioration. It is the lone natural forest in Delhi that boasts a wide variety of plant, birds, animals, other tiny organisms and insect species. Delhi receives an rainfall ranging between 600-800 mm annually on an average. The soil in this part of the city is mostly alluvial and fertile in nature. Vegetation of Delhi is thorny scrub, a peculiarity of semi-arid and arid region. Nitrogen is the nutrient required in the greatest quantity by plants and its availability in soil is also frequently the limiting factor for vegetation growth(Stevenson et al. 2000). However, although appropriate amount of nitrogen can enhance plant growth (potentially desirable), it can also induce undesirable alterations in the competitive relationship of species. This can reduce biodiversity to enhance the susceptibility of plants to secondary stress factors. Deposited loads of acidity and nitrogen can be attributed most closely to annual average ambient concentrations of sulphur and nitrogen contents in air. Enhanced nutrient supply to an natural ecosystem may result via foliar uptake of nitrogen oxides, nitric acid and ammonia, and via wet and dry deposition of nitrates, nitrites and ammonia to soils (Stevenson et al. 2000). Further, plant uptake of nitrogen species from soil, denitrification, and immobilisation in soil organic matter may remove the acidification that would otherwise occur from ammonia or nitric acid deposition (Nagel 2004).

Nitrogen omitted from the ecosystem in harvesting helps preventing potential acidification, but if any nitrogen is left in the system, unless its removal by denitrification, will subsequently oxidise and leads to acidification(Obbink et al. 2010). Cycling of nitrogen within ecosystems is almost exclusively carried out by biological processes. These are affected by a variety of environmental factors that can lead to, or mask, potentially negative effects. Therefore, although there is direct study based evidence that nitrogen deposition is influencing semi-natural ecosystems, particularly in Europe, it is difficult to assess the scale and gravity of the effects, to determine the impact mechanisms. If the ambient air concentrations suggest that there may be problems from acid deposition or nitrogen enrichment, further investigations may be required, such as measuring actual deposition rates to soil acid neutralising capacity(Stevenson et al. 2000).

Estimates of dry deposition of nitric acid , nitrogen oxides, and ammonia can be obtained from their annual average concentrations and typical dry deposition velocities("Dry Atmospheric Deposition" n.d.). The research of dry deposition processes has been stimulated by the acid rain problem in the USA, Europe and Asia(Sutton et al. 2014). Ambient concentrations of nitrogen species gets deposited as acid loadings as well as nitrogen loadings and their corresponding estimation can be done in the following ways:

- **Method for Estimation of acid deposition loadings:** Nitrogen omitted from the ecosystem in harvesting helps preventing potential acidification, but if any nitrogen is left in the system, unless its removal by denitrification, will subsequently oxidise and leads to acidification(Obbink et al. 2010). Natural fixation of nitrogen can also induce acidification by raising the nitrogen pool, although fixation itself is a neutral process with regard to acidification. Based on typical literature values for deposition velocities, Table below sets out approximate estimates of the maximum rates of acidity deposition via dry deposition for concentrations of 1 $\mu g/m^3$ of the various nitrogen species in air. In accordance with European practice, the rates of deposition of nitric oxide are considered to be negligibly slow.

Table 6.7: Annual acid deposition estimates for 1 $\mu g/m^3$ concentrations of pollutants in ambient air

	Typical dry deposition Velocity cm/sec	Dry gaseous	Wet deposition
		Equivalents/ha-yr	
NO_2	0.36	25	nil
HNO_3	2	100	75
NH_3	2	370	400

The acid deposition rates are calculated by multiplying the annual average concentrations by the factors from Table 6.7 for each species. This method, which ultimately requires multiplying the ambient concentrations by the modelled dry deposition velocities, is called the inferential technique(Sutton et al. 2014). The critical load of nitrogen acidity is defined by (Nagel 2004) "*The highest deposition of acidifying compounds that will not cause chemical changes leading to harmful effects on ecosystem structure to function*".

- **Method for Estimation of nitrogen loadings:** When the supply of other nutrients and climate allow, biomass accumulation can happen in response to increased availability of nitrogen from moderate increases in NOx and ammonia ambient concentrations. The deposition of nitrogen may have an adverse eutrophication effect at an individual plant and community level. Plant growth stops when these nutrient levels acquire physiological threshold values, at threshold points which differ for different species. It has also been suggested that changes to air borne nitrogen deposition may also influence the biomass allocation between roots and shoots. Increases in the shoot (transpiration surfaces): root (water uptake) ratio reduce plant resistance to drought stresses(Obbink et al. 2010). Reduced mycorrhizal infection is also linked to high nitrogen deposition that is important in nutrient-poor soil, since these infections are beneficial to acquisition of phosphorous by plant(Obbink et al. 2010). The estimates of acidity deposition from nitrogen dioxide, nitric acid and ammonia presented in Table 6.7 can be converted into nitrogen deposition rates for comparison with critical loads of nitrogen, as set out in Table 6.8. These loadings assume that none of the nitrogen is removed by denitrification, harvesting, or other relevant processes.

Table 6.8: Annual nitrogen deposition estimates for 1 $\mu g/m^3$ concentrations of pollutants in ambient air

	Typical dry deposition Velocity cm/sec	Dry gaseous	Wet deposition
		kg N/ha-yr	
NO_2	0.36	0.3	nil
HNO_3	2	1.4	1.1
NH_3	2	5	3

The critical load of nitrogen was defined at the UNECE Skokjlster Critical Loads Workshop as to be *"A quantitative estimate of an exposure and deposition of nitrogen as NHx and/or NOy below which harmful effects in the ecosystem structure to function do not occur according to present knowledge"* (Nagel 2004). The total nitrogen deposition critical loads are defined in relationship to their eutrophication effect on plants and ecosystems. Critical loads are intended to be a simplified to general guideline for a range of sensitive European ecosystems. The acid accumulation and nitrogen deposition loadings obtained through above two methodologies can be compared with critical loads prescribed by UNECE and WHO(Obbink et al. 2010; Stevenson et al. 2000) collectively to estimate impacts of NOx ambient concentrations on the ecology.

- **Estimation of Acid Deposition loadings and Nitrogen Deposition loadings from computed NOx ambient concentrations:**

As has been discussed in the methods for acid deposition loadings and nitrogen deposition loadings, the values for acid and nitrogen loads have been estimated in the table-6.9, which can then be compared with critical loads prescribed by UNECE and WHO to draw relevance for potential ecological impacts on ecosystems of Delhi region.

Table-6.9: Computed acid deposition loads and Nitrogen deposition loads corresponding to NO_2 ambient concentrations

Year	NO_2 Ambient conc. (µg/m3)	Acid deposition loads (Eq /ha-yr)	Nitrogen deposition loads (kg N/ha-yr)
2001	52.986	1324.638	15.896
2002	40.791	1019.767	12.237
2003	43.369	1084.223	13.011
2004	47.110	1177.755	14.133
2005	56.899	1422.476	17.070
2006	59.502	1487.552	17.851
2007	62.494	1562.347	18.748
2008	63.473	1586.832	19.042
2009	68.41	1710.28	20.52
2010	73.92	1848.10	22.18
2011	116.22	2905.46	34.87
2012	97.08	2427.06	29.12
2013	99.02	2475.41	29.70
2014	88.67	2216.76	26.60
2015	90.38	2259.55	27.11

NO_2 ambient annual average concentrations generated indirectly from VAPI model have been utilized here. The acid deposition rates are calculated by multiplying the annual average concentrations by the factors from Table 6.7 for NO_2 species. This method, which ultimately requires multiplying the ambient concentrations by the modeled dry deposition velocities, is called the inferential technique(Sutton et al. 2014). Similiarly, nitrogen deposition rates are calculated by multiplying the annual average concentrations by the factors from Table 6.8 for NO_2 species.

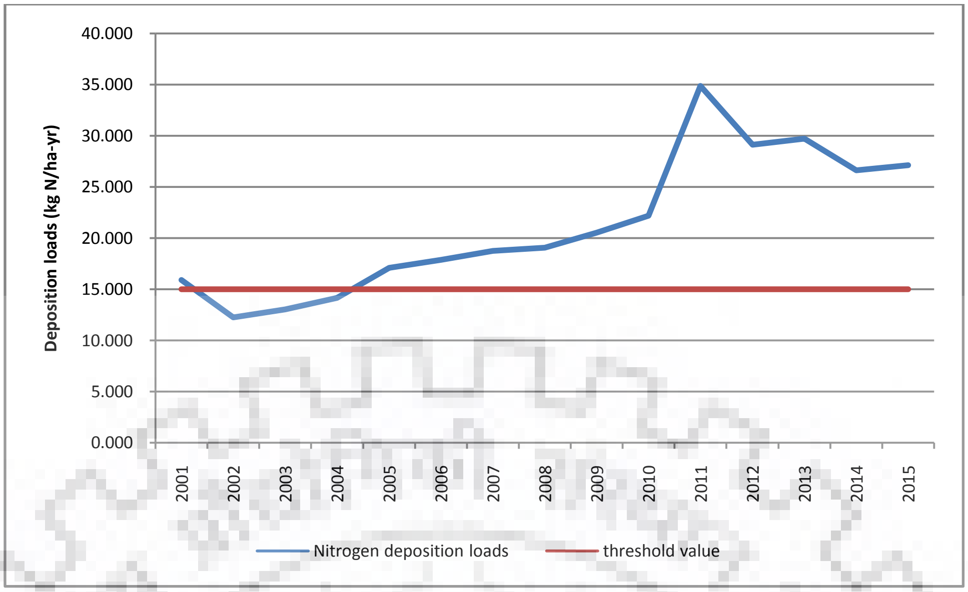


Fig-6.7: graphical representation of the rising trend of deposition loads and the threshold values

Results and discussion: The threshold values for nitrogen deposition rates for deciduous trees and deciduous forest ecosystems prescribed by UNECE and WHO vary from 15-20 kg N/ha-yr and 10-20 kg N/ha-yr respectively(Stevenson et al. 2000). If these threshold values are exceeded by any means, then potential impacts can vary from nutrient imbalance; increase shoot/root ratio and changes in ground flora. The estimated average levels of nitrogen deposition loads have been around 15-35 kg N/ha-yr, almost double the threshold limits, implying possible potential impacts on the forest ecosystems of capital city region with repurcursions ranging from nutrient imbalance, increased shoot-root ratio and changes in ground flora. Increases in the shoot (transpiration surfaces): root (water uptake) ratio reduce plant resistance to drought stresses.

CHAPTER 7: IMPACT ANALYSIS OF PARTICULATE MATTER AMBIENT CONCENTRATIONS

7.1 EMISSION INVENTORY AND PRELIMINARY ANALYSIS

Particulate matter, perhaps the most characteristic of diesel emissions, is responsible for the black smoke traditionally associated with diesel powered vehicles. The diesel particulate matter emission is usually abbreviated as PM or DPM, the latter acronym being more common in occupational health applications. A very complex aerosol system is formed by diesel particulates. The existing medical research suggests that PM is one of the major harmful emissions produced by diesel engines. Worldwide diesel particulates(Kittelson 1998) are controlled by diesel emission regulations and, along with NOx, have beeen the focus of diesel emission control technology. Mechanically generated non-exhaust PM from road traffic comes from abrasion of brake, tyre, road pavement and by the re-suspension process of road dust while traffic run on the roads(Amato et al. 2014). Various researchers have suggested that non-exhaust emissions are dominant contributor to total PM10 and PM2.5 emissions from road transportation(Kumar et al. 2014).

- **EMISSION INVENTORY FOR VEHICULAR EXHAUST PM EMISSIONS**

  VAPI model estimates the PM emissions due to vehicular exhaust mechanisms which have been tabulated here. These emissions have been generated on seasonal basis for capital city i.e. winters, summers and monsoon as these are termed as the extreme climate seasons there. PM emissions generated on seasonal basis are found to be same.

Table -7.1: PM annual average emissions and ambient concentrations

year	2W	3W	CARS	BUSES	GOODS VEHICLES	TOTAL EMISSIONS	AMBIENT CONC. (µg/m3)
2001	2495.96	1025.12	741.96	3816.17	2936.16	11015.38	26.07
2002	2684.95	988.52	810.70	4036.17	3274.62	11794.96	27.92
2003	2965.50	965.91	856.66	4362.27	3456.23	12606.57	29.84
2004	3278.17	909.47	958.66	3946.16	3795.16	12887.61	30.50
2005	3566.40	878.99	1075.65	3685.76	3551.95	12758.75	30.20
2006	3769.18	838.97	1158.75	3296.58	3571.02	12634.51	29.90
2007	3974.27	780.09	1254.11	3036.56	3599.17	12644.20	29.93
2008	4093.85	744.68	1349.54	2962.19	3639.83	12790.08	30.27
2009	4249.24	684.49	1418.36	3227.03	3691.78	13270.90	31.41
2010	4429.84	618.42	1562.85	3293.50	3736.65	13641.26	32.28
2011	4615.23	542.77	1684.57	3574.78	3792.41	14209.75	33.63
2012	4807.01	459.68	1920.96	2769.97	3257.97	13215.60	31.28
2013	5025.28	394.58	2031.80	2435.10	3049.65	12936.40	30.62
2014	5289.55	277.30	2147.16	2295.05	2852.76	12861.82	30.44
2015	5587.07	222.13	2283.63	2052.78	2846.14	12991.75	30.75

Results and inferences drawn from the above VAPI model generated data:

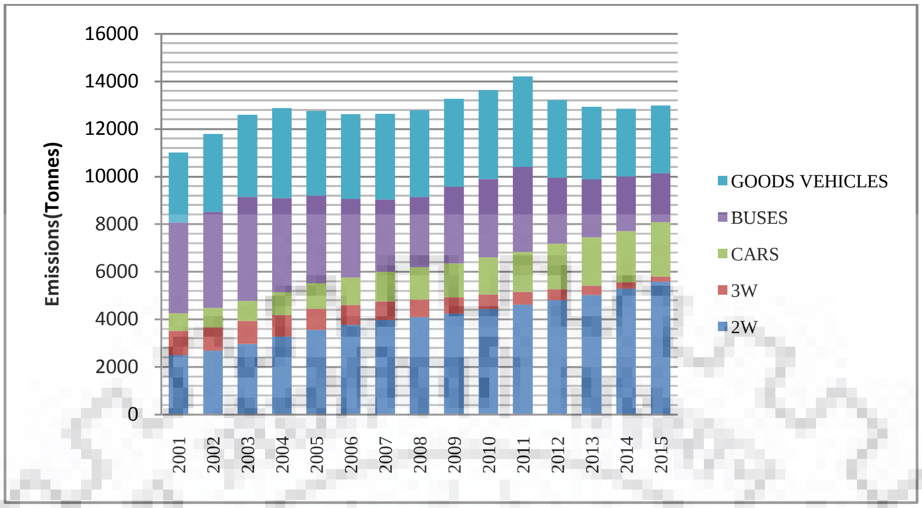


Fig-7.1: Estimated annual average PM vehicular emissions from the vehicle categories

- **Evidently, two wheelers have been emitting great quantities of particulate matter in the atmosphere and same trend has been continuing over the observed time period**. See fig-7.1, Cars and taxis are also contributing to the PM ambient content but there is huge difference of approximately 3000 tonnes/yr and that difference has been maintained over the years even though the number of two wheelers has almost doubled the number of cars/taxis during the time period. Two wheelers have been emitting high concentrations of PM due to the lack of proper regulation norms for PM control in two wheelers engines. CPCB has prescribed the regulatory norms for all relevant vehicular exhaust pollutants for all vehicle categories but the vehicular exhaust PM norms don't exist for two wheelers(see Table 7.4) and hence their concentrations has been rising in an uncontrolled manner as has been depicted through the emissions trend-graph. Similiarly, PM regulation limits (see Table 7.2) don't even exist for cars/taxis. With Two wheelers and car/taxi numbers rising at a rapid rate (see Fig-7.2) and with no emission control norms at place , they are contributing large PM emission contents to the atmosphere. Buses used to be the major emitter of PM(for years 2001-2003) but with the replacement of diesel buses with CNG ones, PM emissions have almost reduced to half (2013-2015) of the earlier emissions.

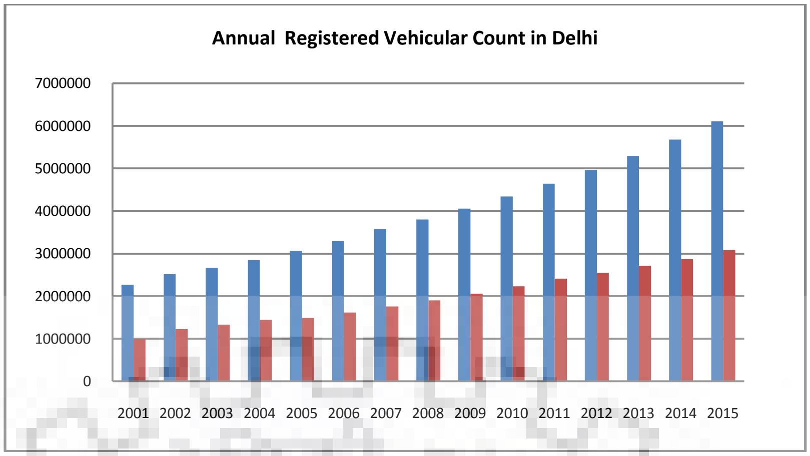


Fig-7.2: Annual registered number of two-wheelers and cars/taxis vehicular in Delhi

Table-A: Emission norms for passenger cars

Norms	CO	HC+NOx
1991 norms	14.3-27.1	2.0(ONLY HC)
1996 norms	8.68-12.40	3.00-4.36
1998 norms	4.34-6.20	1.50-2.18
India stage 2000 norms	2.72	0.97
Bharat stage-II	2.2	0.5
Bharat stage-III	2.3	0.35
Bharat stage-IV	1.0	0.18

Table-B: Emission norms for Heavy Diesel vehicles

NORMS	CO(g/kmhr)	HC(g/kmhr)	NOx(g/kmhr)	PM(g/kmhr)
1991 Norms	14	3.5	18	-
1996 Norms	11.2	2.4	14.4	-
India stage 2000 Norms	4.5	1.1	8.0	0.36
Bharat Stage-II	4.0	1.1	7.0	0.15
Bharat stage-III	2.1	1.6	5.0	0.10
Bharat stage-IV	1.5	0.96	3.5	0.02

Table-C: Emission norms for 2/3 wheelers

Norms	CO(g/km)	HC+NOx(g/km)
1991 Norms	12-30	8-12(only HC)
1996 Norms	4.5	3.6
India stage 2000 norms	2.0	2.0
Bharat stage-II	1.6	1.5
Bharat stage-III	1.0	1.0

- **Three wheelers are the least emitter** owing to the fact that they have been running on CNG and with increasing cars, taxis and metro transport, their number has been depleting over the years, thus helping in reducing the particulate matter emissions. PM emissions have reduced significantly over the years due to replacement of diesel run buses with CNG driven buses and phasing out of old heavy goods vehicles in the capital region. Simultaneously, BS standards have reduced the PM limits by almost 94%(see Table-2) while reforming from BS-I to BS-IV.

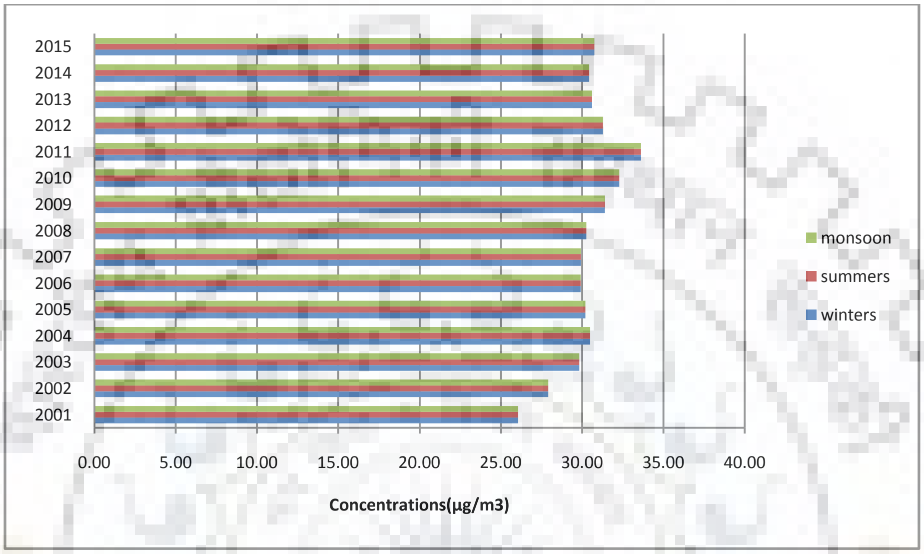


Fig-7.3: Annual average vehicular exhaust PM ambient concentrations trend graph for three seasons of Capital city

- **Inference 1**: (see fig-7.3) Concentrations are not at all affected by climatic changes. Hence, it can be inferred that improved BS standards can be put in place to control the PM emissions as climatic conditions are not a governing factor for these vehicular emissions.

- **Inference 2:** (see fig-7.3) Vehicular exhaust PM emissions have almost been stagnant during the study period as not much change has occurred in the PM ambient concentrations generated collectively from all vehicles plying on the Delhi roads except for year (2009-2011). PM regulation limits exist only for diesel-run heavy vehicles rather than for all vehicle categories as diesel is considered to be an major after-combustion-source of PM content, thus cars/taxis, two-wheelers which have proved to be ever emitting source of particulate matter for the Delhi region. Even after non-existence of compulsory emission norms for other vehicle category, PM ambient concentrations don't amount upto a significant figureas much lower, "near-zero" levels of pollutants are emitted from modern diesel engines(W. Addy Majewski n.d.) equipped with emission after-treatment devices such as NOx reduction catalysts and particulate filters.

- **Inference 3:** Although PM ambient concentrations have not shown any significant increase over the period of 2001-2015, but with ever rising cars and two wheelers, this figure wont remain constant for long and very soon in coming years , vehicular exhaust PM concentrations can become a significant contributor of total PM ambient content which is actually been sourced majorly from non-vehicular exhaust. In several European countries a large part (about 50–85%) of the total traffic PM10 emissions originates from non-exhaust sources. Moreover the lack of abatement measures for non-exhaust emissions has led to their increasing contribution to the PM airshed(Amato et al. 2014).

❖ **EMISSION INVENTORY FOR VEHICULAR NON-EXHAUST PM EMISSIONS**

Mechanically generated non-exhaust PM from road traffic comes from abrasion of brake, tyre, road pavement and by the re-suspension process of road dust while traffic run on the. Brake and tyre wear are an significant source of trace metals in the urban environment, and at locations highly affected by traffic emissions can be more prevalent than through industrial emissions(Alistair Thorpe and Roy M. Harrison 2008). VAPI model estimates of PM2.5 and PM10 emissions due to vehicular non-exhaust mechanisms have been tabulated here in Table-7.3 and Table-7.2 respectively.

Table-7.2: PM10 non-exhaust total annual emissions and ambient concentrations

	2W	3W	CARS	BUSES	GOODS VEHICLES	TOTAL EMISSIONS	AMBIENT CONC. (µg/m3)
2001	4736.231	315.12	3597.16	3726.164237	4528.654	16903.34	40.00512784
2002	5214.631	285.22	4197.16	3946.126492	4846.953	18490.10	43.76051712
2003	5523.968	236.33	4826.46	4298.694237	5196.463	20081.91	47.52786123
2004	6135.236	225.43	5325.37	4025.463297	5569.643	21281.14	50.36606769
2005	6561.857	218.15	6025.25	3893.469363	5325.665	22024.40	52.12513636
2006	7080.708	211.02	6536.80	3660.56639	5596.085	23085.17	54.63568213
2007	7714.219	206.82	7123.80	3729.945348	5995.427	24770.21	58.62365503
2008	8137.049	247.83	7711.22	3733.148634	6572.336	26401.59	62.48463877
2009	8660.209	251.26	8134.87	4196.94534	7309.244	28552.53	67.57526848
2010	9257.21	249.07	9024.29	4441.903285	7945.851	30918.33	73.17440146
2011	9876.532	236.11	9773.52	4923.465999	8736.89	33546.52	79.39454561
2012	10522.97	214.23	10552.73	2435.001589	4173.133	27898.07	66.02635276
2013	11195.22	230.27	11086.22	2287.746267	4648.654	29448.11	69.69483182
2014	11993.65	153.48	11634.82	2348.406218	4783.834	30914.18	70.79789701
2015	12886.25	199.95	12299.51	2289.112651	10478.88	38153.70	90.29836279

Table-7.3: PM2.5 non-exhaust annual average total annual emissions and ambient concentrations

	2W	3W	CARS	BUSES	GOODS VEHICLES	TOTAL EMISSIONS	AMBIENT CONC. (µg/m3)
2001	142.94	12.71033	174.9617	128.8621	212.1506	671.63	1.590
2002	188.52	9.854632	200.1634	93.46636	158.1855	650.19	1.539
2003	256.82	10.59649	248.7466	116.7467	173.8251	806.74	1.909
2004	294.65	11.62245	283.5694	128.5325	180.6315	899.01	2.128
2005	327.21	11.03571	301.4247	140.3696	192.0039	972.04	2.301
2006	353.08	10.67477	327.0157	131.9728	201.7533	1024.50	2.425
2007	384.67	10.4623	356.3816	134.4741	216.1506	1102.14	2.608
2008	405.76	12.53726	385.7684	134.5896	236.9496	1175.60	2.782
2009	431.84	12.71033	406.9625	151.3107	263.5171	1266.34	2.997
2010	461.61	12.59977	451.4573	160.142	286.4684	1372.28	3.248
2011	492.50	11.94432	488.9387	177.5036	314.9874	1485.87	3.517
2012	524.73	10.83708	527.9204	87.78807	150.4522	1301.73	3.081
2013	558.25	11.64854	554.6092	82.47914	167.5959	1374.58	3.253
2014	598.07	7.763884	582.0539	48.61351	172.4695	1408.97	3.335
2015	642.58	10.11496	615.3064	82.5284	377.7906	1728.32	4.090

RESULTS AND DISCUSSION

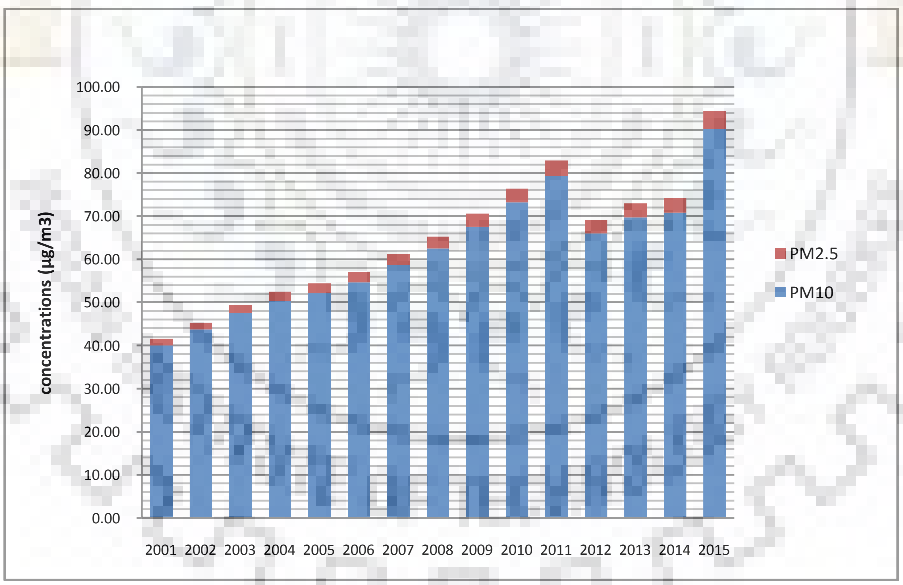


Fig-7.4: Bar graph depicting annual average non-exhaust PM10 and PM2.5 concentrations

Inference: Clearly, it can be inferred(see Fig-7.4) that non-exhaust vehicular PM2.5 emissions are extremely low as compared to PM10 non-exhaust vehicular emissions. Also, these PM10 values are greater than total particulate matter emitted by vehicles through vehicular exhaust. Thus, it can be stated that non-vehicular exhaust PM emissions are more fatal and need to be controlled strictly as they are much more in concentration as compared to vehicular exhaust PM10 which has been already highlighted in many studies (Alistair Thorpe and Roy M. Harrison 2008; Amato et al. 2014; Hooftman et al. 2016; Kittelson 1998). The results generated presented here also depict the similar picture, for instance, annual average vehicular exhaust PM concentrations for the time period 2001-2015 are have not exceeded the limit of 35 µg/m3 whereas the PM10 ambient concentrations are clearly about to exceed 100 µg/m3 with time and there is a high probability for that to happen as no control limits exist for non-exhaust PM emissions(Alistair Thorpe and Roy M. Harrison 2008) since as of yet no mechanism exists to reduce their production and hence are accumulating due to rapidly increasing population of vehicles in Delhi region.

VAPI model generates PM ambient concentrations emitted in the atmosphere through the vehicular exhaust but it does not demarcates them separately as PM10 and PM2.5, i.e. they are calculated as a combined concentration value. But for further impact assessment of PM concentrations we need separate values for PM10 and PM2.5 thus after going through various studies relevant to vehicular exhaust borne particulate matter characterization, PM2.5/PM mass ratio for vehicular exhaust has been assumed to be 0.72(Das et al. 2006) for this case study. Thus, this factor can be used for bifurcating the PM10 and PM2.5 emissions from the combined tail-pipe exhaust generated PM emissions generated by VAPI model, which can in turn be used for projecting health and environmental impacts of PM.

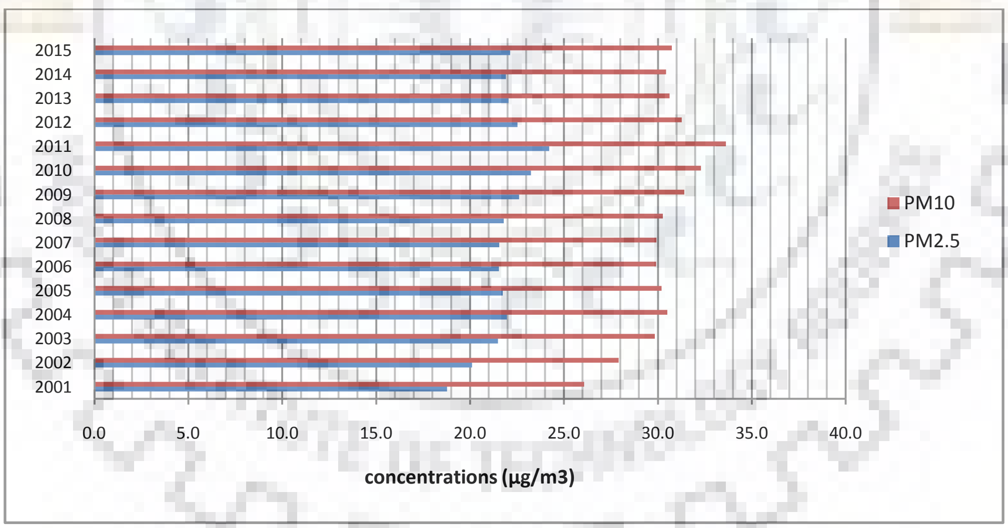


Fig-7.5: Bar graph depicting annual average exhaust PM10 and PM2.5 concentrations

Using the above bifurcation factor, PM10 and PM2.5 ambient concentrations due to vehicular exhaust have been finally obtained and these have been depicted in the graph above i.e, Fig-7.5. These PM10 and PM2.5 values are combined together with PM10 and PM2.5 values generated for non-vehicular exhaust mechanisms of vehicles. The net values are then used for impact assessment of particulate matter on health and environment.

7.2 HEALTH IMPACT ASSESSMENT

WHO AIRQ+ software has been used here to determine the health impacts of the PM emissions on the human beings. Net concentrations PM10 and PM2.5 produced from vehicles together through combustion process and non-exhaust mechanisms are fed into the AirQ+ software to generate results for the estimated number of attributable cases for associated mortality and morbidity related to PM10 andPM2.5 long-term exposure.

- **Methodology:** The model computes average relative risk estimates along with lower and upper limits (i.e. range) for the 95% confidence interval. In each of the subsequent figures, solid color bars show estimated values of excess number of cases and thin vertical lines show their lower and upper limits i.e. range for the 95% confidence interval.

- **Health impact assessment for long-term exposure of PM2.5:** Under this, mortality and morbidity cases are estimated owing to long-term exposure of ambient concentrations of PM2.5 which are the combined values for vehicular exhaust and non-exhaust vehicular pollution. For the estimation of health risks, 10 $\mu g/m^3$ has been considered as the cut-off or the threshold value as this is the lowest level at which total, cardiopulmonary and respiratory mortality have been shown to increase with more than 95% confidence in response to long-term exposure to PM2.5 and the impacts of exposure exceeding this concentration are calculated by the program. Following health issues have been dealt with while doing estimation of excess number of attributable cases for the various age groups of Delhi.

  - **Adult mortality due to Lung Cancer:** The Global Burden of Disease estimates ranks pollution as the fifth largest killer in India. Estimates of the respiratory mortality show India to rank second among the countries globally affected by $PM_{2.5}$ and O_3 pollution. It is anticipated that recent upward trends in industrial and energy sectors transportation, migration and urban settling, population growth in India along with climate change will raise the levels of O_3 and $PM_{2.5}$ in the future, which could worsen the vulnerability of a growing population. Impact assessment for cancer mortality has been done for adults aging more than 30 years that comprise of almost 34-37% of the total population of Delhi(“Statistical Abstract of Delhi” 2016).

  - **Mortality due to IHD (Ischemic Heart Disease) :** Studies conducted in USA and Europe (10-year in five major cities) indicated that hospital admissions for heart disease were usually associated with increased exposure to fine particulates. Furthermore, a very recent large prospective cohort study and meta-analysis in 11 European cities from the ESCAPE project confirmed that long term exposure to PM is associated with incidence of coronary events, and it is evident this even at levels of exposure below the current acceptable European limit values (for PM2.5 its 25 $\mu g/m^3$, for PM10 its 40 $\mu g/m^3$). In California cohort study , evidence were presented linking PM2.5 long-term exposure with increased risks of incident disease heart mortality, especially among postmenopausal women(Du et al. 2016). Impact assessment for mortality due to IHD has been done for adults aging more than 25 years that comprise of almost 44-47% of the total population of Delhi("Statistical Abstract of Delhi" 2016).

- **Mortality due to COPD:** COPD(chronic obstructive pulmonary disease) is a term that refers to a group of lung diseases including chronic airway obstruction ,chronic bronchitis and emphysema. The condition is characterized by airflow passage obstruction and persistent cough and phlegm. COPD is the third leading cause of mortality in the world and, in UK, 3 million people(COMEAP 2016) are estimated to be suffering from the disease. Each year COPD accounts for 30,000 deaths in the UK, representing 23% of all respiratory deaths, and it also results in 130,000 emergency admissions to hospital. There is a strong link between the PM particles and the deaths caused due to cardiovascular diseases, and several pathways have been recognized that can explain the link between PM particles and cardiovascular diseases, the first is the direct pathway. In this way, PM2.5, in particular UFPs directly translocate into the blood stream and remote target organ(Du et al. 2016). Impact assessment for mortality owing to COPD has been done for adults aging more than 30 years that comprise of almost 34-37% of the total population of Delhi("Statistical Abstract of Delhi" 2016).

- **Mortality due to ALRI in children:** Acute lower respiratory infections (ALRI) is a collective term used to refer pneumonia and bronchiolitis which happens to be a leading cause of morbidity and mortality in children under five years of age. According to recent estimates, every year about 120–156 million cases of ALRI occur globally(Sonego et al. 2015) with approximately 1.4 million estimated death cases with more than 95% of these deaths occuring in low and middle income countries. It has also been estimated that $PM_{2.5}$ exposure led to about 570,000 premature mortalities(Ghude et al. 2016) in 2011. Even the slightest increase in airborne fine particulate matter PM2.5, tiny pollution-causing particles could lead to acute lower respiratory infection (ALRI) in young children. Impact assessment for child mortality owing to ALRI has been done for children aging between 0-5 years that comprise of almost 8-10% of the total population of Delhi("Statistical Abstract of Delhi" 2016).

- **RESULTS AND DISCUSSION:**

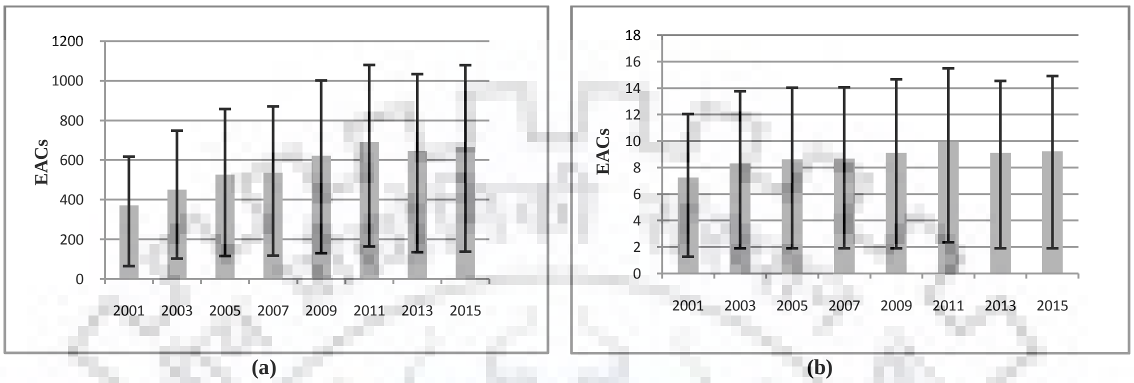
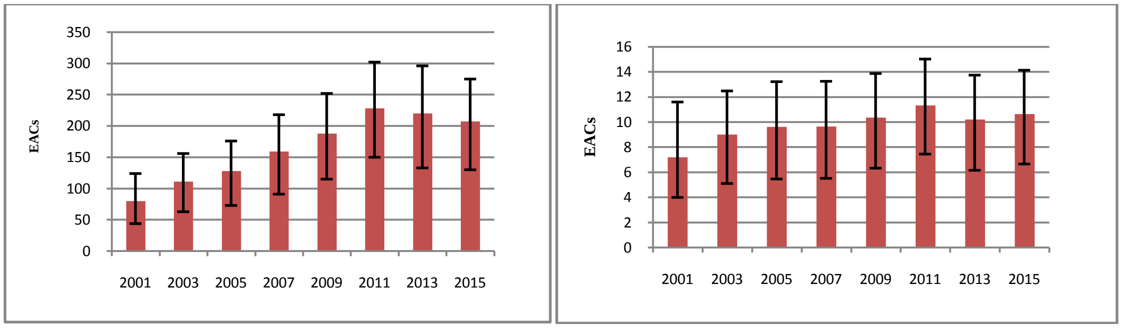


Fig-7.6: shows the Adult mortality(Age: 30+ years) attributed to Lung Cancer due to long term exposure of PM2.5 for the period 2001-2015 where 10 μg/m^3 is considered as the threshold value for impact assessment. Thick solid bars indicate the excess number of attributable cases and thin bars show lower and upper limits i.e., range for 95% confidence limits. The trend-line above shows the trend of PM2.5 ambient concentrations. (a) shows estimated total excess attributable cases for the year (b) shows incidence per 100000 population.

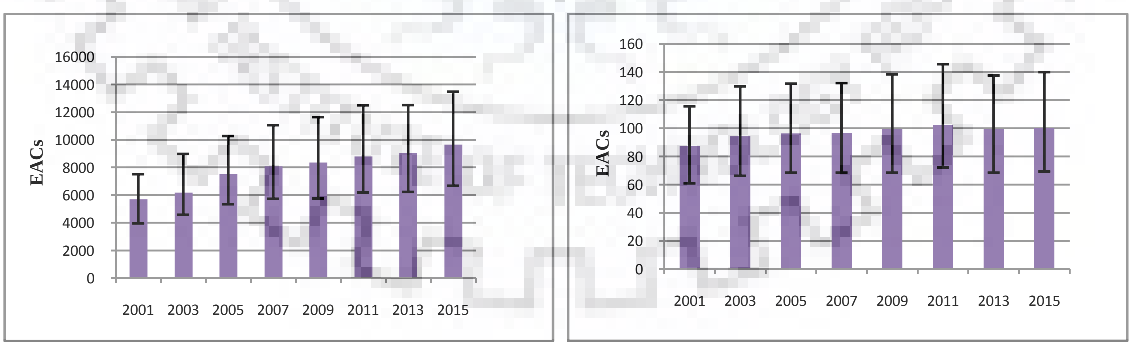
Inference: Excess number of attributable cases for mortality in adults(of age group 30+ years)caused by incidence of Lung cancer owing to long term exposure of PM2.5 is found to be ranging from 1090-180 for the year 2011 and the most probable value is 710 which is being shown by the thick solid bar (see fig-7.6(a)) whereas the incidence for the total mortality per 100000 adult population for the year 2011(see fig-7.6(b)) is ranging from 2-15 depicted by the markers of thin vertical lines placed over the bars. The results indicate that more than 710 adult deaths caused by long term exposure to $PM_{2.5}$ could be "avoided" if concentration of $PM_{2.5}$ would not exceed 10 μg/m^3 , which happens to be the threshold recommendation by the WHO Air Quality Guidelines (2005). The values in the *'Lower'* and *'Upper'* markers correspond to the estimates calculated with, respectively, lower and upper confidence interval limits of the Relative risk. The interval between the lower and upper values represents a part of the uncertainty associated with the estimation. Its clearly depicted that trend for total mortality cases estimates is in tandem with the trendline for PM2.5 concentrations.



(a) (b)

Fig-7.7: shows the ALRI induced mortality in children(Age:0-5 years) due to long term exposure of PM2.5 for the period 2001-2015 where 10 μg/m^3 is considered as the threshold value for impact assessment. Thick solid bars indicate the excess number of attributable cases and thin bars show lower and upper limits i.e., range for 95% confidence limits. (a) shows estimated total excess attributable cases for the year (b) shows incidence per 100000 population.

Inference: Excess number of attributable cases of mortality in children (of age group 0-5 years) suffering from ALRI(Acute lower respiratory infections, such as pneumonia and bronchiolitis) owing to long term exposure of PM2.5 is found to be ranging from 150-300 for the year 2011 and the most probable value is 225 which is being shown by the thick solid bar (see fig-7.7(a)) whereas the incidence for the total mortality per 100000 adult population for the year 2011(see fig-7.7(b)) is ranging from 8-15 depicted by the markers of thin vertical lines placed over the bars. The results indicate that more than 225 infant deaths caused by long term exposure to $PM_{2.5}$ could be "avoided" if concentration of $PM_{2.5}$ would not exceed 10 μg/m^3 , which happens to be the threshold recommendation by the WHO Air Quality Guidelines (2005). Its clearly depicted that trend for total mortality cases estimates is in tandem with the trendline for PM2.5 concentrations. Also the incidence of ALRI in children and consequent mortality rate incidence is higher in children as compared to the mortality incidence in adults.



(a) (b)

Fig-7.8: shows the IHD cases in adults(Age: 25+ years) due to long term exposure of PM2.5 for the period 2001-2015 where 10 μg/m^3 is considered as the threshold value for impact assessment. Thick solid bars indicate the excess number of attributable cases and thin bars show lower and upper limits i.e., range for 95% confidence limits. (a) shows estimated total excess attributable cases for the year (b) shows incidence per 100000 population.

Inference: Excess number of attributable cases for IHD mortality in adults(of age group 25+ years) owing to long term exposure of PM2.5 is found to be ranging from 6500-13500 for the year 2015 and the most probable value is 9760 which is being shown by the thick solid bar (see fig-7.8(a)) whereas the incidence for the IHD mortality per 100000 adult population for the year 2015(see fig-7.8(b)) is ranging from 70-140 depicted by the markers of thin vertical lines placed over the bars. The results indicate that more than 9760 adult deaths caused by long term exposure to $PM_{2.5}$ could be "avoided" if concentration of $PM_{2.5}$ would not exceed 10 μg/m^3 , which happens to be the threshold recommendation by the WHO Air Quality Guidelines (2005). Its clearly depicted that trend for total mortality cases estimates is in tandem with the trendline for PM2.5 concentrations.

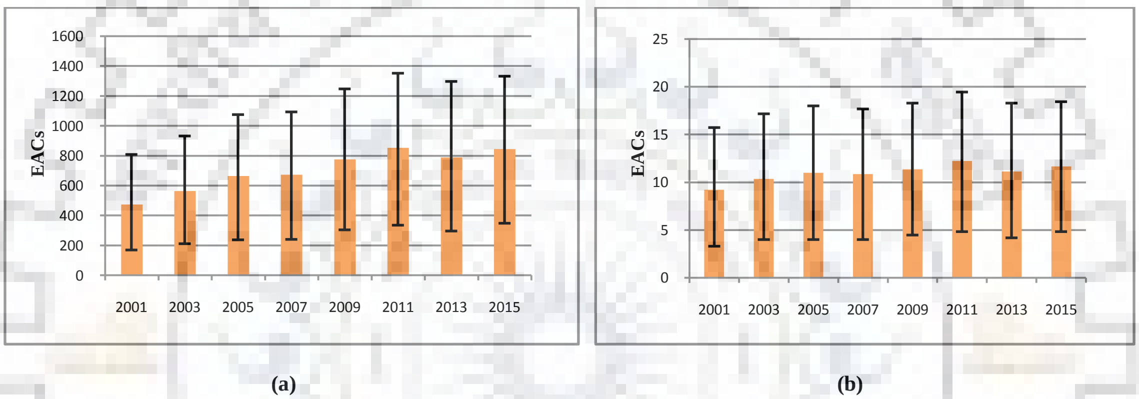


Fig-7.9: shows the COPD induced mortality (Age: 30+ years) due to long term exposure of PM2.5 for the period 2001-2015 where 10 μg/m^3 is considered as the threshold value for impact assessment. Thick solid bars indicate the excess number of attributable cases and thin bars show lower and upper limits i.e., range for 95% confidence limits. (a) shows estimated total excess attributable cases for the year (b) shows incidence per 100000 population.

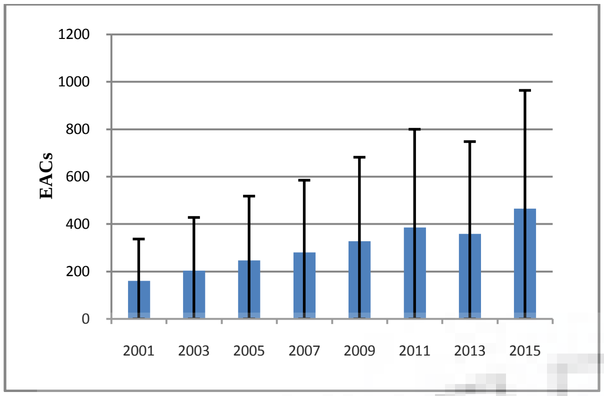
Inference: Excess number of attributable cases for COPD induced mortality in adults(of age group 30+ years) owing to long term exposure of PM2.5 is found to be ranging from 340-1350 for the year 2011 and the most probable value is 850 which is being shown by the thick solid bar (see fig-7.9(a)) whereas the incidence for the total mortality per 100000 adult population for the year 2011(see fig-7.9(b)) is ranging from 5-18 depicted by the markers of thin vertical lines placed over the bars. The results indicate that more than 850 adult deaths caused by long term exposure to $PM_{2.5}$ could be "avoided" if concentration of $PM_{2.5}$ would not exceed 10 μg/m^3 , which happens to be the threshold recommendation by the WHO Air Quality Guidelines (2005). Its clearly depicted that trend for total mortality cases estimates is in tandem with the trendline for PM2.5 concentrations.

- **Health impact assessment for long-term exposure of PM10:** Exposure to airborne small particles, such as particulate matter with a diameter below 10 µ (PM10), have been examined and found to be related to adverse health effects(Mészáros et al. 1992), especially in the cardiovascular and respiratory systems. Under this assessment, morbidity cases are estimated owing to long-term exposure of ambient concentrations of PM10 which are the combined values for vehicular exhaust and non-exhaust vehicular pollution. For the estimation of health risks, 10 $\mu g/m^3$ has been considered as the cut-off or the threshold value as this is the lowest level at which total, cardiopulmonary and respiratory mortality have been shown to increase with more than 95% confidence in response to long-term exposure to PM10 and the impacts of exposure exceeding this concentration are calculated by the program. Following health issues have been dealt with while doing estimation of excess number of attributable cases for the various age groups of Delhi.

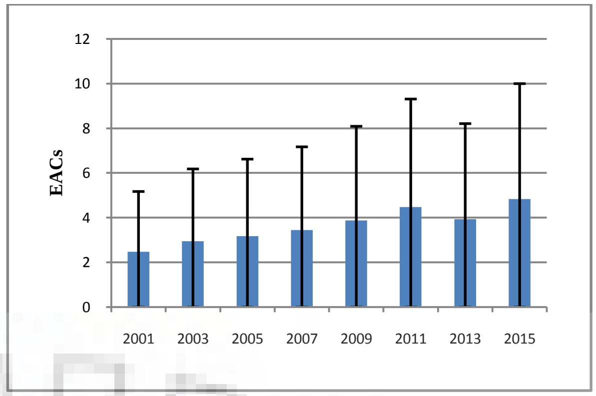
- **Chronic Bronchitis morbidity in adults:** Chronic bronchitis is a common clinical condition comprising of chronic cough and sputum production for at least three months in two or more consecutive years. Chronic bronchitis is a phenotype of chronic obstructive pulmonary disease (COPD), among persons with COPD, chronic bronchitis portends increased frequency and severity of exacerbations. Among persons without COPD, chronic bronchitis symptoms predict an increased risk of developing COPD, lower health-related quality-of-life scores, and increased risk for all-cause mortality. For prevalent chronic bronchitis, a statistically significant positive association was seen with PM10(Hooper et al. n.d.), as exposure to higher concentrations of PM10 was significantly associated with all possible outcomes: chronic bronchitis, chronic cough, chronic phlegm, and chronic cough or phlegm.

- **Prevalence of bronchitis in children:** Statistically significant positive associations were found between PM10 and the prevalence of phlegm, morning cough, hay fever, bronchitis and nocturnal cough(Hoek et al. 2012). Woodruff et al examined infant deaths in the United States and levels of inhalable particles (PM10) in the air. They excluded infant deaths in the first month after birth as likely to reflect complications of pregnancy and delivery and found that PM10 was associated with higher death rates in the next 11 months of life. This excess risk seemed to be principally attributed to respiratory illness, arising from exposure to PM10 concentrations.

- **RESULTS AND DISCUSSION:**



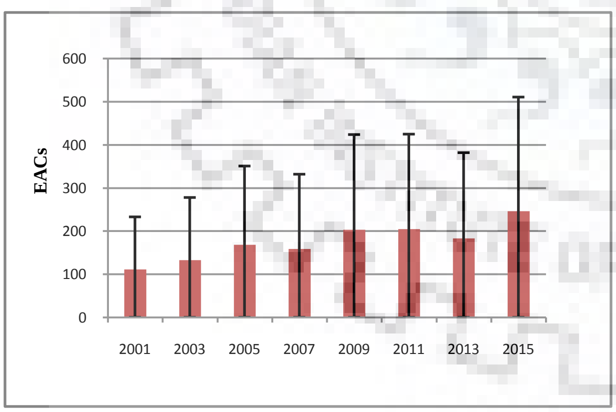
(a)

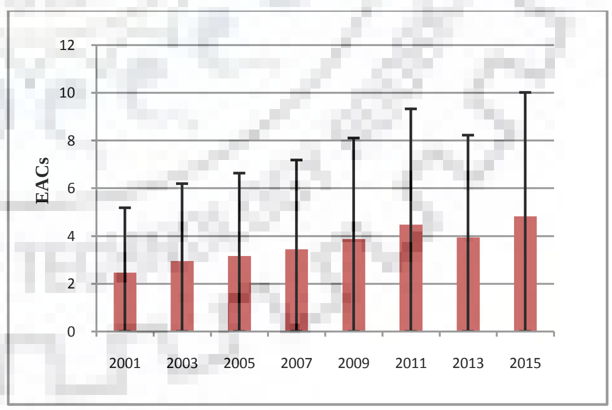


(b)

Fig-7.10: shows the chronic bronchitis morbidity cases in adults(Age: 25+ years) due to long term exposure of PM10 for the period 2001-2015 where 10 µg/m^3 is considered as the threshold value for impact assessment. Thick solid bars indicate the excess number of attributable cases and thin bars show lower and upper limits i.e., range for 95% confidence limits. (a) shows estimated total excess attributable cases for the year (b) shows incidence per 100000 population.

Inference: Excess number of attributable cases for chronic bronchitis induced morbidity in adults(of age group 30+ years) owing to long term exposure of PM10 is found to be ranging from 0-950 for the year 2015 and the most probable value is 450 which is being shown by the thick solid bar (see fig-7.10(a)) whereas the incidence for the total mortality per 100000 adult population for the year 2015(see fig-7.10(b)) is ranging from 5-11 depicted by the markers of thin vertical lines placed over the bars. The results indicate that more than 450 adult deaths caused by long term exposure to PM_{10} could be "avoided" if concentration of $PM_{2.5}$ would not exceed 10 µg/m^3 , which happens to be the threshold recommendation by the WHO Air Quality Guidelines (2005). It is clearly depicted that trend for total mortality cases estimates is in tandem with the trendline for PM10 concentrations.





(a) (b)

Fig-7.11: shows the Bronchitis morbidity cases in children(Age: 0-14 years) due to long term exposure of PM10 for the period 2001-2015 where 10 µg/m^3 is considered as the threshold value for impact assessment. Thick solid bars indicate the excess number of attributable cases and thin bars show lower and upper limits i.e., range for 95% confidence limits. (a) shows estimated total excess attributable cases for the year (b) shows incidence per 100000 population.

Inference: Excess number of attributable cases for bronchitis morbidity in children(of age group 0-14 years) owing to long term exposure of PM2.5 is found to be ranging from 0-510 for the year 2015 and the most probable value is 350 which is being shown by the thick solid bar (see fig-7.11(a)) whereas the incidence for the morbidity per 100000 child population for the year 2015(see fig-7.11(b)) is ranging from 0-10 depicted by the markers of thin vertical lines placed over the bars. The results indicate that more than 350 children morbidity caused by long term exposure to PM_{10} could be "avoided" if concentration of PM_{10} would not exceed 10 $\mu g/m^3$, which happens to be the threshold recommendation by the WHO Air Quality Guidelines (2005).

7.3 ENVIRONMENTAL IMPACT ASSESSMENT

Particulate matter though has a number of ecological impacts and relevant studies to assess them have been carried out from time to time across the world but their assessment is has not been done theoretically and analytically and rather practical methods are employed to achieve concrete results. Particulate matter owing to their very small size possess very low deposition velocities and their deposition or settlement requires good amountof time. Many studies were referred to understand the assessment methods incorporated for these particulates(Kaushar et al. 2013; Mariraj Mohan n.d.; NEERI n.d.). Most of the studies were carried out to assess the repurcursions of the particulate settling in the lakes or river systems(Chambers and Eadie 1981; Håkanson 2006; Hecky et al. 1993; Morales-Baquero et al. 2006) . Many studies were referred which discussed the deposition of particulates on stone buildings, monuments and other buildings(Rodriguez-Navarro and Sebastian 1996; Saiz-Jimenez 1993; Thatcher and Layton 1995) but all these researches involved the use of sampling techniques to obtain the samples of the deposited particulates and then assessed for possible impacts. The particulate matter is actually collective term used for a number of particles that can be over hundred and the only characteristic they share is their size that is why they are termed as PM10 or PM2.5 or PM1.0 and to assess the reactivity of such huge number of particulate is a difficult task. The closest the researches have come across is to evaluate the deposition velocities for the same sized particles which are used to compute the dry deposition flux of the particles but further asesesement has not been possible. Although individual risk assessment for the particles has been done in many studies but that is beyond the scope of this study , hence not incorporated.

CHAPTER 8: IMPACT ANALYSIS OF CARBON-DI-OXIDE AMBIENT CONCENTRATIONS

Industrialized countries have managed to de-link sulfur dioxide emissions from economic growth. Having said that, it is inferred that emissions have fallen even as national income has risen but they have failed to do the same with carbon dioxide emissions. Per capita CO_2 emissions remain closely related to a country's level of economic development, and thus standard of living. It is evident that as long as the world economy is carbon-based – driven by energy from coal, oil, and natural gas – growth cannot be de-linked substantially from CO_2 emissions(Ghosh et al. 2009). Megacities are able to prosper as they have come up with factories , industries and power plants in their vicinity to provide employment and energy for their development. But they have also been at the receiving end of their negative impacts such as increase in transport vehicles, increase in car manufacturing plants thus selling more automobiles, etc . If we see the case of the national capital territory of India, the source apportionment highlights a major concern.

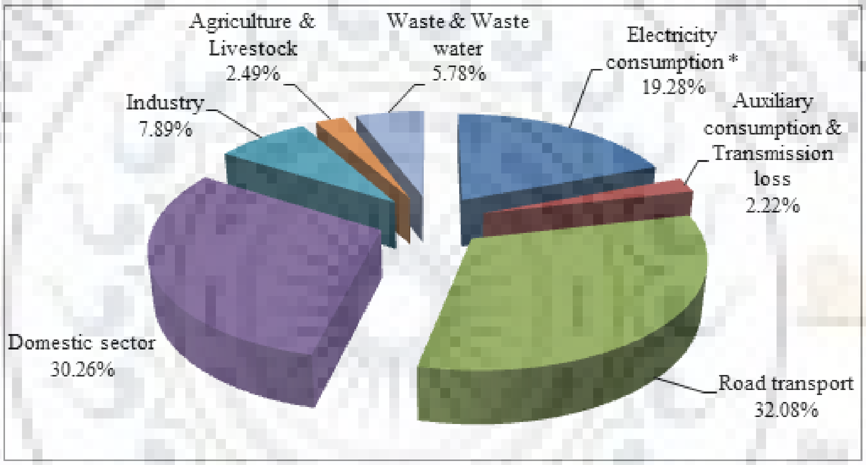


Fig-8.1: Carbon dioxide equivalent emissions in Delhi, Source: (Ramachandra et al. 2015)

Major portion of the carbon dioxide content in Delhi city is being contributed by transport sector which is almost around 32.08% and the next largest contributor is domestic sector(Ramachandra et al. 2015).

8.1 EMISSION INVENTORY AND PRELIMINARY ANALYSIS

To validate the above stated fact, emission inventory for carbon-dioxide emissions is presented here for the period 2001-2015 which is generated using VAPI model considering suitable parameters.

Table-8.1: Carbon-dioxide annual average total annual emissions and ambient concentrations

Year	2W	3W	CARS	BUSES	GOODS VEHICLES	TOTAL EMISSIONS	AMBIENT CONC. (μg/m3)
2001	318566.51	351035.84	1096123.73	1280274.02	291335.14	3337335.23	7898.47
2002	351236.75	389123.51	1397061.10	1196202.10	348952.62	3682576.08	8715.55
2003	416313.06	410335.50	1403135.23	1496003.94	391632.76	4117420.49	9744.70
2004	486203.31	468623.10	1832232.63	1865126.85	446523.50	5098709.39	12067.12

2005	526012.78	490393.56	2196080.60	2024270.72	484313.59	5721071.26	13540.06
2006	598517.68	555458.03	2254925.89	2149253.66	535141.26	6093296.53	14421.00
2007	655276.72	593102.35	2852605.10	2321201.80	610200.84	7032386.80	16643.55
2008	794297.79	638336.04	3310608.98	2906603.24	658635.45	8308481.52	19663.68
2009	939149.58	692421.44	4240927.23	3646316.62	697143.22	10215958.09	24178.11
2010	1138681.43	733904.25	4634395.06	4057266.15	737678.62	11301925.51	26748.27
2011	1751023.93	782524.17	5318557.65	4407501.84	765480.62	13025088.21	30826.48
2012	1878475.08	805780.91	6069932.74	3625310.08	615844.28	12995343.09	30756.08
2013	2009935.99	810583.56	7139550.43	3706312.26	650083.41	14316465.64	33882.78
2014	2498723.68	838364.50	8325548.07	2935759.58	692027.51	15290423.35	36187.84
2015	2631346.72	858543.76	9607057.12	3459009.81	878153.16	17434110.58	41261.31

❖ Results obtained from the emission inventory

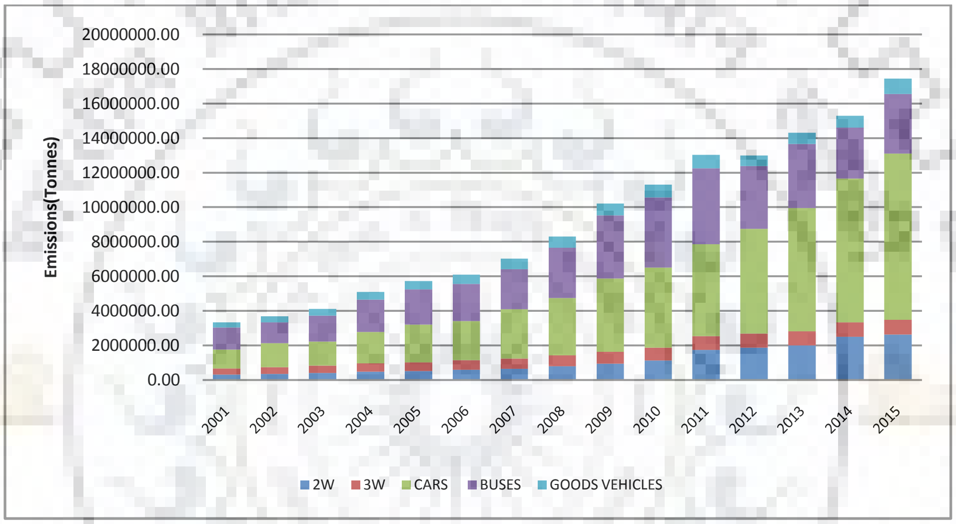


Fig-8.2: Carbon-di-oxide emissions(in Tonnes) for the period 2001-2015

- **Inference 1**: the emissions data presented above is actually similar for all three seasons of Delhi, implying vehicular emissions are not affected by climatic conditions and simply governed by the fuel technology and fuel consumption.
- **Inference 2**: As can be seen in fig-8.2 , total vehicular emissions for the years have always been in a continous rising trend and all the vehicle categories are contributing to the rise. But comparatively cars/taxis are largest emitter of the carbon-dioxide and buses is the second largest emitter among all vehicle categories. Also the emissions emitted by cars are rising with a rapid rate that can be simply attributed to the rapid rise in cars' numbers in the Delhi city.

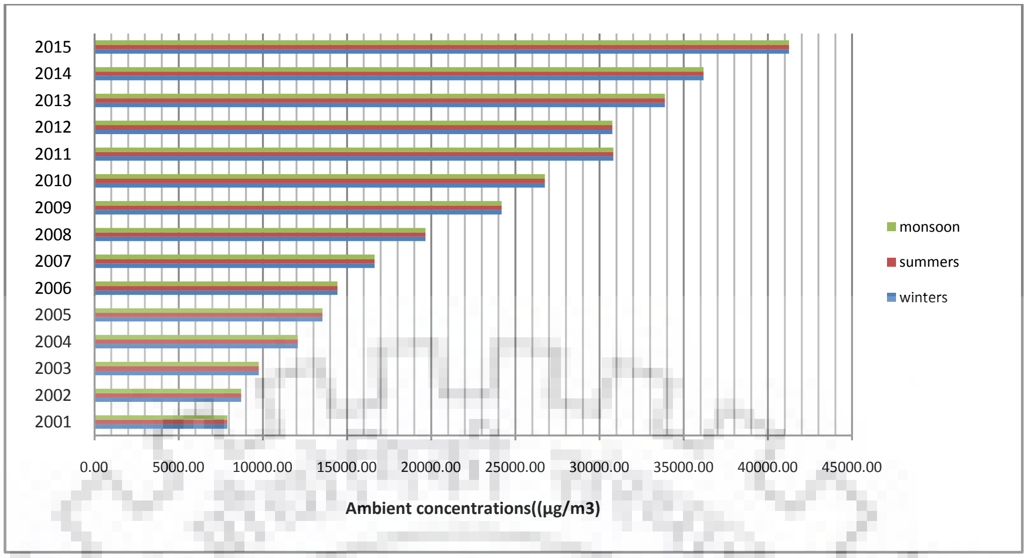


Fig-8.3: Carbon-di-oxide ambient concentrations trend line for the period 2001-2015

- **Inference 3**: As can be seen in fig- 8.3, average ambient concentrations for the years have a continous rising trend line, a natural consequence of greater emissions in subsequent years.

  Discussion: With no BS vehicular regulations at place to curb the emissions, the above depicted trend for emissions is hard to change. None of the nations have enforced vehicular regulations for the controlling the carbon-di-oxide emissions ever and any future possibility for this has no meaning since, CO_2 is a natural product of combustion reactions and to limit its release , we simply need to limit our fuel use which is only possible with the replacement of fuel-driven vehicles with alternative power driven vehicles for example, hydrogen fuel use, electricity driven vehicles such as Metro cars which have zero carbon foot print owing to no fuel use. Hydrogen use as a fuel for automobiles is a far future reality and electric cars are still under the developmental phase, moreover there are other infrastructure liabilities related to them and hence, fuel driven vehicles could not be replaced for upcoming one or two decades.

8.2 HEALTH IMPACT ASSESSMENT

Carbon dioxide, a naturally occurring gas in the atmosphere, comprising almost 0.004% of the atmosphere, is vital for the survival of plants and animals. Excess , however, can cause all life on Earth to end. Carbon dioxide plays a key role in plant life and helps keep the earth warm. Oxygen is carried to body tissue during breathing and carbon dioxide is released. The gas guards the pH level of blood. If carbon dioxide is confined, it can reduce the amount of oxygen reaching the body(Raub et al. 2000). The health impacts of excess quantity of carbon-dioxide in atmosphere are listed as : headaches, dizziness, restlessness, a tingling or pins or needles feeling, difficulty breathing, sweating, tiredness, increased heart rate, elevated blood pressure, coma, asphyxia, and convulsions. Such symptoms becomes visible only when ambient concentrations of CO_2 reaches some threshold values. In a study (Robertson 2006), different threshold values for the CO_2 have been prescribed after extensive research. For example, it has prescribed 5000ppm as the safe limit for C_{O2} concentrations if you are working in confined areas like offices , workshops, factory ,etc, but as the study progresses, 600ppm is now introduced as the safe limit for atmosphere above which possible symptoms of carbon-dioxide poisoning may start to show up which includes difficulty in breathing, rapid pulse rate, headache, hearing loss, hyperventilation, sweating and fatigue. As the outdoor concentrations of CO_2 rise , indoor concentrations get increased by two or three folds. However , global concentrations of 350 ppm are considered to be safe and not heating effect inducing but recently as per the studies published, our planet has already crossed the mark of 400 ppm.

Thus if 600 ppm is termed a s the threshold limit for CO_2 ambient concentrations then in terms of $\mu g/m^3$ it is equivalent to 1079750 $\mu g/m^3$. And as seen in table-8.1, the maximum value of the CO_2 is for the year 2015 which is 41261.31 $\mu g/m^3$ and that comprises of only a meager 3.821% of the threshold quantity required to be breached to bring about any health impacts. Though the indoor concentrations can be much higher as compared to outdoor ambient concentrations but that would still need to cross the mark of 5000 ppm to affect the health of the beings. Hence, no health impacts are possible with the current concentrations of CO_2 in the atmosphere of Delhi.

8.3 ENVIRONMENTAL IMPACT ASSESSMENT

A new study(Gabriel et al. n.d.) published in Nature Climate Change pinpoints the temperature increases caused by CO_2 emissions in different regions around the world. Using simulation results from 12 global climate models, Damon Matthews, a professor in Concordia's Department of Geography, Planning and Environment, along with post-doctoral researcher Martin Leduc, produced a map that shows how the climate alters in response to cumulative carbon emissions around the world. They found that temperature increases in most parts of the world respond linearly to cumulative emissions. Globally, the researchers saw an average temperature increase of 1.7 ±0.4°C per trillion tonnes of carbon in CO_2 emissions (TtC), which is consistent with reports published by Intergovernmental Panel on Climate Change(Gabriel et al. n.d.). But the researchers went beyond these globally averaged temperature rises, to calculate climate change at a local scale. At a glance, here are the average increases per trillion tonnes of carbon that we emit, separated geographically(Leduc et al. 2016).

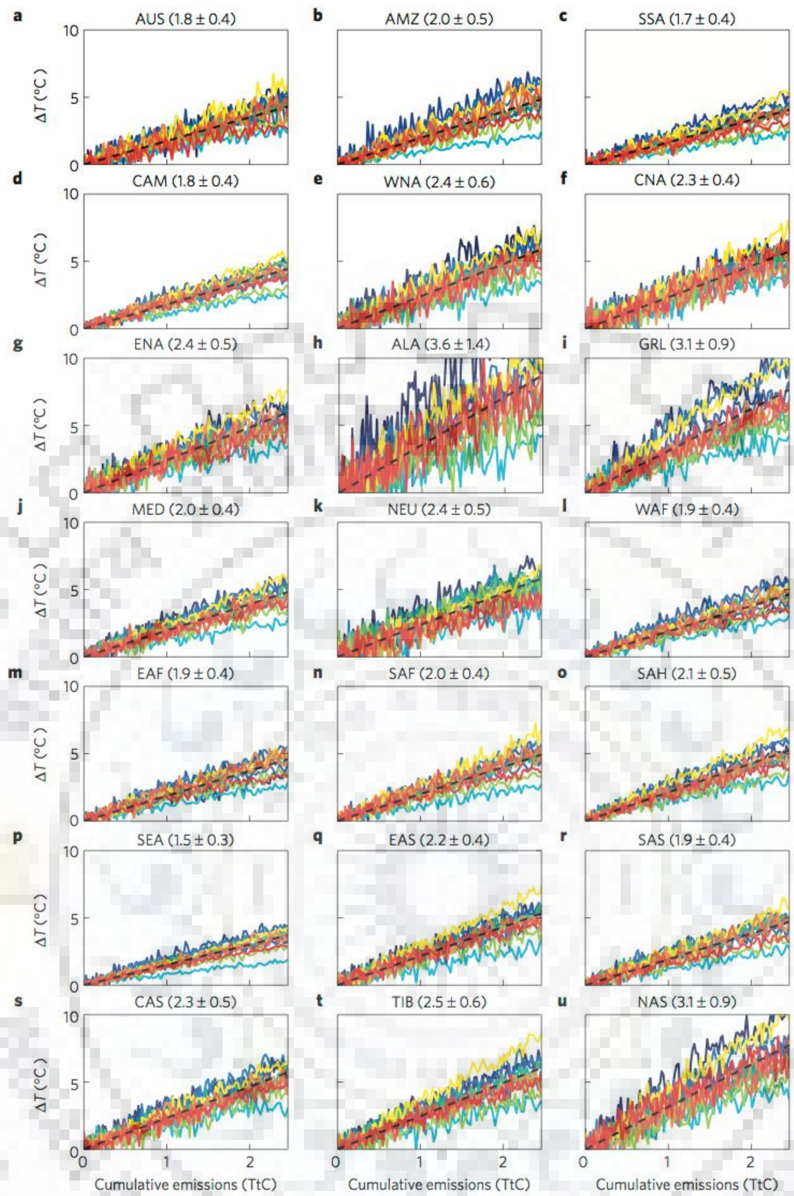


Fig-8.4: Estimates and time series of the regional temperature response to cumulative emissions calculated over 21 land regions abbreviated as AUS(a)(Australia), CNA(f)(Central North America) and so on. SAS(r) stands for South Asia which is the region where India lies.

Since, New Delhi lies in the South Asian region then it can be inferred that New Delhi experiences an approximate temperature rise of (1.9°± 0.4°)C per trillion tonnes of carbon in carbon emissions per year. The cumulative carbon emissions from the vehicular exhaust emitted by vehicles run in Delhi region during 2015 have been estimated to be approximately 17434110.58 tonnes making up only 1.74% of the 10^9 tonnes of carbon and this proportion of the carbon emissions is capable of rising the temperature of the region by approximately 0.04002° C using the relation given above.

CHAPTER 9: IMPACT ANALYSIS OF HYDROCARBONS AND CARBON-MONOXIDE EMISSIONS

In reality, the hydrocarbons is the collective designation for a multitude of specific compounds. The US Environmental Protection Agency has listed more than 1,000 different compounds present in exhaust or evaporative emissions from on-road and non-road equipment, using conventional (gasoline, diesel) and various alternative fuels such as ethanol, biodiesel, CNG(Hickey et al. 2014). When hydrocarbons released from combustion reactions are discussed then it is relevant to all the organic compounds produced which includes aldehydes, alkenes, alkynes, poly-aromatic hydrocarbons, etc formed due to incomplete combustion of the fuels in engines.

9.1 EMISSION INVENTORY AND PRELIMINARY ANALYSIS OF HYDROCARBONS

Hydrocarbons emissions(in Tonnes) generated by traffic during the period 2001-2015 are estimated by VAPI model for three seasons and corresponding ambient concentrations(μg/m^3) are also computed. The following table shows the data:

Table-9.1: Hydrocarbon emissions in Tonnes and corresponding ambient concentrations

Year	2W	3W	CARS	BUSES	GOODS VEHICLES	TOTAL EMISSIONS (Tonnes)	AMBIENT CONC. (μg/m3)
2001	53013.50	5234.85	9985.736	2384.75	6564.46	77183.30	182.67
2002	57687.36	1963.04	11024.493	5355.02	4623.75	80653.67	190.88
2003	56930.19	1854.62	11568.414	5489.95	4912.85	80756.04	191.13
2004	55736.20	2076.60	12846.236	5674.79	5284.95	81618.78	193.17
2005	54417.67	2282.65	12100.42	11028.14	5668.89	85497.77	202.35
2006	52833.39	2457.73	12694.79	12071.09	5706.62	85763.62	202.98
2007	37990.44	2162.01	13376.84	12566.16	5762.33	71857.78	170.07
2008	35822.26	2226.82	14059.37	11426.61	5842.82	69377.88	164.20
2009	34121.00	2367.49	14551.62	14784.28	5945.62	71770.02	169.86
2010	34501.54	2149.72	14585.05	16836.38	6034.44	74107.13	175.39
2011	36264.97	1927.61	21455.59	19219.46	6144.80	85012.42	201.20
2012	35404.13	1321.32	19274.38	16909.87	4990.97	77900.68	184.37
2013	35090.17	1109.60	19214.95	13396.31	4647.38	73458.41	173.85
2014	36843.41	739.16	19114.84	14603.85	4305.87	75607.13	178.94
2015	38231.24	743.02	19086.40	11897.61	4449.97	74408.25	176.10

RESULTS AND DISCUSSION

The above data is same for all the three seasons of Delhi city implying that no seasonal variation exists and the emissions are not at all governed by climatic conditions.

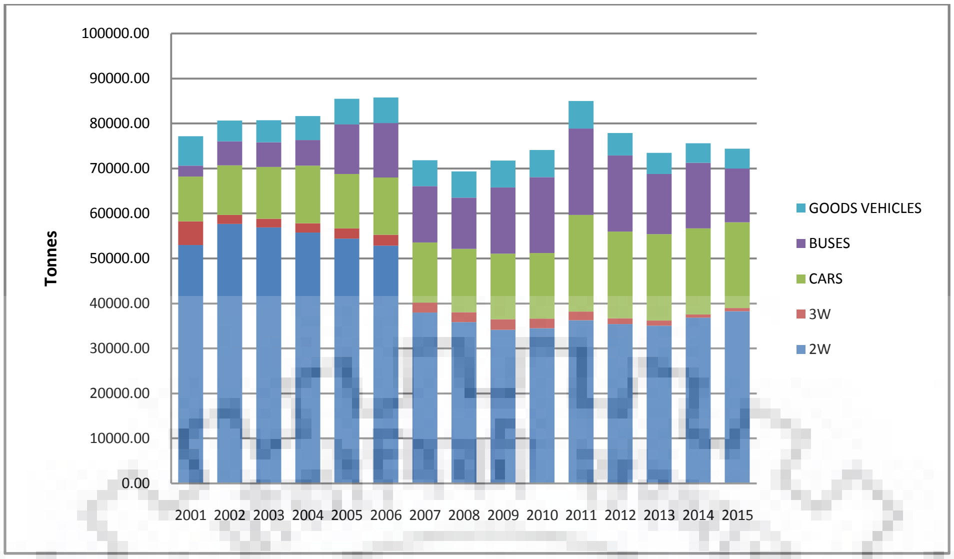


Fig-9.1: Estimates for Total Hydrocarbons emissions for the period 2001-2015

- **Inference-1:M**aximum emissions are contributed by two-wheelers and also their fleet number is maximum among all vehicle categories which has been stated many times before in the report. Least emitter tag is earned by three-wheelers running on CNG and thus contributing very insignificant amount of hydrocarbons.
- **Inference-2:** Two-wheelers emissions trend shows a significant dip after 2006 which can be attributed to the implementation of the strict BS-III but the total emissions seems to be rising gradually which can be attributed to the leniency given in the BS-III for the heavy diesel vehicles where the earlier limit of 1.1(g/kmhr) was increased to 1.6 (g/kmhr) thus them to emit more. Since, buses were also running on diesel along with cars and heavy vehicles, buses appear to have added increased amounts of hydrocarbons in the atmosphere.
- **Inference-3:** Attributable to the above discussed leniency in the emission limits, and increased two-wheelers fleet, emissions seems to be rising over the years and much more stringent norms are required to control them. After 2011, emissions show a gradual increase which needs to be mitigated at the earliest.

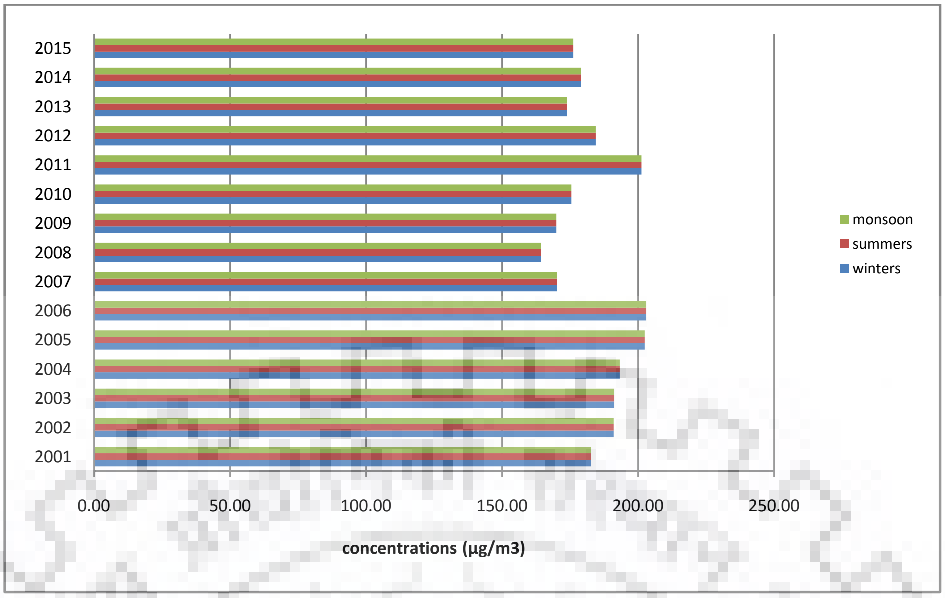


Fig-9.2: Seasonwise Hydrocarbon ambient concentrations for the period 2001-2015

- **Inference-1:** Concentrations showing rise and fall trend owing to the reasons discussed above. Also the concentrations are not all altered by climatic conditions thus their emission is not governed by meterological factors.

9.2 EMISSION INVENTORY AND PRELIMINARY ANALYSIS OF CARBON-MONOXIDE

Carbon-monoxide emissions(in Tonnes) generated by traffic during the period 2001-2015 are estimated by VAPI model for three seasons and corresponding ambient concentrations(µg/m^3) are also computed. The following table shows the data:

Table-9.2: Carbon-monoxide emissions in Tonnes and corresponding ambient concentrations for summers

Year	2W	3W	CARS	BUSES	GOODS VEHICLES	TOTAL EMISSIONS	AMBIENT CONC.(µg/m3)
2001	121753.16	13874.94	77120.78	15732.62	26978.06	255459.57	604.60
2002	128852.46	10715.64	81963.42	11645.32	26204.61	259381.44	613.88
2003	125741.85	11520.75	96746.16	16236.06	28051.44	278296.26	658.64
2004	123843.75	12974.85	112356.20	15764.31	27321.52	292260.62	691.69
2005	124237.04	11153.32	115274.66	26014.82	29326.98	306006.82	724.23
2006	126374.48	11853.54	119137.79	27248.54	29387.84	314002.20	743.15
2007	78282.79	14373.65	122092.18	25909.04	29477.72	270135.38	639.33
2008	76881.09	12207.51	125893.88	25488.26	29607.55	270078.29	639.19
2009	75791.48	21060.09	129109.30	28061.12	29773.40	283795.39	671.66
2010	76333.74	23311.52	132326.84	28997.55	29916.67	290886.31	688.44
2011	80081.31	11728.54	135833.31	31705.12	30094.69	289442.97	685.02
2012	79354.46	10978.12	115472.30	20809.01	26978.06	253591.95	600.18

2013	82228.63	9705.78	113551.56	18455.71	24905.22	248846.91	588.95
2014	86523.50	9840.01	110614.29	15258.44	23063.52	245299.76	580.55
2015	89390.50	9105.06	107822.54	15962.38	20712.40	242992.87	575.09

Table-9.3: Carbon-monoxide emissions in Tonnes and corresponding ambient concentrations for winters

Year	2W	3W	CARS	BUSES	GOODS VEHICLES	TOTAL EMISSIONS	AMBIENT CONC.(µg/m3)
2001	177753.26	14476.16	89132.51	15732.62	26978.06	324072.62	766.98
2002	178825.26	11315.64	91988.87	11645.32	26204.61	319979.69	757.30
2003	185754.56	12241.67	115684.35	16236.06	28051.44	357968.08	847.20
2004	183756.35	13558.03	123356.18	15764.31	27321.52	363756.38	860.90
2005	174421.74	12091.28	126491.01	26014.82	29326.98	368345.84	871.76
2006	186347.56	12438.16	130683.83	27248.54	29387.84	386105.94	913.80
2007	140566.02	13492.17	135656.39	25909.04	29477.72	345101.34	816.75
2008	145979.56	13371.91	137712.92	25488.26	29607.55	352160.20	833.46
2009	112392.34	23207.87	141184.95	28061.12	29773.40	334619.67	791.94
2010	108584.10	25413.98	145090.94	28997.55	29916.67	338003.24	799.95
2011	126929.52	12708.20	148704.22	31705.12	30094.69	350141.76	828.68
2012	121870.65	11684.56	125124.77	20809.01	26978.06	306467.05	725.32
2013	133179.08	10551.83	122162.58	18455.71	24905.22	309254.43	731.91
2014	149746.14	10329.63	118207.40	15258.44	23063.52	316605.13	749.31
2015	146211.72	10128.36	115080.31	15962.38	20712.40	308095.16	729.17

Table-9.4: Carbon-monoxide emissions in Tonnes and corresponding ambient concentrations for monsoon

Year					GOODS VEHICLES	TOTAL EMISSIONS	AMBIENT CONC.(µg/m3)
	2W	3W	CARS	BUSES			
2001	174753.26	14476.16	86752.32	15732.62	26978.06	318692.43	754.25
2002	175825.26	11315.64	88971.87	11645.32	26204.61	313962.69	743.06
2003	182754.56	12241.67	111684.35	16236.06	28051.44	350968.08	830.64
2004	180756.35	13558.03	119226.18	15764.31	27321.52	356626.38	844.03
2005	171109.93	11998.92	122664.43	26014.82	29326.98	361115.08	854.65
2006	184687.38	12378.81	126869.92	27248.54	29387.84	380572.49	900.70
2007	137956.30	13235.20	130491.18	25909.04	29477.72	337069.44	797.74
2008	142664.68	13194.86	132243.55	25488.26	29607.55	343198.90	812.25
2009	108756.11	23100.18	135854.66	28061.12	29773.40	325545.47	770.47
2010	104008.60	24304.34	140555.05	28997.55	29916.67	327782.21	775.76
2011	123553.59	12651.72	143239.83	31705.12	30094.69	341244.96	807.62
2012	118323.70	11428.17	120429.26	20809.01	26978.06	297968.20	705.20
2013	131811.22	10181.87	118998.82	18455.71	24905.22	304352.85	720.31
2014	146403.86	9238.33	114626.21	15258.44	23063.52	308590.36	730.34
2015	144728.15	9155.83	112872.82	15962.38	20712.40	303431.58	718.13

RESULTS AND DISCUSSION:

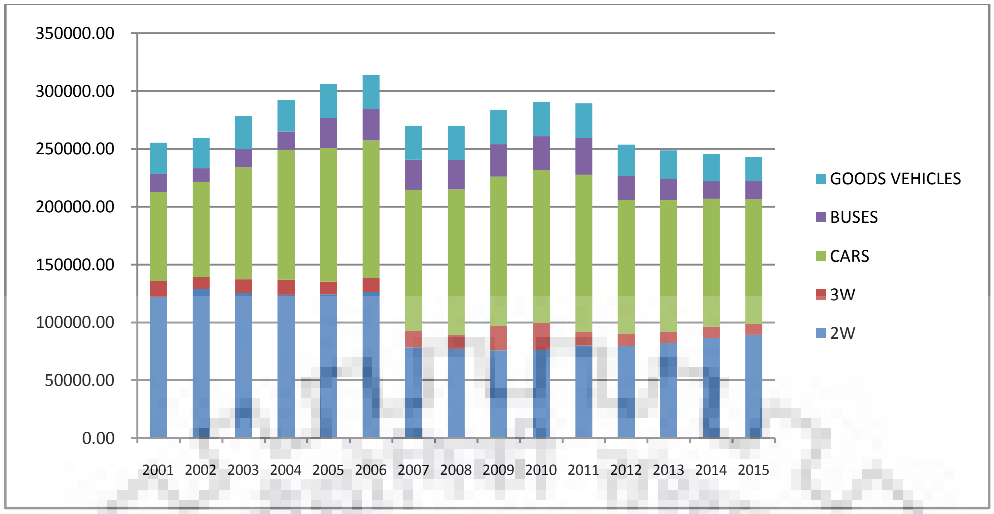


Fig-9.3: Total carbon-monoxide emissions for the period 2001-2015 for winters

- **Inference-1:** Maximum emissions are contributed by cars. Least emitter tag is earned by three-wheelers running on CNG.
- **Inference-2:** Two-wheelers emissions trend shows a significant dip after 2006 which can be attributed to the implementation of the strict BS-III but the total emissions seems to be rising gradually which can be attributed to the leniency given in the BS-III for the heavy diesel vehicles where the earlier limit of 1.1(g/kmhr) was increased to 1.6 (g/kmhr) thus them to emit more
- **Inference-3:** Attributable to the above discussed leniency in the emission limits, and increased two-wheelers fleet, emissions seems to be rising over the years and much more stringent norms are required to control them. After 2011, emissions show a gradual increase which needs to be mitigated at the earliest.

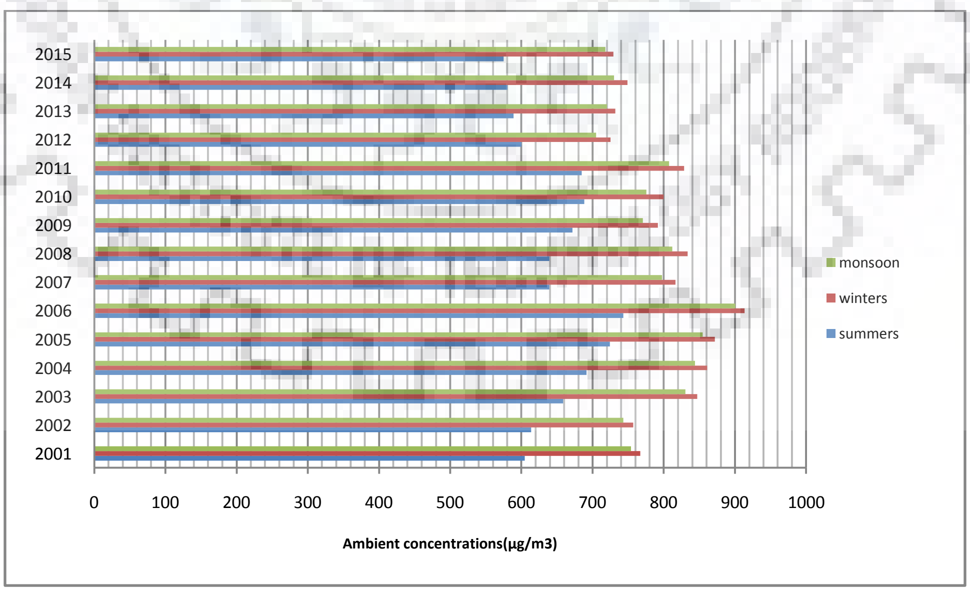


Fig-9.4: season-wise carbon-monoxide concentrations for the period 2001-2015

- **Inference-1:** Ambient concentrations were found to be maximum in winters and least in summers simply implying that with decrease in temperature , portion of the unburned fuel increased giving rise to more CO emissions. CO is produced when there is insufficient oxygen (O_2) for the complete oxidation of hydrocarbons. Thus, CO emissions increase when the engine is operated under conditions in which there is an excess of fuel with respect to the oxygen necessary for its combustion. Furthermore, the formation of CO is favoured by low combustion temperature, such as those encountered immediately after engine start-up, or by temperature inhomogeneity in the combustion chamber(Hickey et al. 2014).

9.3 HEALTH IMPACT AND ENVIRONMENTAL IMPACT ASSESSMENT

Hydrocarbons in air by themselves alone cause no significant harmful effects. They are of concern because the hydrocarbons undergo chemical reactions in the presence of sunlight and nitrogen oxides forming photochemical oxidants of which the predominant one is ozone(Subramanian n.d.). HC emissions were initially thought to present a relatively low toxicity threat, and, the main concern was their determining role as precursors to the secondary pollutant ozone (O_3) and its build-up at a tropospheric level along with other hazardous secondary pollutants(Hickey et al. 2014).

Similiarly, CO is also termed as an ozone precursor and the effects of CO alone on the environment are limited and the main concern surrounding this pollutant is its very high toxicity, which acts by limiting O_2 transport in the body. The affinity of CO for haemoglobin, pigment present in the blood which transports oxygen from the lungs to the tissues in the form of carboxyhaemoglobin, is approximately 212 times greater than that of oxygen. In almost all referred studies related to ozone formation from hydrocarbons, CO and NOx ambient concentrations, practical methods were employed using the complicated chemistry involved in the formation of ozone which helped in establishing the relationship between the ambient content of the precursors and product contaminant i.e., ozone. Thus, the formation of ozone from these vehicular emissions have not been dealt in this study. Also they are known to take part in the formation of photochemical smog which is major polluting agent in the winters in Delhi. The conditions for the formation of photochemical smog include abundant sunlight , air stagnation, and high concentrations of hydrocarbons, CO and nitrogen oxides in the atmosphere. Smog is formed from the photochemical reactions occurring in the lower atmosphere by the interaction of hydrocarbons and nitrogen oxide released by some stationary sources and exhausts of automobiles. This interaction results in a series of complex reactions producing secondary pollutants such as ozone, aldehydes, ketones, and peroxyacyl nitrates (Subramanian n.d.). Smog is complex formation incorporating many factors and favourable conditions thus, its analytical measurement and subsequent assessment is altogether separate scope of study and hence has not been dealt here.

CHAPTER 10: ECONOMIC IMPACTS OF THE BHARAT STAGE STANDARDS

The higher the number of the standard turns, more stringent it becomes and ultimately making it more trickier for the automakers to evolve the engines to make them compliant with the emerging bharat stage standard. While the implentation of a stringent emission standard may sound good, especially amidst the mounting concerns over the ever-rising pollution levels in the country, it's a lot tougher to be done than said. Firstly, it takes years for automaker to come up with a engine technology to be run by its manufactured automobiles for a couple of years and whenever a new standards is introduced , the onus to implement it lies on the automakers and not on the consumers of its products. Then depending on the output demand of the emission standard , it can take many years for the manufacturer to tweak around the exisiting technology to make the engine emission norm compliant and ultimately, limiting the vehicular emissions pollution. Evolution of the automobile engine demands research and development and once that is done , full scale production technology also need to be put in place. Clearly, it raises the cost of the final product which is ultimately borne by the end consumers. Finally, the whole standard implementation set up will not reap any benefits as there is also the requirement of cleaner fuel to run these vehicles that comply with a stricter emission regulation as it is not feasible to make internal combustion engines pollute less while using poor quality of fuel. As per a report, the Centre has spent around Rs 18,000 to 20,000 crore for producing cleaner fuel. (talking of BS IV norms implemented last year nationwide after the supreme court ruling).

All of this comes at a cost which eventually makes the vehicle more expensive for the end customer of the product and that can be a cause of concern for automakers given how price sensitive the Indian market is. With the unexpected implementation order of supreme court last year in March, 2017 to roll out BS IV nationwide, automobiles sellers are facing the problem of the huge left over stock of the BS III compliant vehicles which will incur huge losses for the automobile manufacturers and on top of that they have to switch to a new technology in a short span of time and then there is BS VI in line to come in 2020. Estimation of the economic impacts of the Bharat stage emission standards is beyond the scope of this study and thus they have not been dealt here.

CHAPTER 11: CONCLUSIONS AND RECOMMENDATIONS

11.1 CONCLUSIONS

Chapter 6 to chapter 10 presents the analysis of the vehicular emissions, controlled by Bharat Stage Standards in India, on health, environment and economy for Delhi city and the corresponding inferences and conclusions have been drawn there and below is a summary of the conclusions obtained from the analysis.

- Vehicular emissions standards for NOx pollutants have been made stringent in the subsequent norms and the results were visible only after the implementation of the BS IV i.e. 2010 onwards. The visible reduction in the emissions was also attributed to the removal of the diesel run buses and due to phasing out of the age old vehicles. Also, NOx emissions were greatly affected by temperature alterations and maximum emissions were estimated for summers implying rise in NOx emissions as a direct impact of ambient temperature rise. Thus, only the implementation of the strict emission norms wont help in lowering the vehicular pollution as ambient temperature is also involved here and affecting the release of the NOx gases. Moreover, diesel run vehicles are the major culprit in the increased NOx concentrations and due to less charges on diesel, diesel run vehicles are highly preferred worldwide and SUV segment is the currently popular among the car runners and many studies have already stated the detrimental effects of the usage of these diesel run cars.
- NO_2 makes up a major portion of the NOx emissions almost 60-70% of the emitted NOx and the estimated NO_2 concentrations are almost around 90 $\mu g/m^3$ after 2011 whereas the acceptable limit for NO_2 concentrations as stated by WHO is 40 $\mu g/m^3$. Obviously the concentrations are almost double the acceptable limit and the estimated mortality rate attributable to this is quite high , ranging from 1200 to 3200 for the observed period 2001-2015. And the corresponding acid deposition loads for ambient NO2 concentrations easily exceed the UNCE recommended acceptable limits for the observed period and thus have consequent ecological impacts on the deciduous vegetation around the city.
- Emission norms for PM doesnt exist for passenger cars and two-/three- wheelers and they have proved to be the largest emitter of the particulate matter. Also, emission norms exist only for PM10 thus the finer PM2.5 gets away with the restriction and comprises for about 75% of the PM emitted from the vehicles. Also the non-exhaust PM emissions are quite high as compared to the exhaust emitted particulate matter. Particulate matter being the harmful content of the air pollution has various effects on the human health and the analysis of these using the AirQ+ software has portrayed a serious picture of it. Among the studied effects of the long term exposure of PM2.5, such as adult mortality due to lung cancer , children mortality due to ALRI , cases of IHD among adults and

COPD induced mortality in adults, maximum number of cases were estimated for heart diseases among the Delhi citizens which is a serious issue.

- Whereas, the estimation of the morbidity rate due to long term exposure of PM10 in adults and children have been observed to be quite lower and the issues face d by them are limited to bronchitis and chronic bronchitis as these particles fail to reach the internal organs due to its coarse size as compared to ultrafine and tiny PM2.5.
- Major portion of the carbon dioxide content in Delhi city is being contributed by transport sector which is almost around 32.08% and nowhere in the world where vehicular emissions norms exist, CO2 control limits have been assigned as it is nearly impossible to stop the production of this product during combustion reactions and the only alternative to limit its emission is to switch to electric vehicles and hydrogen run vehicles. Human health impacts of the CO2 concentrations exposure are limited to headache, dizziness , minor irritations but can aggravate to major problems if exposed to large concentrations in a confined space. The analysis shows the current concentrations to be in much lower than the safer limits and the hence the detrimental effects are not to be observed.
- The cumulative carbon emissions from the vehicular exhaust emitted by vehicles run in Delhi region during 2015 have been estimated to be approximately 17434110.58 tonnes making up only 1.74% of the 10^9 tonnes of carbon and this proportion of the carbon emissions is capable of rising the temperature of the region by approximately 0.04002° C. This is just an estimate and if the vehicle count keeps on rising with the current rate then the temperature rise factor can easily reach 0.1° C.
- Carbon-monoxide emissions are given out in great quantity from the vehicles and especially during the winters as the concentrations were found to be maximum in winters and least in summers simply implying that with decrease in temperature , portion of the unburned fuel increased giving rise to more CO emissions. CO is produced when there is insufficient oxygen (O_2) for the complete oxidation of hydrocarbons. Thus, CO emissions increase when the engine is operated under conditions in which there is an excess of fuel with respect to the oxygen necessary for its combustion. .Maximum emissions are contributed by cars. Least emitter tag is earned by three-wheelers running on CNG.
- When hydrocarbons released from combustion reactions are discussed then it is relevant to all the organic compounds produced which includes aldehydes, alkenes, alkynes, poly-aromatic hydrocarbons, etc formed due to incomplete combustion of the fuels in engines. Maximum emissions are contributed by two-wheelers and also their fleet number is maximum among all vehicle categories. Two-wheelers emissions trend shows a significant dip after 2006 which can be attributed to the implementation of the strict BS-III but the total emissions seems to be rising gradually which can be attributed to the leniency given in the BS-III for the heavy diesel vehicles where the earlier limit of 1.1(g/kmhr) was increased to 1.6 (g/kmhr) thus them to emit more. Since,

buses were also running on diesel along with cars and heavy vehicles, buses appear to have added increased amounts of hydrocarbons in the atmosphere.

11.2 RECOMMENDATIONS

- Bharat stage standards have been successful in lowering the NOx emissions but due the temperature effect and rising NO2 content in the NOx emissions, these standards need to be improved and engines requires major technical advancement to lower the NO2 formation among the NOx pollutants formed during combustion reactions.
- No vehicular emission norms exist for passenger cars and two-/three- wheelers for limiting the release of PM through vehicular emissions. Moreover , the existing norms only limit PM10 release in heavy diesel run vehicles. It is recommended that Bharat stage standards should incorporate the norms for the control of PM2.5 as it is observed to comprise of the major portion of the PM10 released in vehicular exhaust making almost 75% of the PM10. PM10 is mainly released as non-exhaust content that can't be restricted by any emission norms.
- For Delhi, transport sector is the major contributor of the CO2 emissions but emission norms doesn't exist for their control but some innovative concepts can be tried such as for instance, European Comission for energy, climate and environment has come up with CO2 reduction targets mandating the charging of carbon taxes if the vehicular fleet exceeds the set emissions limits for a particular year. The emission limits are set in accordance with the mass of the vehicles. Thus, such practices can be run on a trial basis to see if it helps to garner any reduction in the carbon emissions.
- Carbon-monoxide emissions and hydrocarbons are effectively controlled by vehicular emissions norms and significant reductions have been observed in the time period of study i.e., 2001-2015 particularly, during 2011-2015 with the advent of stricter BS IV, thus these emissions will be significantly reduced with the upcoming BS VI standards to be implemented by 2020 nationwide.

11.3 FUTURE SCOPE

- In this study, while carrying out the health and ecological impact analysis of NOx vehicular emissions, only that portion of the NOx is considered which comprises of the NO2 content as the comparable standards or the critical levels prescribed by the environment protection agencies such as WHO , UNCE and CBCB etc. Thus the remaining portion of the NOx emissions which comprise of the NO emissions has not been analysed here which is often omitted in many other studies or researches too owing to its instable state which eventually leads to its conversion to NO2 or ozone. Thus it is still undecided that where that left over portion of the NOx emissions goes. Hence, impact analysis of this unaccounted vehicular emission borne NO can be a separate subject of study in the future researches.

- Environmental impact analysis of PM2.5 and PM10 is usually done in limited fields such as settlement of particles in rivers , streams or lakes or deposition of these particulates on roadside vegetation or deposition assessment of particulates on stone built monuments using the deposition analyzing devices. Since, these assessment techniques require the use of specialized devices, the environmental impact assessment of these vehicular borne particulates have not been conducted here. Also, any analytical relationships doesn't exist for estimating ambient PM deposition over surfaces or vegetation or any other probable ecological impacts of their exposure to animals or birds or other essential organisms in the ecosystem. Thus, this can be a subject matter of research for future studies.
- Hydrocarbons and carbon-monoxide are not harmful individually but are potential ozone precursors and also take part in smog formation. The estimations of ozone and smog content in relation to the ambient concentrations of hydrocarvbons and carbon-monoxide, both of which form significant portions of the vehicular exhaust emissions, have not been studied thoroughly and thus demands a thorough research in this regard.

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