ASSESSMENT OF IMPACT OF VEHICULAR POLLUTION ON AMBIENT AIR QUALITY : A CASE STUDY OF GURGAON CITY

By

Deepak Malik
Enrollment No.: P020108002

COLLEGE OF ENGINEERING STUDIES

Submitted

IN PARTIAL FULFILLMENT OF THE REQUIREMENT OF THE DEGREE OF DOCTOR OF PHILOSOPHY

TO

UNIVERSITY OF PETROLEUM AND ENERGY STUDIES
DEHRADUN

October, 2014

ASSESSMENT OF IMPACT OF VEHICULAR POLLUTION ON AMBIENT AIR QUALITY : A CASE STUDY OF GURGAON CITY

By

Deepak Malik
Enrollment No.: P020108002

COLLEGE OF ENGINEERING STUDIES

Submitted

IN PARTIAL FULFILLMENT OF THE REQUIREMENT OF THE DEGREE OF DOCTOR OF PHILOSOPHY

TO

UNIVERSITY OF PETROLEUM AND ENERGY STUDIES
DEHRADUN

October, 2014

TABLE OF CONTENTS

ACKNOWLEDGEMENTS

It is a matter of great honour for me to present my thesis report on **"Assessment of Impact of Vehicular Pollution on Ambient Air Quality: A Case Study of Gurgaon City"**. First and foremost, I am profoundly grateful to my project guides Dr. Mukesh Saxena, Professor and Ex. HOD, Department of Mechanical Engineering, University of Petroleum and Energy Studies, Dehradun and Dr. Niraj Sharma, Scientist, Traffic Planning and Environment Division, Central Road Research Institute, New Delhi for their expert guidance and continuous encouragement during all stages of thesis. Their help in the form of valuable information and research thoughts at proper time has brought life in this thesis. I feel lucky to get an opportunity to work with them. I am thankful to the kindness and generosity shown by them towards me, as it helped me immensely in completing the project. I also wish to thank the entire faculty of Department of Mechanical Engineering, University of Petroleum and Energy Studies for their constant encouragement.

In particular, I owe my deepest regards and reverence to Dr. Mukesh Saxena Professor and Ex. HOD, Department of Mechanical Engineering, University of Petroleum and Energy Studies, Dehradun and Dr. Niraj Sharma, Scientist, Transportation Planning and Environment Division, Central Road Research Institute (CRRI) CSIR, New Delhi for their constant guidance and endless support, right from the development of the concept, setting framework for the approach adopted and to bring the study in its present form. They always provided me a genial atmosphere and gave me access to all possible resources. Both Dr. Mukesh Saxena and Dr. Niraj Sharma gave me the time and motivation required during various phases of my project work.

I also wish to express my heartfelt gratitude and appreciation to all the staff of the Department of Mechanical Engineering, University of Petroleum and Energy Studies, and Central Road Research Institute for their kind help and valuable assistance during the entire course of my project work.

I would like to express my thanks to my family members for their unconditional support and bearing with me through the course of my research. I am grateful for the blessings of my parents Mr. Tarif Singh Malik and my mother Mrs. Suman Malik. I would also like to mention my wife Dr. Anjali Malik who was a source of inspiration for me and my two children Pareesha and Shaurya who are my lifelines.

I am also thankful to all other friends and loved ones for their unconditional support and motivation during this research.

DEEPAK MALIK

DECLARATION

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which has been accepted for the award of any other degree or diploma of the university or other institute of higher learning, except where due acknowledgment has been made in the text.

Deepak

(DEEPAK MALIK)

October 28, 2014

CERTIFICATE

This is to certify that the thesis entitled "**Assessment of Impact of Vehicular Pollution on Ambient Air Quality: A Case Study of Gurgaon City**"submitted by **Sh.Deepak Malik** to **University of Petroleum and Energy Studies, Dehradun** for the award ofthe degree of Doctor of Philosophy is a bona fide record of the research work carried out by himunder our supervision and guidance. The content of the thesis, in full or parts have not beensubmitted to any other Institute or University for the award of any other degree or diploma.

Internal Research Supervisor	**External Research Supervisor**
(Dr. Mukesh Saxena)	**(Dr.Niraj Sharma)**
Professor and Ex. HOD	Scientist
Department of Mechanical Engineering,	Traffic Planning and Environment Division,
University of Petroleum and Energy Studies, Dehradun	Central Road Research Institute, New Delhi
Place: Dehradun	Place: New Delhi
Date:01/11/2014	Date:01/11/2014

iv

THESIS COMPLETION CERTIFICATE

This is to certify that the thesis on "**Assessment of Impact of Vehicular Pollution on Ambient Air Quality: A Case Study of Gurgaon City**" by **Sh.Deepak Malik** in Partial completion of the requirements for the award of the Degree of Doctor of Philosophy (Engineering) is an original work carried out by him under our joint supervision and guidance.

It is certified that the work has not been submitted anywhere else for the award of any other diploma or degree of this or any other University.

Internal Research Supervisor	**External Research Supervisor**
(Dr. Mukesh Saxena)	**(Dr.Niraj Sharma)**
Ex. Professor	Scientist
College of Engineering Studies,	Traffic Planning and Environment Division,
University of Petroleum and Energy Studies, Dehradun	Central Road Research Institute,
Place: Dehradun	Place: New Delhi
Date: 01/11/2014	Date: 01/11/2014

v

EXECUTIVE SUMMARY

Transport affects the local and global environment in many ways and for a number of pollutants the road transport sector is one of the most significant contributors to environment externalities. The transportation activities particularly related to motor vehicle have been closely identified with increasing air pollution levels in various urban centres of the world.

Urban development is primarily linked with high vehicular density in urban areas which ultimately impacts air pollution. As most of the motor vehicles are found in urban cities and the trends is towards increasing urbanization specially in developing countries like India, it is expected that the vehicular air pollution related problems will further increase in future in these urban cities.

Vehicular Air Pollution

Transport sector contributes around 14% towards the global emissions of greenhouse gases. CO_2 represents the largest proportion of basket of greenhouse gas emissions. With rapid urbanization, road transport related CO_2 emissions from urban areas are likely to increase further in coming years mainly due to inadequate public transport system, high vehicle density in urban areas and increasing share of private vehicles vis-a-viz public transport vehicles in developing countries.

The problem of air pollution has assumed serious proportions in some of the major metropolitan cities of India due to concentration of large number of vehicles. In India, the number of motor vehicles has grown from 0.3 million in 1951 to 142 million in 2011, of which, two wheelers (mainly driven by two stroke engines) account for 70% of the total vehicular population. Two wheelers (2W) and car {four wheelers (4W), excluding taxis} which mainly constitute personal mode of transportation, account for approximately four-fifths of the total vehicular population. Vehicles in major metropolitan cities in India are estimated to account for 70% of CO, 30%-40% of NOx, 30% of SPM and 10% of SOx of the total pollution load of these cities.

Motivational Need and Overview

Gurgaon, an important satellite town in NCR has witnessed tremendous population growth and as a result motor vehicles increased immensely & threatening the urban-environmental conditions. In-spite of innovative approaches to develop Gurgaon in a systematic and coordinated manner, the seriousness of urban problems due to sudden population rise has been accelerating and threatening the urban-environmental conditions in Gurgaon. Transport facilities in Gurgaon are not adequate and have been deteriorating over the years. The development of public transport has not kept pace with traffic demand both in terms of quality and quantity. As a result, use of personalized vehicle and intermediate public transport is growing at a rapid rate. Public has encroached the parking space, footpaths and has further restricted the traffic flow. The levels of air quality due to vehicular pollution would be worthwhile to study.

Hence, an effort will be made through this study by considering the above factors and trying to establish a baseline traffic and transport scenario to understand its impact on Ambient Air Quality with seasonal variation, further to establish the relation between total vehicles and air pollutants and to establish relation between various air pollutants and meteorological attributes. CALINE 4 model has been used to predict the concentrations of CO and a sensitivity analysis has been performed with different combination of meteorological and traffic parameters to identify the most influential input variable among the various input variables. Based on the outcome of this study the remedial measure in form of Environmental Management Plan has been suggested to address the problem.

Review of Literature

To study the impact of vehicular pollution on ambient air quality, literature was reviewed extensively from different sources such as Ministry of Environment and Forests Library, Central Pollution Control Board, IIT, Delhi –Library, Indian Road Congress Publications, Ministry of Road Transport and Highways, Google Scholar etc. The literature gave reference of around 200 studies related to air pollution, and for the purpose of our study we have mentioned around 120 studies which are more closely related to impact of vehicular pollution on ambient air quality. The review of the literature was comprehensively summarized in the form of a table in literature review chapter, which provides a brief overview of the key published studies in the domain of ambient air quality and its relationship with different sources of pollution for identifying different sources explaining the phenomena.

Gaps identified from previous literature

In majority of the research papers the researches have tried to identify the various types of pollutants that are emitted by automobiles in city which becomes a cause for increasing air pollution problem. In some of the studies the researchers have tried to monitor and collect the data for various air pollutants in different part of the cities and have compared the collected primary data with National Ambient Air Quality Standards to identify the areas with high pollution levels.

Some researchers have tried to understand urban vehicular pollution problems vis-à-vis ambient air quality in megacity, while some researchers have tried to study the impact of air pollution on health, while some researchers have tried to study the relation between meteorological factors and air pollutants. Recently some of the researchers have studied the vehicular air pollution with regards to CO_2 emissions while some researchers have tried to evaluate various air dispersion models for urban highway corridor.

There was no comprehensive study which could highlight various air pollution impacts due to vehicular pollution in a city. Hence, it was felt that a comprehensive study to assess impact of vehicular pollution on ambient air quality should be undertaken.

Objectives of the present study

The brief objectives of the present study was to establish a baseline traffic in terms of traffic volume and transport scenario in terms of traffic composition to understand its impact on ambient air quality with seasonal variation within the urban limits of Gurgaon; to establish the relation between total vehicles and air pollutants at selected corridors and to study the relation between various air pollutants and meteorological attributes at selected corridors; to predict air concentrations of Carbon monoxide (CO) using CALINE 4 model for future 5 years; to carryout sensitivity analysis on predicted concentrations with different combination of meteorological and traffic parameters; and to suggest remedial measures by preparing Environmental Management Plan.

Reasearch Methodology

The five road corridors representing different land-use pattern were selected for the study. National Highway- 8, Mehrauli- Gurgaon road and Gurgaon – Sohna road are important roads which account for major incoming and outgoing traffic movement in the city. All three road corridors which represent different land-use patterns (high traffic zone, major commercial area and a rural area) have been chosen for the present study. The other road corridors which have been selected represents other land-use pattern i.e. semi urban and residential areas.

The following field surveys were conducted for the research study:

i. **Traffic Volume Count Survey**
ii. **Ambient Air Quality Monitoring Survey**
iii. **Fuel Station Survey** (Fuel used in vehicle & Age of vehicle)
iv. **Road Geometry Survey** (carriageway width, median width)

Apart from above surveys meteorological data was collected from Indian Meteorological Department (IMD) for wind speed, wind direction, rainfall, stability class and ambient temperature. The mixing height data (for winter month) was also obtained from IMD and was used in the present study for modeling purpose.

Four hourly classified traffic volume count survey has been conducted at all the five road corridor for period of 16 hours from 6.00 am to 10.00 pm on normal working days covering both morning peak hours and evening peak hours. The traffic volume data has been collected on 4 hourly basis for the time periods 06.00 to 10.00 hours; 10.00 to 14.00 hours; 14.00 to 18.00 hours and from 18.00 to 22.00 hours during two seasons - monsoon (in the month of August 2010) and pre-monsoon (in the month of March 2011). While hourly data for 24 hours was collected for the month of December, 2010 for modeling purpose. Ambient air quality monitoring survey was also conducted simultaneously at all the five road corridors for parameters – PM_{10}, $PM_{2.5}$, SO_2, NOx and CO. Fuel station survey was carried out the fuel being used in vehicle & its vintage. The road geometry surveys was carried out at all five road corridors to collect the information about road geometry. The details collected on road geometry included information pertaining to laning of the road; carriageway width and median width.

In the present study to predict air concentrations of Carbon monoxide CALINE4 model was used to predict the concentration of CO emitted from vehicle exhaust under standard meteorological conditions. The model was run for 24-hour period during post-monsoon season. Hourly weighted emission factors were calculated using the hourly traffic data recorded on study corridors. As the road corridor 1 (near IFFCO Chowk on NH-8) recorded the significantly higher traffic volumes in comparison to other road corridors, the modeling was performed only for the corridor 1. Further, as CO is the principal pollutant from the vehicular exhaust, the modeling was performed for CO only. Under standard meteorological condition, the CALINE4 model predicts the pollutant concentration in the prevailing wind direction; hence hourly concentration values at predetermined receptor locations were obtained. CO predictions have been done for year 2010 and for next five years thereafter i.e. for year 2015.

18 receptor points (9 points on each side of the road corridor) was selected at pre-identified receptor location with a specified distance from the edge of the mixing zone width (road width + 3 m on each side of the corridor) i.e. 1 m, 5m, 10m, 20m, 30m, 50m, 75m, 100m and 150m from the edge of the road on both the side.

The following results were obtained from CALINE4 model run for year 2010–

a) During the 24-hour period in which the model was run, two distinct peak concentration levels were observed during the morning and evening time; however the evening time peak concentration levels were significantly higher than the morning peak concentration level.

b) Morning Time Peak - The morning time peak was recorded between 9 am to 10 am. The total vehicle recorded vehicles were 22060 and emission load was 59725.95 gm/km

c) Evening Time Peak – The evening time peak was recorded between 7 pm to 8 pm. The total vehicle recorded vehicles were 23162 and emission load was 69319.25 gm/km.

The maximum predicted concentration at 1 m distance from the mixing zone was 3.41 mg/m^3 on Left side of the road. The pollutant concentration decreases drastically to 1/3rd within 50m distance from the mixing zone. After 50m distance, the pollutant concentration decreases gradually to baseline concentration levels.

In order to predict CO concentration for year 2015, all the meteorological parameters were kept constant and only projected traffic volume was calculated with an annual rise of 8% for first 3 years and 7% for 4^{th} and 5^{th} year. The maximum predicted CO concentration at receptor point on Left side of the road at 1 m distance from the mixing zone was found to be 4.44 mg/m^3. If we compare the predicted CO Concentrations of year 2010 and year 2015, it is observed that the CO Concentration will increased by 1.03 mg/m^3 in 5 next years' time. It is also observed that the predicted CO Concentration levels in year 2015 will exceed the limits of NAAQS of 4.0 mg/m^3. The projected maximum hourly total traffic volume and total traffic load for year 2015 was 33353 and 99819.72 gm/km respectively.

Conclusions and Findings

The baseline traffic and transport scenario was established to understand the impact on ambient air quality at selected 5 road corridors within Gurgaon city.

The corridor 1 is 6-lane road and has a capacity of handling about 1.2 lakhs passenger car units (PCU) per day, while at present the corridor is handling over 2.5 lakhs PCUs. Similarly corridor 2 is 4-lane road and has a capacity of handling about 0.4 lakhs PCUs, while at present the corridor is handling over 1.0 lakhs PCUs. Simultaneously it was also observed that pollutants PM_{10}, $PM_{2.5}$ and CO concentrations when compared with National Ambient Air Quality Standards of CPCB were also found to be above permissible limits both in corridor 1 & corridor 2. The percentage proportion of buses is very less (less than 3%) in all the 5 road corridors which shows inadequate public transport facility in the city. On the other hand, the percentage proportion of car/jeeps and 2 wheelers is very high (over 70%) which, shows more use of personalized vehicle in absence of adequate public transport system. According to the results of seasonal variation in ambient air quality, high concentration of air pollutant was recorded in the winter seasons due to low temperature and low wind speed. This may be due to the stable atmospheric conditions leading to accumulation of pollutants in the area.

To establish the relation between air pollutants and total vehicles a correlation and regression analysis was undertaken between various air pollutants and total vehicles for all 5 road corridors. Linear regression models developed in the study have been scrutinized using R^2 values. The R^2 values were found supporting the hypothesis that there is a significant relationship between total traffic volume and level of air pollutants. The R^2 values reported moderately high to very high values ranging from 0.6 to 0.99 for various pollutants.

To establish the relationship between meteorological parameters and air pollutant concentration the data collected for PM, SO_X, NO_X and CO was statistically compared with meteorological variables such as relative humidity, temperature and wind speed. The correlation analysis established a moderately high relationship between air pollutant concentration and wind speed, a moderate relationship between relative humidity and a weak relationship is seen between air pollutant and temperature.

The concentration of CO was predicted for corridor 1 where two distinct peak concentration levels were observed during the morning and evening time. The morning time peak was recorded between 9 am to 10 am. The evening time peak was recorded between 7 pm to 8 pm. The maximum predicted concentration of CO for year 2015 at 1 m distance from the mixing zone was 4.44 mg/m^3 on Left side of the road. When we compared the CO Concentrations of year 2010 and year 2015 it was observed that the predicted CO Concentration increased by 1.03 mg/m^3 in next 5 years. The predicted CO concentration when compared with NAAQS was also found to be exceeding the permissible limits.

The sensitivity analysis on predicted concentrations of CO was carried out with different combination of meteorological parameters (wind speed & wind angle) and traffic parameters (road width & median width). The results of sensitivity analysis revealed that wind angle, wind speed and road width are significant input variables while median width was less significant input variable.

The increasing air pollution from motorized vehicles is the leading cause of deterioration of air quality in Gurgaon. Concentration of PM_{10}, $PM_{2.5}$ & CO at road corridors 1, 2 and 3 are exceeding the National Ambient Air Quality Standards. Also calculated AQI levels at these three road corridors show an unhealthy air quality. Hence an Environmental Management Plan with site specific remedial measures has been suggested for these road corridors. In addition to this a general remedial measures are also suggested which can be implemented on all the 5 road corridors and on other urban roads of Gurgaon.

As a remedial measure an environmental management plan has been suggested which emphasis on strengthening of Public Transport in Gurgaon. Mass Transport system in Gurgaon is inadequate. Intra-urban mass transport system is almost negligible. The result is that personalized mode of transport is used heavily which is creating congested conditions on roads. The share of mass transport needs to be increased substantially by way of augmenting mass transport infrastructure, not only for intra-urban but also with Delhi and other urban areas.

The other suggestions pertains to proper traffic management, traffic segregation, providing adequate traffic control system, proper land use planning, regulating pedestrian/ vehicle restricted areas and by introducing cleaner fuels. The road side plantation acts as a carbon sink. The road side plantation along M.G. Road and Sohna road is almost absent. Also at various locations along NH 8 the tree planation cover is missing. Suggestion to plant more trees along these roads so that maximum pollutants can either be filtered or absorbed near the source has been proposed. A preview of further research which may be needed in this area has also been suggested.

ABBREVIATIONS

2W	Two Wheelers
4W	Four Wheelers
ARAI	Automotive Research Association of India
BARC	Bhabha Atomic Research Centre, Mumbai
CALINE 4	California Line Source Dispersion Model (Version 4)
CESE	Centre for Environmental Science & Engineering, Mumbai
CFCs	Chlorofluorocarbons
CMVR	Central Motor Vehicle Rules
CNG	Compressed Natural Gas
CNG	Compressed Natural Gas
CO	Carbon monoxide
CO_2	Carbon monoxide
CoP	Conformity of Production
CPCB	Central Pollution Control Board
DMRC	Delhi Metro Rail Corporation
DPCC	Delhi Pollution Control Committee
DTC	Delhi Transport Corporation
EIA	Environmental Impact Assessment
EPA	Environmental Protection Agency
EPCA	Environmental Protection & Control Authority (for NCT/NCR)
ERP	Electronic Road Pricing
GFLSM	General Finite Line Source Model
GHGs	Greens House Gases
HC	Hydro Carbon
IEA	International Energy Association
IFFCO	Indian Farmers Fertilizer Cooperative Limited
IIT	Indian Institute of Technology
IITLS	Indian Institute of Technology Line Source (model)
IMD	Indian Meteorological Department
IOC	Indian Oil Corporation
ISBT	Inter State Bus Terminal

LHS	Left Hand Side
LPG	Liquefied Petroleum Gas
MOEF	Ministry of Environment and Forests
MoPNG	Ministry of Petroleum and Natural Gas
MoRT&H	Ministry of Road Transport and Highways
MVA	Motor Vehicles Act
NAAQS	National Ambient Air Quality Standards
NAMP	National Air Quality Monitoring Programme
NCR	National Capital Region
NCRPB	National Capital Region Planning Board
NCT	National Capital Territory
NH_3	Ammonia
NH	National Highway
NO_X	Oxides of Nitrogen
O_3	Ozone
OICA	Organisation Internationale des Constructeurs d'Automobiles
Pb	Lead
PCUs	Passenger Car Units
PM	Particulate Matter
PM_{10}	Particulate Matter with a diameter less than 10 µm
$PM_{2.5}$	Particulate Matter with a diameter less than 2.5 µm
PUC	Pollution Under Control
RHS	Right Hand Side
RoW	Right of Way
RRTS	Rapid Rail Transit System
RSPM	Respirable Suspended Particulate Matter
SO_2	Sulphur dioxide
SPM	Suspended Particulate Matter
S	South
SW	South West
SSE	South South East
SSW	South South West

TERI	The Energy Research Institute, New Delhi
TSPM	Total Suspended Particulate Matter
UA	Urban Agglomerations
UAs	Urban Agglomerations
UN	United Nations
UNEP	United Nations Environmental Programme
USEPA	United States Environmental Protection Agency
WEF	Weighted Emission Factor
W	West
WSW	West South West
WHO	World Health Organization

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1.0

INTRODUCTION

1.1 INTRODUCTION

Transport affects the local and global environment in many ways and for a number of pollutants the road transport sector is one of the most significant contributors to environment externalities. Although, the significance of motor vehicle in overall socio economic development cannot be denied, but recently motor vehicles have been identified with various environmental pollution problems. The transportation activities particularly related to motor vehicle have been closely identified with increasing air pollution levels in various urban centers of the world. Substantial CO_2 emissions apart from significant quantities of CO, SPM and NO_x are emitted from the transport activities, particularly from the road transportation, causing serious environmental and health impacts. Besides air pollution, the pollutants emitted from these vehicles are responsible for various regional and global problems such as global warming, acid rain, ozone depletion etc., which are even threatening the very survival and existence of the mankind. Worldwide, the number of motor vehicles is growing faster than global population – about 5 per cent per year compared with 2 per cent for population (Sharma et al., 2008).

The analysis of global motor vehicular registration trends reveal that the global fleet has been growing linearly since 1970's and each year, for four decades, an additional 18 million motor vehicles have been added to world fleet.

India has experienced a tremendous increase in the total number of registered motor vehicle. The total number of registered motor vehicles increased from 0.3 million in 1951 to 142 million in 2011(MoRT&H, Year Book 2010-11). The total registered vehicles in the country grew at a Compounded Annual Growth Rate of

9.9% between 2010 and 2011. The decadal registered motor vehicle trend since 1951 to 2011 is shown below in **Table 1.1:**

Table 1.1: Decadal Registered Motor Vehicle Trend – India (1951 - 2011)

Year	No. of Registered Motor Vehicles (in million)
1951	0.3
1961	0.7
1971	1.9
1981	5.4
1991	21.4
2001	55.0
2011	141.8

Source: Ministry of Road Transport and Highways, Govt. of India
(Road Transport Year Book 2009-10 and 2010-11)

Urban development is primarily linked with high vehicular density in urban areas which ultimately impacts air pollution. As most of the motor vehicles are found in urban cities and the trends is towards increasing urbanization specially in developing countries like India, it is expected that the vehicular air pollution related problems will further increase in future in these urban cities.

1.2 VEHICULAR AIR POLLUTION

Environmental concerns have become one of the most impotant issues in transport policy debates. Significant quantities of CO, HC, NOx, SPM and other air toxins are emitted from the motor vehicles into the atmosphere causing serious environmental and health impacts. Air pollution from motor vehicles in many countries, has replaced coal smoke as the major cause for concern. However, continuing growth in vehicle use means that efforts to reduce emissions from individual vehicles are being overtaken by increase in the volume of traffic. Vehicular traffic has become a major source of air pollution in urban areas.

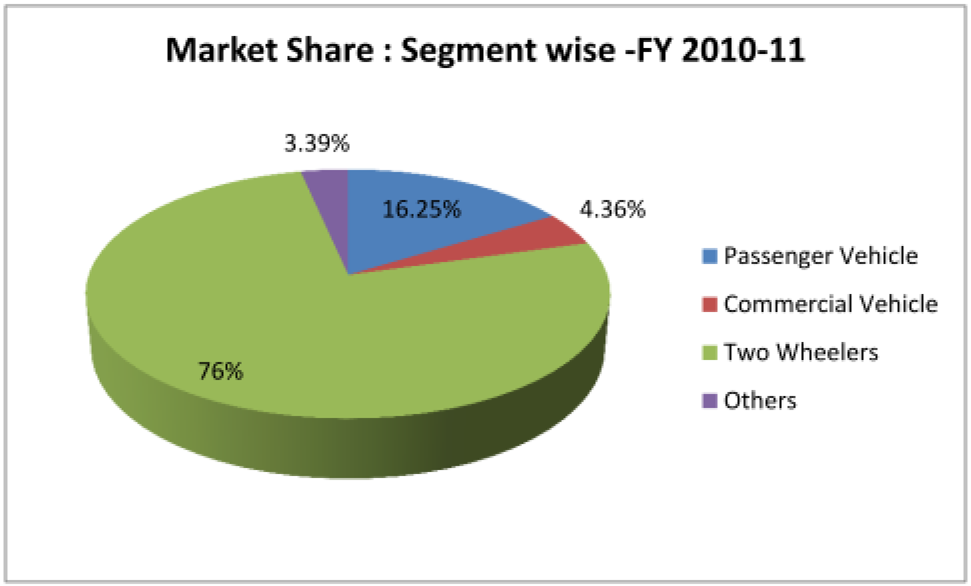
Transport sector contributes around 14% towards the global emissions of green house gases (CPCB, 2010). Carbon dioxide represents the largest proportion of basket of greenhouse gas emissions. With rapid urbanization, road transport related CO_2 emissions from urban areas are likely to increase further in coming years mainly due to inadequate public transport system, high vehicle density in urban areas and increasing share of private vehicles vis-a-viz public transport vehicles in developing countries (Sharma et al., 2010). During, the past three decades CO_2 emissions from transport have increased faster than those from all other sectors and are projected to increase more rapidly in future. From 1990 to 2007, CO_2 emissions from the world's transport sector have increased by 36.5%. Also, for the same period, road transport emissions have increased by 29% in industrialized countries and 61% in the other countries (CPCB, 2010). Worldwide, transport sector is responsible for approximate 23% of energy related CO_2 and 13% of all GHGs emitted from various sources. Further, CO_2 emissions is expected to increase by 1.7% a year from 2004 to 2030 largely attributable increased demand for mobility in developing countries where it is expected to grow with an average of 2.8% a year for the same period.

1.3 VEHICULAR AIR POLLUTION IN INDIA

Like many other parts of the world, air pollution from motor vehicles has become one of the most serious and rapidly growing problems in urban cities of India as well. Although, the improvements in air quality with particular reference to the criteria pollutants (SPM, SO_2, NO_X) have been reported for some of the metropolitan cities, the air pollution situations in most of the Indian cities is still not known and is a cause of increasing concern. Air pollution levels in urban centers (particularly metropolitan cities) generally exceed the National Ambient Air Quality Standards (NAAQS) specified by the Central Pollution Control Board (CPCB) and the World Health Organization guidelines for air pollution levels (CPCB, 2006). Vehicular emissions have been identified as one of the major contributors in deteriorating air quality in these centers.

The problem of air pollution has assumed serious proportions in some of the major metropolitan cities of India. The problem has further been compounded by the concentration of large number of vehicles and comparatively high motor vehicles to population ratios in these cities. In India, the number of motor vehicles has grown from 0.3 million in 1951 to 142 million in 2011, of which, two wheelers (mainly driven by two stroke engines) account for 70% of the total vehicular population. Two wheelers (2W) and car {four wheelers (4W), excluding taxis} which are mainly constitute personal mode of transportation, account for approximately four-fifths of the total vehicular population. Similarly, human population has also increased from 361 million to more than 1000 million during this period. In India, 25% of the total energy (of which 98% comes from oil) is consumed by road sector only. Although gasoline vehicles dominate (approximately 85%) the vehicular population, the consumption of diesel is six times more than the consumption of gasoline (petrol). A gradual shift in passenger and freight movement from rail to road-based transportation has also lead to marked increase in fuel consumption by the road sector which ultimately results in increased emissions of various pollutants. Vehicles in major metropolitan cities in India are estimated to account for 70% of CO, 30%-40% of NOx, 30% of SPM and 10% of SOx of the total pollution load of these cities (Goyal et al., 2006).

Increase in urban population, which constitute about 31% of the India's population (from approximately 17% to 28% during 1951-2001) has resulted in larger concentration of vehicles in these urban cities specially in four major metros, namely Delhi, Mumbai, Chennai and Kolkata account for more than 15% of the total vehicular population of the whole country, whereas, more than 45 other metropolitan cities (with human population more than 1 million) account for 35% of the vehicular population in the country. Two wheelers account for about 75% of the total vehicular population. Segment wise market shares of vehicles in India in 2010-11 is shown in **Figure 1.1.**



Source: SIAM

Figure 1.1: Segment Wise Market Share of Vehicles in India 2010-11

1.4 URBANISATION TRENDS

Between 1950 and 2000 the global urban population has more than tripled to reach 2.86 billion. More people are residing in urban areas than in rural areas today. While urbanization has considerably slowed down in developed countries, developing countries are getting urbanized the most; accounting for 68% of the urban population in 2000. By 2020, 77% of the global urban population (3.26 billion) is expected to be in developing countries.

The 2011 census of India shows that out of the total population of 1210 million, about 833 million (68.84%) live in rural areas and 377 million (31.16%) in urban areas. The percentage decadal growth of population in rural and urban areas during last decade is 12.2 and 31.8 percent respectively. The census shows that there are 468 Class I Urban Agglomerations (UAs)/towns which accounts for 70% of total urban population (264.9 million persons), live in these Class I UAs/Towns. Out of 468 UAs/Towns belonging to Class I category, 53 UAs/Towns each has a population of one million or above each. Known as Million Plus UAs/Cities, these are the major urban centers in the country. About 160.7 million persons (or 42.6% of the urban population) live in these Million Plus UAs/Cities. While the number of urban centers doubled between 1901 and 1991, the urban population increased eight-fold in the same period. Further demographic and economic growth is likely to concentrate in and around 60 to 70 large cities in the country having a population of million people or more.

1.5 MOTIVATIONAL NEED AND OVERVIEW

Gurgaon has witnessed tremendous growth in the recent past and has emerged as a major commercial hub in the NCR. Rampant urbanization and industrial growth have resulted in about 74% increase in Gurgaon's' population in the last 10 years (Census, 2011).The main reasons for the growth of Gurgaon can be attributed to the Government of Haryana, which opened the doors for the private sectors development and investments, attracting people mainly from Delhi to settle here. The growth of the residential colonies, industrial areas, clubs, hotels, shopping malls, golf course, and corporate houses reveal that Gurgaon can be compared to any modern cities of today.

In-spite of innovative approaches to develop Gurgaon in a systematic and coordinated manner, the seriousness of urban problems due to sudden population rise has been accelerating and threatening the urban-environmental conditions in Gurgaon.

Transport facilities in Gurgaon are not adequate and have been deteriorating over the years. The development of public transport has not kept pace with traffic demand both in terms of quality and quantity. As a result, use of personalized vehicle and intermediate public transport is growing at a rapid rate. Public has encroached the parking space, footpaths and has further restricted the traffic flow. The quality of road surface in most part of the city is also not very good. In addition, most of the intersections are without traffic rotaries/ signal lights.

Automobile exhaust has emerged as the most important line sources of air pollution in the urban context. Gurgaon being one of the most upcoming towns of NCR has been facing immense vehicular pressure on National Highway-8 (NH-8) in recent years. Having single connectivity from South Delhi to Gurgaon (Mehrauli - Gurgaon), the 21 Km Delhi-Gurgaon stretch handles over 2.0 lakh Passenger Car Units (PCUs) daily against its capacity of 40,000 PCUs. Traffic on Mehrauli - Gurgaon is fast attaining dangerous proportions.

Available studies conducted in India and abroad indicate that vehicular emissions are one of the causes of respiratory and ocular ailments, but do not quantify a cause-effect relationship between pollutants and health. The deterioration of urban air in arterial streets due to vehicular traffic exhaust and its interaction with the environment is causing a perceivable discomfort in daily life. Hence, an effort will be made through this study by considering the above factors and trying to establish a baseline traffic and transport scenario to understand its impact on Ambient Air Quality with seasonal variation, further to establish the relation between total vehicles and air pollutants and to establish relation between various air pollutants and meteorological attributes. CALINE 4 model has been used to predict the concentrations of CO for future five years and a sensitivity analysis has been performed with different combination of meteorological and traffic parameters to identify the most influential input variable among the various input variables. Based on the outcome of this study some suggestive measures in form of Environmental Management Plan has been proposed which would be suitable for the policy makers for taking appropriate measures to address the problem.

1.6 OBJECTIVES OF THE PRESENT STUDY

Traffic pollution is becoming a major source of air pollution in urban environment. Meteorological factors play a critical role in ambient concentration of air pollutants. Even though the total discharge of air pollutants into the atmosphere may remain constant, the ambient concentrations of air pollutants may vary depending upon meteorological conditions.

The other parameters related to road traffic, affecting the environmental pollution as identified in extant literature are: traffic flow, traffic speed, and proportion of heavy vehicles, width of the road, gradient, surface roughness and median width. The vehicle exhaust emissions increase with the frequency of speed change and idling time. The growing vehicle pollution and non-expanding road infrastructure have forced the automobile to travel under congested conditions including increased stopped delays at intersections. Transport facilities in Gurgaon are not adequate and have been deteriorating over the years thus contributing towards pollution of ambient air. Hence, there is a need to study the impact of vehicular pollution on ambient air quality in Gurgaon city. This specific research addressed the following:

i. To establish a baseline traffic in terms of traffic volume and transport scenario in terms of traffic composition to understand its impact on Ambient Air Quality with seasonal variation within the urban limits of Gurgaon.

ii. To establish the relation between total vehicles and air pollutants at selected corridors and to study the relation between various air pollutants and meteorological attributes at selected corridors.

iii. To predict air concentrations of Carbon monoxide (CO) using CALINE 4 model for future 5 years

iv. To carryout sensitivity analysis on predicted concentrations with different combination of meteorological and traffic parameters.

v. To suggest remedial measures by preparing Environmental Management Plan.

1.7 CHAPTER SCHEME

The tentative chapter scheme of the thesis has been divided into 5 Chapters:

Chapter 1.0: Introduction - This chapter introduces the topic and gives an over view how urbanisation is leading to increase in vehicular population and thereby affecting the air quality in urban towns. It also explains the motivational needs for the study and objectives of this study.

Chapter 2.0: Literature Review - This chapter describes in details and provides an overview of the key published studies in the domain of establishing baseline ambient air quality in urban areas followed by studies related to interaction between air pollution and meteorology. The later section describes about characteristic of various air dispersion models, introduction to CALINE 4 model and comparison with other line models. The last section describes about the literature related to air quality index followed by gaps identified from previous literatures.

Chapter 3.0: Research Methodology – This chapter describes in details about the study region, followed by various field surveys which were conducted to collect the data. The later sections describes in details about the methodology followed for predicting air quality using CALINE 4 model followed by detailed methodology about how the sensitivity analysis using CALINE 4 model was performed in the study to identify the most influential input variable among the various input variables. The last section provide details about the methodology adopted to study the cumulative effect of concentration of individual pollutants expressed through Air Quality Index based on which environmental management plan has been suggested.

Chapter 4.0: Results and Discussion - This chapter discusses the various results that have been made out of the present study. Also a suggestive Environmental Management Plan has been proposed to mitigate the problem.

Chapter 5.0: Conclusions and Findings - This chapter deals with brief summary of report that has been drawn out of the present study. It also presents the significant findings of the study and novelty of the research. Finally, the last section presents the recommendations for future work that can be undertaken by researchers.

CHAPTER - 2

REVIEW OF LITERATURE

2.1 REVIEW OF LITERATURE

At any point of time, the quality of air i.e. ambient air quality would be determined by the amount of pollutants present, the rate at which they are released from different sources and also how quickly the pollutants get dispersed into the environment. There have been lot of research on assessment and establishment of baseline ambient air pollution and also there have been lot of research studies to study the impact of meteorological parameters on air pollutant. Lately there have been research studies on air dispersion modelling. Previous researches have used various mathematical models or simulations to assess air pollution, its dispersion in the environment and the impact on overall air quality in the region so as to able to estimate the level of pollution concentration. Such models then result in assisting designing of effective control strategies to reduce emissions of harmful air pollutants (Singh et al., 2006). To study the impact of vehicular pollution on ambient air quality, literature was reviewed extensively from different sources such as Ministry of Environment and Forests Library, Central Pollution Control Board, IIT, Delhi – Library, Indian Road Congress Publications, Ministry of Road Transport and Highways, Google Scholar etc. The literature gave reference of around 200 studies related to air pollution, and for the purpose of our study we have mentioned around 120 studies which are more closely related to impact of vehicular pollution on ambient air quality.

Extant researches on assessing ambient air quality in urban areas have highlighted the role of vehicular pollution as a major contributor to air pollution and air quality (Kandlikar and Ramachandran, 2000; Goyal et al., 2006; Anjaneyulu et al., 2006; Ganguly et al., 2009; Sharma et al., 2013). Nearly 50% of global CO and NO_X emissions from fossil fuel combustion come from gasoline and diesel powered engines. In the city centres, especially on highly congested roads, traffic can be responsible for as much as 90-95% of ambient CO levels, 80-90% of the NO_X and large portion of the particulates, posing a significant threat to human health and natural resources.

In Europe and United State, Small and Kazimi (1995) reported that motor vehicles emission account for 92 – 98% of national emission of CO. Furthermore, Cline (1991) stated that transportation accounts for an important fraction of greenhouse gases (especially CO_2) emission. As per an estimate, air pollution contribution of transport sector was about 72% in Delhi and 48% in Mumbai (Goyal et al., 2006).

The origin of urban air pollution is mainly in anthropogenic emission sources, which include automobiles, industries, and domestic fuel combustion. In arid and semi-arid regions, deserts contribute to urban air pollution as does the sea in coastal regions. The air pollutants so generated are detrimental to human health. In addition, they cause negative impacts directly or indirectly, if at high concentrations, on vegetation, animal life, buildings and monuments, weather and climate, and on the aesthetic quality of the environment (Stern, 1976; Godish, 1985; Takemura et al., 2007, Shen et al., 2009). Rates of increase of air pollutant concentrations in developing countries such as India are higher than those in developed countries and hence atmospheric pollution is often severe in cities of developing countries all over the world (Mage et al., 1996).

In India extant researches have been carried out to establish baseline traffic and transport scenario and to understand impacts on ambient air quality in urban areas. Saini et al. in 1994 monitored suspended particulate matter in Chandigarh to study deteriorating air quality. Atmospheric concentrations of the SPM in the Chandigarh city and its industrial area were measured from April to December 1993. The data collected was investigated and its statistical distribution, the weekly, daily and monthly variations was studied. On the whole a resident of city was exposed to over the maximum desirable level of 200 $\mu gm/m^3$ for about 126 day whereas a person in the industrial area was exposed to over the stipulated limit of 500 $\mu g/m^3$ for about 13 day. Later Bansal in 1996 monitored NO_2 Concentration to establish ambient air quality of Bhopal city with reference to nitrogen dioxide. In the commercial areas maximum NO_2 was recorded as 96.4 $\mu gm/m^3$. Corresponding value in the industrial area as 66.3 $\mu gm/m^3$ and 53.5 $\mu g/m^3$ in the residential area. Das et al. in 1997 monitored SO_2, NO_2 and CO concentration during evening peak traffic hours in Jaipur to study the rapid assessment of air quality in Jaipur city and to identify critical zones for evolving a proper environmental management strategy. Later Panwar et al. in 1997 monitored SPM, SO_2 and NO_x in 62 cities across India to study ambient air quality status of various cities in India. The air quality levels were compared against the prescribed standards to draw inferences regarding the pollutant (s) of concern and the severity of the problem at various cities/towns in the country. Analysis of the data reveals the prevalence of high SPM pollution levels in most of the cities, while only a few of them have high SO_2 or NO_x problem.

Similarly Joshi in 1998 established baseline for suspended particulate matter, oxides of nitrogen and sulphur di-oxide to study the ambient air quality in Indore city. The change in concentration of these parameters for a period of five years from 1991 to 1995 was monitored and various causal factors were discussed. The values of suspended particulate matter exceeded the prescribed standards for commercial and residential areas for most of the time, while they were mostly within limits in the Industrial areas. Later Srinivas in 1999 established ambient air quality baseline for SO_2, NO_x, and SPM to study the spatial patterns of air pollution in Delhi. Joshi again in year 2000 monitored suspended particulate matter and respirable dust concentration in ambient air along road sides in Indore city. High particulate matter concentration, both respirable and non respirable, were found to exceed the permissible limits at most of the locations. The bad road conditions and high density of vehicular movement are the main causal factors for high concentrations of particulates which gradually build up due to high rise buildings on either sides of the road in the city area in contrast to open areas located in the outskirts of the city. Later Dayal et al. in 2000 established baseline of suspended particulate matter, nitrogen and sulphur oxides to study vehicular emissions and ambient air quality in Bangalore city. Ambient air was monitoring was carried out for 10 congested areas in the city for a period of 14 days. The main parameters measured included suspended particulate matter, oxides of nitrogen and sulphur dioxide. The results indicated that in six of the 10 congested areas, the SPM values were above the limit. While both nitrogen oxides and sulphur dioxides were within the prescribed limit in all the areas, the concentration of nitrogen oxides was found nearing the World Health Organisation (WHO) limit in some places. Mohanty in 2000 established ambient air quality at 11 monitoring stations in and around Koraput to calculate air quality index. Air quality index and standard deviation at different sampling points were calculated. The results show a comparative study of the air quality in different areas of Koraput. The study identifies the potential sources for effective pollution control measures to improve the air quality in Koraput district in future. Ramamurthy in 2001 measured CO, NO_X and SO_2 to study the various pollutants emitted from vehicles. From the study, it is proved that the CO level is closely related to the density of motor vehicles plying on the roads. With increase in number of motor vehicles CO levels also increases, which pollutes the roadside environment severely in future. Shishir et al. in 2001 monitored NO_x, NO, NO_2 to study atmospheric behaviour of NO_x from vehicular traffic. Senthilnathan in 2002 monitored four major pollutants namely SO_2, NO_x, PM_{10} and SPM present in air by using air pollution indexing technique and offered a software solution for computation of AQI. Mahendra in 2003 monitored CO, NOx, SO_2 and SPM to assess the air pollution concentration from road traffic in Bangalore. Traffic flows and air pollution concentrations of CO, NO_x, SO_2 and SPM were measured simultaneously. It was evident that the traffic generated CO concentrations in the study intersections were high and exceeding the permissible standards prescribed by the CPCB. This may be attributed to the interrupted flow of traffic near the intersection due to frequent ‘stop’ and ‘go’ situations. Measures to reduce vehicular pollution were also discussed. Gadgil in 2004 established the baseline concentration of SPM, NO_2 and SO_2 at 13 important traffic intersections in Pune city. The statistical analysis of the sampling results indicated that there was not only high correlation between SPM and NO_2 but also the levels of these pollutants were above the National Ambient Air Quality Standards (NAAQS) laid down by the Central Pollution Control Board (CPCB), India. The SO_2 concentrations were found to be well below the NAAQS. Shukla in 2006 established the baseline traffic scenario and ambient air quality in Lucknow city to study the traffic impact on ambient air quality. The study was undertaken with an aim to establish some relationship between the transport aspects and air pollution.

In recent years in Asian countries with monsoonal climates, such as India and China, the aerosol problem has become increasingly acute due to increased loadings of atmospheric pollutants from increasing vehicular and industrial emissions as well as from increasing energy demands associated with a rapid pace of industrialization and increasing energy demands for domestic uses (Srivastava et al., 2008; Tsang et al., 2008; Zhang et al., 2008). On the other hand, sustainable development in the Asian monsoon countries depends on the monsoons (Lua et al., 2008; Li et al., 2009). It is well recognized that pollution problems are exacerbated by stable atmospheric conditions, such as subsidence and formation of inversion layers during the dry pre-monsoon season, or during monsoon break periods. During the monsoon season, heavy rain can wash out air pollutants and clean the air. Recent studies have suggested that aerosols in the atmosphere can also affect the monsoon water cycle by significantly altering the energy balance in the atmosphere and at the surface (Ramanathan et al., 2001; Li, 2004) and by modulating cloud and rainfall processes (Rosenfeld, 2000; Menon et al., 2002; Ramanathan et al., 2005; Lau and Kim, 2006).

The Indian subcontinent experiences tropical and subtropical climatic conditions resulting in extreme temperatures, rainfall, and relative humidity. These features introduce large variability in aerosol characteristics on a range of spatial and temporal scales over India (Ramachandran, 2007). Atmospheric particulate matter is the major air pollutant in India. In many Indian cities, the levels of particulate pollutants in the ambient air have been found to be above the permissible limit (Meenakshi and Saseetharan, 2004).

The urban climate and air pollution of Gurgaon are connected in several ways. Apart from topography, climatic parameters such as stability of the near-surface atmosphere, wind direction, and wind speed govern the dispersion of air pollution. Understanding the interaction between air pollution and meteorology can be a valuable tool for urban planners to mitigate negative effects of air pollution. These particulate pollutants concentrations in various studies have been statistically compared with meteorological variables such as rainfall, temperature, humidity and wind speed (Sanchez-Ccoyllo and Andrade, 2002; Bahattin and Ibrahim, 2007). The results of these study have been very useful in understanding the role of particulate pollutants such as PM_{10} (Particulate Matter less than 10 microns in aerodynamic diameter) and SPM (Suspended Particulate Matter) in urban weather and climate variability and changes. Doreena Dominick et al. (2012) studied the assessment of influence of meteorological factors on PM_{10} and NO_2 at selected three stations in Malaysia and found that at all the three stations; NO_2 had a reverse relationship with wind speed, while PM_{10} had a negative relationship with relative humidity and wind speed, but a positive relationship with ambient temperature.

2.2 LITERATURE REVIEW ON AIR POLLUTION DISPERSION MODELLING

In air pollution dispersion studies, the air quality models are used to predict concentrations of air pollutants in space and time. They form one of the most important components of an urban air quality management plan (Elsom, 1994, Longhurst et al., 2000). Modelling calculates the current and predicts future air quality and helps in decision making process. The air quality models can be classified as point, area or line source models depending upon the source of pollutants, which it models. Line source models are used to simulate the dispersion of vehicular pollutants near highways or roads where vehicles continuously emit pollutants. In urban environment it has to be taken into consideration along with other types of sources viz. area and/or point sources whereas, the highway dispersion models are generally used for modelling the output of existing or proposed highways/roads at a distance of tens to hundreds of meter downwind. Several models have been suggested to predict pollutant concentration near highways or roads treating them as line sources. At present, most of the widely used highway dispersion models are Gaussian based (Sharma et al., 2000; Singh et al., 2006).

The dispersion models require the input of data which includes:

(i) Meteorological conditions such as wind speed and direction, the amount of atmospheric turbulence (as characterized by what is referred to as the stability class), the ambient air temperature and the height to the bottom of any temperature inversion that may be present aloft.

(ii) Emissions parameters such as vehicle volume, type of vehicle etc.

(iii) Terrain elevations at the source location and at the receptor location. The location, height and width of any obstructions (such as buildings or other structures) in the path of the gaseous emission plume.

There are several ways of classifying the variety of existing models according to their specific attributes (Sharma, 2004). However, the most important and popular way of classifying air pollution models is based on the model structure and the approach used for the closure of the turbulent diffusion equation (Jude, 1989) which is widely used in urban air pollution modelling also (Sharma and Khare, 2001).

The problem fundamental to all modelling studies in air pollution is the identification of the function 'F' that would allow the prediction of the concentration of the pollutant C (x, t) at any point in space x, and time t, if the emissions and other meteorological variables are given. Three different approaches have been established to identify 'F'

(i) Deterministic mathematical modelling (analytical and numerical models)
(ii) Statistical modelling
(iii) Physical modelling

Atmospheric dispersion modelling is one of the large classes of phenomena, which include a deterministic part and a random element. The deterministic component may be modelled with all the precision allowed by the experimental input, whereas the random stochastic part is less precise or unpredictable. There are two extreme approaches to atmospheric modelling, the statistical and the analytical approach. Statistical technique, in its extreme form, looks into pure time series, whereas in analytical approach, an attempt is made to understand the physical process and to establish cause – effect relationship, which facilitates the final outcome. However, almost none of these ideal approaches are available/ applicable directly in their present theoretical form. Most statistical models include some explaining variables, whereas most would be 'pure' analytical models requiring some statistical smoothening of input (Sharma, 2004).

2.3 DETERMINISTIC MATHEMATICAL MODELS

The deterministic mathematical models (DMM) calculate the pollutant concentrations from emission inventory and meteorological variables according to the solutions of various equations that represent the relevant physical processes. In other words, differential equation is developed by relating the rate of change of pollutant concentration to average wind and turbulent diffusion which, in turn, is derived from the mass conservation principle. The common Gaussian LSM is based on the superposition principle, namely concentration at a receptor, which is the sum of concentrations from all the infinitesimal point sources making up a line source. This mechanism of diffusion from each point source is assumed to be independent of the presence of other point sources. The other assumption considered in DMM is the emission from a point source spreading in the atmosphere in the form of plume, whose concentration profile is generally Gaussian in both horizontal and vertical directions. Deterministic model includes analytical model and numerical model. Both analytical and numerical models are based on mathematical abstraction of fluid dynamics processes.

Limitation of deterministic model:

(i) Inadequate dispersion parameters

(ii) Inadequate treatment of dispersion upwind of the road

(iii) Requires a cumbersome numerical integration especially when the wind forms a small angle with the roadways.

(iv) Gaussian based plume models perform poorly when wind speeds are less than 1m/s.

2.3.1 ANALYTICAL MODELS

Analytical models provide solutions to the basic equations describing the process. In fact, most of the present analytical models for air quality predictions are based on Gaussian equation. These Gaussian models despite several limitations and assumptions have found favour with the scientific community, as they are very simple and include the solution to the simple Gaussian equation (Barratt, 2001). In addition to their user-friendly nature and simplicity, these models are conceptually appealing as they are consistent with the random nature of the turbulence of the atmosphere. Further the development of Gaussian type dispersion equations/ models has reached a level of sophistication such that they are routinely used as assessment tools by various regulatory agencies (USEPA, 2000). These simplified models can be applied with reasonable confidence to pollutant transport within unidirectional flows (e. g., over relatively flat terrains). However they are less reliable for situations where the flows are more complicated. For example, flow over complex terrain or separated flows around obstructions and building wakes where these Gaussian dispersion models cannot be applied (Hanna, 1982; Pasquill and Smith, 1983; Turner, 1994; Seinfield and Pandis, 1998).

The concentration of pollutants I at location (x, y, z) from a continuous elevated point source with an effective height of H is given by following Gaussian dispersion equation (Turner, 1970)

$$C(x, y, z, H) = \frac{Q}{2\pi\sigma_y\sigma_z U} \exp -\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2 \left[\exp -\frac{1}{2}\left(\frac{z+H}{\sigma_z}\right)^2 + \exp -\frac{1}{2}\left(\frac{z-H}{\sigma_z}\right)^2\right] \qquad \ldots\ldots.(1)$$

Where, σy and σz are horizontal and vertical dispersion parameters, determined as a function of stability class and distance from the source. U is the mean wind speed, Q is the uniform rate of release of pollutants and H is the effective plume height. For a continuously emitting infinite line source at ground level when wind direction is normal to the line source, the equation (1) reduces to

$$C(x,z) = \frac{Q}{\sqrt{2\pi}U\sigma_z} \left\{\exp -\frac{1}{2}\left(\frac{z+h_0}{\sigma_z}\right)^2 + \exp -\frac{1}{2}\left(\frac{z-h_0}{\sigma_z}\right)^2\right\} \qquad \ldots\ldots.(2)$$

For ground level sources $H = h_0$ (plume rise).

Most of the highway dispersion models used for the preliminary estimation for screening purpose retained the basic Gaussian dispersion approach but used modified vertical and horizontal dispersion curves to account for the effects of surface roughness, averaging time and vehicle induced turbulence (Gilbert, 1997; Sunil, 2008).

2.3.2 NUMERICAL MODELS

Over the past several years, numerical models have been increasingly used to solve the complicated dispersion problems such as dispersion of heavier – than –

air boundary layer flow over complex terrain, studying gas diffusion in thermally stratified flows, dispersion of pollutants around structures/ buildings and in regional and mesoscale dispersion modelling. In addition, various numerical models based upon Lagrangian trajectory and Eulerian grid models are increasingly used for the prediction of various secondary pollutants like ozone. The formation of ozone involves highly complex and nonlinear photochemical reactions between VOC's and NOx. These models can handle, at least theoretically, non-stationary, nonhomogeneous conditions along with complex configurations of spatial domains such as rough terrains. These numerical models require rigorous mathematical computations through computer software and as such cannot be conveniently used for screening purpose by regulatory agencies. Moreover, these models require large input data and larger computational capabilities (Sharma, 2004).

2.4 STATISTICAL MODELS

In contrast to deterministic modelling, the statistical models calculate concentrations by statistical methods from meteorological and traffic parameters after an appropriate statistical relationship has been obtained empirically from measured concentrations. Regression, multiple regression and time-series technique are some key methods in statistical modelling. The time-series analysis techniques [Box–Jenkins models] have been widely used to describe the dispersion of Vehicular Exhaust Emissions at traffic intersection and at busy roads. Various studies involving statistical techniques have been used to forecast real-time, Short term as well as long-term pollutant concentrations and for their trend analysis. This has been done by mostly using long-term (some time short also) emission, meteorology and pollution concentration data. This modelling technique has been employed to find concentrations of primary as well as highly complex secondary pollutants like ozone (Sharma, 2004).

Limitation of statistical model:

(i) Require long historical data sets and lack of physical interpretation

(ii) Regression modelling often underperforms when used to model non-linear systems

(iii) Time series modelling requires considerable knowledge in time series statistics i.e. autocorrelation function (ACF) and partial auto correlation function (PACF) to identify an appropriate air quality model

(iv) Statistical models are site specific

2.5 PHYSICAL MODELS

In physical modelling, a real process is simulated on a smaller scale in the laboratory by a physical experiment, which models the important features of the original processes being studied. Typical experimental devices such as wind tunnels or water tunnels are employed, in which the atmospheric flows, for which boundary layer wind tunnels (wind tunnel modelling) are used. This type of physical modelling carried out in the wind tunnel, in which atmospheric flows have been modelled with air as fluid medium, has also been referred to as fluid modelling by various researchers (Sharma, 2004).

Limitation of Physical model:

(i) Major limitations of wind tunnel studies are construction and operational cost

(ii) Simulation of real time air pollution dispersion is expensive

(iii) Real time forecast is not possible

2.6 SUMMARY OF ATMOSPHERIC DISPERSION MODELS

In the early 1970s, a number of highway air pollution models (mostly Gaussian based) were developed. These models provided theoretical estimates of air pollution levels as well as temporal and spatial variation under present and proposed conditions as a function of meteorology, highway geometry and downwind receptor locations. However, comparison of experimental results with these model predictions indicated many deficiencies and limitations. These include consideration of inadequate dispersion parameters, the tendency of these models severely to over predict when the winds were parallel to the road, the inapplicability of these models to very low wind speeds (≤1m/s) and the inadequate treatment of dispersion in the upwind direction of the road (Sharma, 2001; Nagendra et al. 2002).

Various researchers used different methodologies and techniques to overcome these limitations that led to a better understanding of the complex dispersion phenomena and thus a more realistic estimation of pollutants near the roads under different traffic and meteorological conditions. Most effort was directed towards incorporating wind speed corrections, modifying dispersion parameters to account for enhanced turbulence due to vehicle wakes, treatment of the line source and the consideration of oblique winds. Attempts were made to validate and evaluate these models with experimental and field data that led to the development of more refined line source models like HIWAY 4, ROADWAY 3, and the California line source (CALINE) 4.

2.6.1 URBAN MODELS

I. AERMEC Dispersion Model (AERMOD)

An AERMOD based on atmospheric boundary layer turbulence structure and scaling concepts, including treatment of multiple ground-level and elevated point, line, area and volume sources. It handles flat or complex, rural or urban terrain and includes algorithms for building effects and plume penetration of inversions aloft. It uses Gaussian dispersion for stable atmospheric conditions and non-Gaussian dispersion for unstable conditions. AERMOD is designed for transport distance of 50 km or less.

II. Contamination in Ai from Road-Finnish Meteorological Institute (CAR-FMI)

This model was developed by the Finnish Meteorological Institute (FMI) for evaluating atmospheric dispersion and chemical transformation of vehicular emissions of inert (CO, NOx) and reactive (NO, NO_2, O_3) gases from a road network of line sources on a local scale. The CAR-FMI model includes an emission model, a dispersion model and statistical analysis of the computed time series of concentrations. The CAR-FMI model utilizes the meteorological input data evaluated with the meteorological pre-processing model MPP- FMI. Levitina et al. (2005) compared the CAR-FMI with CALINE 4 and found that for the hourly NO_X predicted data, the index of agreement values range from 0.77 to 0.88 and from 0.83 to 0.92 for the evaluations of the CAR-FMI and CALINE4 models respectively.

III. Atmospheric Dispersion Modelling System (ADMS)

ADMS version 3 is an advanced dispersion model (1999) developed by CERC, United Kingdom for calculating concentrations of pollutants emitted continuously from point, line, volume, area sources or discretely from point sources. It characterizes the atmospheric turbulence by two parameters, the boundary layer depth and the Moninobukhov length, rather the single parameter Pasquill-Stability class (CERC, 2000; Sharma et al., 2004; Jungers et al., 2006).

IV. California Puff Model (CALPUFF)

It is a non-steady-state puff dispersion model that simulates the effects of time- and space-varying meteorological conditions on pollution transport, transformation, and removal. CALPUFF is a Lagrangian model that simulates pollutant releases as a series of continuous puffs and is most suitable for releases in the 50 to 200-km range. It has been adopted by EPA as the preferred model for assessing long range transport of pollutants and their impacts. It can model line sources with constant emissions, as well as point, area, and volume sources (USEPA, 2004).

2.6.2 LINE SOURCE DISPERSION MODELS

I. California Line Source Dispersion Model (CALINE)

CALINE model was developed by Benson (1972) for California Department of Transportation (CALTRANS) which was used for predicting CO concentration. In 1975, a revised version of the original model, CALINE 2 was developed. This model could compute concentration for depressed sections and for winds parallel to the roadway. Subsequent studies indicated that CALINE 2 seriously over predicted concentration for stable, parallel wind conditions.

In 1979, a third version, CALINE 3 was developed. CALINE 3 retained the basic Gaussian dispersion methodology but used new horizontal and vertical dispersion curves modified for the effects of surface roughness, averaging time and vehicle induced turbulence. Also, the virtual point source model was replaced by equivalent finite line source model and added multiple link capabilities to the model format. In 1980, Environmental Protection Agency authorized CALINE 3 for use in estimating concentration of non-reactive pollutants near highways. CALINE 4 introduce in 1984 which is the latest version in the CALINE series of models for predicting concentration of CO, NO_2 and aerosols (Robet, 2002). Coe et al. (1998) reformatted CALINE 4 in the form of a CL4 model, a graphical Windows based user interface designed to ease data entry and increase the online help capabilities of CALINE 4.

II. CAL3QHC and CAL3QHCR

CAL3QHC (CALINE3 with Queuing and Hot-spot Calculations) is a computer program that employs the CALINE3 line source dispersion model and a traffic algorithm for estimating the number of vehicles queued at an intersection (USEPA, 2004). It was certified by both the California Air Resources Board and the EPA for modelling CO or other inert pollutant concentrations from motor vehicles at roadway intersections. The pollutant is dispersed according to CALINE3 for each link, and contributions from each link are added to obtain a CO concentration at a particular receptor location. The CAL3QHC model, therefore, added the capability to model emissions from vehicles queuing at intersections and to permit estimation of total CO concentrations from both moving and idling vehicles.

CAL3QHCR (CALINE3 with Queuing and Hot-spot Calculations Refined) is a refined model that uses observed meteorological data rather than screening meteorology. In addition, calm winds are excluded in multi hour concentration estimates. CAL3QHC/CAL3QHCR only simulates dispersion near intersections for roads that are less than 10 m above grade (Hayes et al., 1985; Wahab, 2004).

III. General Motor Model (GM Model)

GM model is developed by Chock (1978) is a simple line source model. It was developed in attempt to remove the limitations of earlier models by incorporating wind speed correction (U0) and by suggesting modified values for the vertical dispersion parameter, z, to take care of the induced effect of the mechanical turbulence generated by traffic (Nagandra and Khare, 2002).

IV. General Finite Line Source Model (GFLSM)

A simple GFLSM (Luhar and Patil, 1989), based on the Gaussian diffusion equation is formulated so that it could be used for any orientation of wind direction with roadway and also does not have the infinite line source. The GFLSM is modified to predict particulate concentrations by incorporating some simple corrections. It is suitable for heterogeneous traffic conditions and is more suitable for long-term predictions.

V. HIWAY

This US-EPA model is a Gaussian steady-state model for predicting concentrations of non-reactive gases at point receptors downwind of the road in a relatively simple terrain (Turner, 1970). Each lane is modelled as a straight and continuous finite line source with uniform emission rate, simulated by a series of point sources integrated at the receptor. HIWAY-4 is a latest version of HIWAY model developed by incorporating modified dispersion curves and an aerodynamic drag factor to the original HIWAY model (Marmur et al., 2003).

VI. ROADWAY

It is a finite difference model, which predicts pollutant concentration near a roadway. It assumes a surface layer describable by surface layer similarity theory with the superposition of the effect of vehicle wakes. The unique part of the ROADWAY model is the vehicle wake theory, which was originally developed by Eskridge and Hunt, and modified, by Eskridge and Thompson (1982), and Eskridge and Rao (1983, 1986). The model can also be used to predict velocity and turbulence along the roadway. ROADCHEM (Eskridge and Thompson, 1982) is a version of ROADWAY, which incorporates the chemical reactions involving NO, NO_2 and O_3 as well as advection and dispersion. It uses surface-layer similarity theory to produce vertical angle turbulence profile (Rao, 2002).

VII. Hybrid Roadway Intersection Model (HYROAD)

HYROAD is designed to predict the concentrations of carbon monoxide (CO) that occur near intersections. HYROAD addresses the “three key aspects controlling the magnitude of CO concentrations: traffic operations at intersections; vehicle emissions; and atmospheric transport and dispersion”. Each module can be used as a stand-alone program and is not dependent upon the functionality of the other two modules. HYROAD’s dispersion module uses a Gaussian puff approach, with dispersion induced by traffic flow and wind characteristics. HYROAD is intended for use as a roadway intersection model and was designed to account for all of the various aspects of intersection modelling, including queuing, signal timing and other vehicle movement characteristics. Although it is currently considered to be an "alternative" model and is not yet on the USEPA refined model list (USEPA, 2004).

It is important to select a model that most accurately simulates the existing or future emissions source(s), even though it is often difficult to replicate project site characteristics exactly. Some models are Urban models (e.g., AERMOD can model point, area or volume sources), while others are designed for specific applications and use only one approximation method (e.g., CALINE 4, which uses only a line source approximation). The evaluation of models is a matter of great interest and it becomes particularly important in all those fields, in which, modelling is used as a decision- making tool. There is an increasing demand for more objective and formalized procedures in order to evaluate the quality (fitness for purpose) of models. Since CALINE 4 model has been used in this study hence comparisons of other models with CALINE 4 model has been discussed in **Table 2.1** below:

Table 2.1: Comparisons of Other Models with CALINE 4*

S.No.	Model	CALINE 4*
1	**CAL3QHC/CAL3QHCR** (i) Simulates dispersion near intersections for roads that are less than10 m above grade (ii) Allows for 60 receptor sites (iii) Accommodate up to 120 roadway links, each of which can be specified as either a free- flow or queued link	(i) Used for vehicles traveling along a segment of roadway can be represented as a "line source" of emissions (ii) Allows for 20 receptor sites (iii) Accommodate up to 20 roadway links
2	**GFLSM** (i) Used for CO and SPM (ii) Suitable for heterogeneous traffic conditions and for long-term predictions	(i) Used for CO, NO_X and PM (ii) Suitable for heterogeneous traffic conditions
3	**HIWAY-4** (i) Based on dispersion curves with an aerodynamic drag factor (ii) Under predict the concentrations at low wind speed	(i) Based on Horizontal and vertical curves (ii) Over predict the concentrations at low wind speed
4	**ROADWAY-2** (i) Applicable in the near field (within 200m of the highway), where the effects of interactions between the vehicle traffic	(i) Applicable for longer distances (within 500m of the highway), where, dispersion is dominated

S.No.	Model	CALINE 4*
	and the atmospheric surface flow are important (ii) Numerical model (iii) Simulating simplified chemical reactions involving nitric oxide (NO), nitrogen dioxide (NO_2), and ozone (O_3)	by the atmospheric turbulence (ii) Gaussian plume dispersion model (iii) Does not simulate any chemical reaction
5	**HYROAD** (i) Used for CO only (ii) Simulate up to 60 receptors and 50 roadway segments	(i) Used for CO, NO_X, and PM (ii) Simulate up to 20 receptors and 20 roadway segments
6	**ADMS** (i) Used for primary pollutants and continuous releases of toxic and hazardous waste products (ii) Up to 50 receptors may be specified	(i) Used for primary pollutant only (ii) Up to 20 receptors may be specified
7	**AERMOD** (i) Large program with many features and input requirements (ii) Practitioners may be forced to spend a significant amount of time just familiarizing themselves with the program and its various requirements	(i) Less input parameters are required (ii) User friendly and simple to understand
8	**CALPUFF** (i) Non-steady-state Lagrangian model (ii) Simulates pollutant releases as a series of continuous puffs (iii) Most suitable for releases in the 50 to 200 km range (iv) Adopted by EPA for assessing long range transport of pollutants (v) Designed primarily for long-range transport (receptors more than 1 km from a source)	(i) Steady-state Gaussian based model (ii) Simulates pollutant releases as a series of continuous plume (iii) Suitable for release in 10km range (iv) Used for screening in EIA (v) Ideally suited for modelling near roadway pollution dispersion (500m range)
9	**CAR-FMI** (i) Utilizes boundary- layer scaling with a (ii) meteorological pre-processing model (iii) Used for evaluating atmospheric dispersion and chemical transformation of vehicular emissions of inert (CO, Nox) and reactive (NO, NO_2, O_3) gases	(i) Utilizes Pasquill Stability Classification (ii) Used for evaluating atmospheric dispersion of vehicular emissions of inert components (CO, NO_2 and Aerosol)

*Various Sources

2.7 BRIEF INTRODUCTION OF CALINE 4 MODEL

CALINE-4 is the fourth version simple line source Gaussian plume dispersion model. It employs a mixing zone concept to characterize pollutant dispersion over the roadway. This version updates CALINE-3, specifically by fine-tuning the Gaussian method and the mixing zone model. Its purpose is to help planners protect public health from the adverse effects of excessive CO exposure.

The main purpose of the model is to assess air quality impacts near transportation facilities. Given source strength, meteorology and site geometry, CALINE-4 can predict the pollutant concentrations for receptors located within 500 meters of the roadway. It predicts the air concentrations of carbon monoxide (CO), nitrogen dioxide (NO_2), and suspended particles near roadways. It also has special options for modelling air quality near intersections, street canyons and parking facilities. The greatest advantage of CALINE-4 in comparison of earlier versions is that it is more user-friendly which has a graphical windows-based user interface, designed to ease data entry and increase the on-line help capabilities of CALINE-4.

CALINE-4 can model roadways at-grade, depressed, and filled (elevated); bridges (flow under roadway); parking lots; and intersections. Bluffs and canyons (topographical or street) also can be simulated. CALINE-4 accepts weighted vehicle emission factors (expressed in grams per vehicle) developed and input by the user for each roadway link. The user inputs composite emission factors by link. Users also enter hourly information on traffic/sources by link. Additional inputs include wind direction bearing, wind speed, atmospheric stability class, mixing height, wind direction standard deviation, and temperature. CALINE-4 is a Gaussian model whose formulations are based on steady-state horizontally homogenous conditions. The region directly over the highway is treated as a zone of uniform emissions and turbulence. An area equal to the travelled roadway plus 3 m on each side is referred to as the mixing zone. Mechanical turbulence (from moving vehicles) and thermal turbulence (from vehicle exhausts) are the dominant dispersive mechanisms.

A modified version of the Pasquill-Smith curves is used for the vertical dispersion coefficient, σz. The vertical dispersion parameter is assumed constant over the mixing zone from the centre of the roadway link to a computed distance from the link centre and then follows a power curve outside this distance. Dispersion is adjusted for vehicular heat flux (Emission factor) and surface roughness, which is assumed to be fairly uniform over the study area. The horizontal dispersion is a function of the horizontal standard deviation of the wind direction, downwind distance, diffusion time, and Lagrangian time scale. CALINE-4 divides highway links into a series of smaller elements. Each element is modelled as an equivalent finite line source (FLS) positioned perpendicular to the wind direction. Each element is subdivided into three sub elements to distribute the emissions. The downwind concentrations from an element are modelled using the crosswind FLS Gaussian formulation. The concentration at individual receptors is a series of incremental contributions from each element FLS. The number of receptors that can be modelled by CALINE-4 is limited to 20, making it difficult to compare results to other models that can handle many more receptor locations. CALINE-4 is an older model with 1980s science. It is a plume model with steady state, homogeneous conditions. The roadway links cannot be more than 10 km above or below local topography (Sunil, 2008).

CALINE 4 divides individual highway links into a series of elements from which incremental concentrations are computed and then summed to form a total concentrations estimate for a particular receptor location. The receptor distance is measured along a perpendicular from the receptor to the link centreline. The first element, €o, is formed as a square with sides equal to the highway width. Its location is determined by the roadway wind angle PHI. Each element is modelled as an equivalent finite line source (FLS) positioned normal to the wind direction and cantered at the element midpoint. A local x−y coordinate system aligned with the wind direction and originating at the element mid-point is defined for each element. The emissions occurring within an element areas summed to be released along the FLS representing the element. The emissions are then assumed to disperse in a Gaussian manner downwind from the element. The length and orientation of the FLS are functions of the element size and roadway wind angle.

CALINE4 computes receptor concentrations as a series of incremental contributions from each element FLS (Benson, 1979).

In California, CALINE4 has been widely accepted for many years as the standard modelling tool to evaluate project-level CO impacts (Jungers et al., 2006). In India, various Gaussian based line source models like CALINE4, GM and HIWAY 4 are routinely used to predict the impact of vehicular pollution along the roads/highways. Few studies using CALINE-4 model have also been reported in literature (Sharma et al., 2005). Although most of the studies involving CALINE-4 models have been to predict CO concentrations along roads and highways, however some recent studies have also been carried to predict concentrations of fine particles and NO/NOx concentrations. Sivacoumar and Thanasekaran (1998) used the GFLSM to predict the CO concentrations near major highway in Chennai. Sharma and Khare (1999) used GFLSM model to predict CO concentrations at three traffic intersections in Delhi. The predicted values were compared with the actual field data and found that the GFLSM model over predicted the CO concentrations by considerable amount. However, after removing the error function, the model performance improved significantly. A study carried out by CRRI (CRRI, 2001) reported the use of CALINE-4 to assess the impact of vehicular pollution on NH-2 between Delhi and Agra. Goyal et al., (1999) have developed a line source model called IITLS for the city of Delhi at IIT, Delhi. This model was proposed to describe the downwind dispersion of pollutants near roadways and its performances were comparable with that of CALINE-3 model and also with observed values.

Nirjar et al., (2002) had used CALINE-4 to predict the concentration of CO along the urban and semi-urban roads in Delhi and found the predicted concentrations to be less than the observed values and found the moderate r^2 correlation between them.

On the basis of the above, a linear model was also developed which when validated on a highway gave fairly accurate results within ± 20%. Gramotnev et al., (2003) used CALINE4 for the analysis of aerosols of fine and ultra-fine particles, generated by vehicles on a busy road. Levitina et al., (2005) found that the performance of CALINE 4 was better at a distance of 34m, compared with that at a distance of 17m. It was also analysed the difference between the model predictions and measured data in terms of the wind speed and direction. The performance of CALINE 4 in most cases deteriorated as the wind speed decreased and also as the wind direction approached a direction parallel to the road. Lin and Ge (2006) used the cell-transmission approach for air quality modelling of CO by CALINE 4 model. The cell based approach defines micro-homogeneous traffic conditions and produces better emission estimation than the link-average approach in current dispersion models. The cell- based approach is also more advantageous than microscopic (i.e., individual vehicle) traffic simulation models in terms of emission estimation as information about individual vehicles (model, year, etc.) in traffic is generally unavailable. The cell-based approach can reduce computational requirement and enables fine spatial, temporal scale prediction of on-road traffic and roadside pollution concentrations. Anjaneyulu et al., (2006) studied the CO concentrations of Calicut city in the state of Kerala, India using CALINE 4 and IITLS and Linear regression models. It was revealed that linear regression model performs better than the CALINE4 and IITLS models.

Extant literature highlighted that CALINE 4 is the most widely used vehicular pollution model to predict air pollution concentration along road corridors under urban and semi urban conditions (Sharma et al., 2013). CALINE 4 offers several advantages over other models and is chosen as the base model for the purpose of developing a modified line source model. Carbon monoxide is chosen for the model predictions because it is principally emitted from vehicular sources and considered as a guide to the levels of other vehicular pollutants, gaseous as well as particulate matter that is small enough to have long term suspension in air. CO has several advantages as a reference material for the estimation of traffic-produced pollutants. As CO is produced both by the petrol and diesel driven vehicles and it is also possible to measure CO atmospheric concentration continuously. Thus these information data can be used effectively for testing the model for short periods when there are fluctuations in the traffic flows and meteorological conditions (Anjaneyulu et al., 2006).

In California, CALINE 4 has been widely accepted for many years as the standard modelling tool to evaluate project-level CO impacts (Neimeier et al., 2006). Although most of the studies involving CALINE 4 models have been limited to predict CO concentrations along roads and highways, however some recent studies have also been carried out to predict concentrations of fine particulates and NO_X concentrations in Florida (Kenty et al., 2007). Further, Yura et al., 2007 have reported that CALINE 4 does not perform well in densely populated areas and differences in topography too could be a decisive factor when the model was used to predict concentrations of $PM_{2.5}$. Majumdar et al., 2008 reveal that CALINE 4 with correction factor (0.37) can be applied reasonably well for the prediction of CO in the city of Kolkata. Ganguly et al., 2009 compared CALINE 4 model and General Finite Line Source Model (GFLSM) code (Luhar et al., 1987) and evaluated their comparative performance. They observed that CALINE 4 has performed better as compared to GFLSM code. They also found good agreement between observed and predicted concentrations at receptor points close to the road which decreased with increasing distance from the road for both the models.

2.7.1 JUSTIFICATION FOR USING CALINE 4 MODEL FOR THE STUDY

CALINE4, the latest in CALINE series models, and is most widely used Gaussian based vehicular pollution dispersion model to predict air pollutants concentrations along the highway under rural (i.e. open), semi urban and urban conditions with and without street canyon effects (Benson 1984). CALINE series of models have been used extensively all over the world including India for regulatory purposes (Akyurtlu and Akyurtlu 2012). CALINE4 offers several advantages over the other previous models (ref. **Table 2.1**) and has been used by many researchers to predict pollutants concentrations of vehicular pollutants along the roads/ highways in Indian climatic conditions (Jain et al. 2006; Majumdar et al. 2009). (Nirjar et al. 2002) had used CALINE4 to predict the concentrations of CO along the urban and semi-urban roads in Delhi and the study results showed under prediction and moderate r^2 correlation values between observed and predicted concentrations. Further, (Gramotnev et al. 2003) used CALINE4 for the analysis aerosols of (fine and ultra-fine particles) generated by vehicles on a busy road and found good agreement between observed and predicted concentrations. (Sharma et al. 2013) used the CALINE4 model in an urban highway corridor in Delhi. The study concluded that model performed satisfactorily in vehicular exhaust contribution in air quality. Dhyani et al. (in press) evaluated and compared the performance of CALINE4 model for hilly and flat terrain. They observed unsatisfactory performance of model in hilly regions due to complex topography and micro meteorological conditions which could not be properly simulated in CALINE4.

CALINE 4 offers several advantages over other models and is chosen as the base model for the study. Carbon monoxide is chosen for the model predictions because it is principally emitted from vehicular sources and considered as a guide to the levels of other vehicular pollutants, gaseous as well as particulate matter that is small enough to have long term suspension in air. CO has several advantages as a reference material for the estimation of traffic-produced pollutants. As CO is produced both by the petrol and diesel driven vehicles and it is also possible to measure CO atmospheric concentration continuously.

Most of the predictions or estimations are carried out as part of Environmental Impact Assessment (EIA) studies (Sharma et al., 2007). According to EIA notification, it had made mandatory for all new and existing highway/road projects to carry out EIA studies. Further, as a part of EIA requirements, prediction estimates of vehicular pollutants along the highways/roads are routinely carried out (CRRI, 2005). Based on the modelling exercise, Environmental Management Plan is suggested so that the predicted air pollution level does not exceed the National Ambient Air Quality Standards (NAAQS). Ministry of Environment and Forests has recommended the use of CALINE 4 model for prediction of air pollutants. Hence CALINE 4 has been used in this study for predicting CO levels.

2.8 LITERATURE REVIEW ON AIR QUALITY INDEX

The Air Quality Index (AQI) is an "index" determined by calculating the degree of pollution in the urban area or at the monitoring point and includes main pollutants – particulate matter, ground-level ozone, sulphur dioxide, carbon monoxide and nitrogen dioxide. Each of these pollutants has an air quality standard which is used to calculate the AQI. The main objectives of AQI are to inform and caution the public about the risks of exposure from daily pollution levels and to enforce required regulatory measures for immediate local impact (Stieb et al., 2005). Ambient air quality is also known as air pollution index which measures point to know the change in level of pollutants from standard level and helps to know the effects on human health due to increase in pollution (Senthilnathan, 2007). Rao et al. (2002) developed long-term AQIs for four major Indian cities including Mumbai, Delhi, Kolkata, and Chennai, and the rapidly urbanizing area around Nagpur. Sharma et al. (2003a) examined AQIs developed for the city of Kanpur to develop an understanding of the relationship between seasonal effects and specific pollutant species comprising the AQI. Sharma et al. (2003b) proposed an AQI for Delhi city also. George Kyrkili et al. (2007) developed an aggregate air quality based on the combined effects of five criteria pollutants (CO, SO_2, NO_2, O_3 and PM_{10}) by taking into account European standards.

Senthilnathan (2008) use the Satellite data to provide the air quality index values for forecasting urban air quality. Shukla et al. (2010) estimated the air quality at five different locations in Lucknow city and found that air quality index was highest in residential zone as compared to other zones. Later Kumar et al. (2011) studied the ambient air quality of Jaipur city and calculated the Air Quality Index at twelve different zones and found that at one location was having severe air pollution while 5 locations had heavy air pollution and remain 6 locations had light air pollution. Panda and Panda (2012) assessed the ambient air quality status of Kalinga Nagar Industrial Complex an emerging steel hub in the district of Jajpur, Odisha and calculated the AQI at 10 locations. It was found that at 2 locations the air quality was severe, while one location had heavy air quality; 2 locations has moderate air quality and remaining 5 locations had light air quality. Later Sarath and Puja (2012) used SIM air model to access air quality at six different cities in India. They used the existing and available secondary data, to put together a baseline of multi-pollutant emissions for each of the cities and then calculate concentrations, health impacts, and model scenarios for 2020. Kaushik et al. (2013) studied the impact of air pollution and its impact on human health in Panipat city of Haryana. It was found that air quality index was higher in commercial areas as compared to residential area and simultaneously the percentage of occurrence of diseases in commercial areas was also higher as compared to residential areas. Kala et al. (2014) studied ambient air quality status on urban roads at 35 locations in Jaipur city of Rajasthan using Air Quality Index and found that at more than half locations have severe air pollution while another one-third suffer from heavy air pollution. Recently Kamath and Lokeshappa (2014) calculated the air quality index at 6 locations in Bangalore city and found that a one location near hospital the air quality had hazardous levels while one residential location had unhealthy air quality levels.

In the present study the air quality index for different road corridor in Gurgaon town has been calculated by using following mathematical equation given below:

$$I_P = \frac{I_{Hi} - I_{Lo}}{BP_{Hi} - BP_{Lo}}(C_P - BP_{Lo}) + I_{Lo}$$

Where: I_P = the index for pollutant P

C_P = the rounded concentration of pollutant P

BP_{Hi} = the breakpoint that is greater than or equal to C_P

BP_{Lo} = the breakpoint that is less than or equal to C_P

I_{Hi} = the AQI value corresponding to BP_{Hi}

I_{Lo} = the AQI value corresponding to BP_{Lo}

Based on the calculated AQI the corresponding air quality for all five road corridors were studied and for such road corridors which had unhealthy air quality levels an environmental management plan has been proposed which can be of help to the local district administration in planning developmental activities in near future.

The review of other literature is comprehensively summarized in tabular form and is given at the end of the chapter as **Table 2.2**, which provides a brief overview of the key published studies in the domain of ambient air quality and its relationship with different sources of pollution for identifying different sources explaining the phenomena.

2.9 GAPS IDENTIFIED FROM PREVIOUS LITERATURE

In majority of the research papers the researches have tried to identify the various types of pollutants that are emitted by automobiles in city which becomes a cause for increasing air pollution problem. In some of the studies the researchers have tried to monitor and collect the data for various air pollutants in different part of the cities and have compared the collected primary data with National Ambient Air Quality Standards to identify the areas with high pollution levels.

Some researchers have tried to understand urban vehicular pollution problems vis-à-vis ambient air quality in megacity, while some researchers have tried to study the impact of air pollution on health, while some researchers have tried to study the relation between meteorological factors and air pollutants. Recently some of the researchers have studied the vehicular air pollution with regards to CO_2 emissions while some researchers have tried to evaluate various air dispersion models for urban highway corridor.

There was no comprehensive study which could highlight various air pollution impacts due to vehicular pollution in a city. Hence, it was felt that a comprehensive study to assess impact of vehicular pollution on ambient air quality should be undertaken which establishes a baseline traffic & ambient air quality scenario in different road corridors in an urban city having different land-use pattern. Further to study the impact on ambient air quality with seasonal variation and to investigate the influence of meteorological conditions on the behaviour of pollutant concentration.

The present study focussed on predicting CO concentrations under mixed traffic conditions on an urban road corridor (a section of the national highway – 8, near IFFCO Chowk) in Gurgaon using two different sets of emission factors for different categories of vehicles presently available and used in India (CPCB, 2000 and ARAI, 2008) and on-site meteorological data.

A study in Gurgaon for impact of vehicular pollution on ambient air quality can help Haryana Pollution Control Board to utilize these results to prepare an air pollution control action plan for the city.

2.10 VEHICULAR POLLUTION CONTROL PROGRAMME IN INDIA

A detailed vehicular pollution control programme giving details of major problems associated with vehicular emission; effect of air pollutants on health and climate; control measures taken in India giving details of initiatives in last 25 years are provided in **Appendix 2.1**.

Table 2.2: Review of Literature – Comprehensive Summary

Author/ Year	Objective of Study	Constructs	Outcome
Dhyani, Rajni et al. (2014)	Air Quality Impact Assessment of a Highway Corridor through Vehicular Pollution Modelling	Air Quality, Vehicular Pollution	CALINE 4 model used to predict the CO Concentrations along a highway corridor in urban limits of Delhi. CO Conc. is limited to distance of ~ 150 m from edge of mixing zone.
Dhyani. R et al. (2013)	Performance evaluation of CALINE 4 model in a hilly terrain – A case study of highway corridors in Himachal Pradesh	Vehicular emission, CO	CO Conc. was predicted using CALINE 4 model in flat and hilly terrain in Himachal Pradesh. The model performed satisfactory for flat terrain as compared to hilly terrain.
Sharma Niraj et al. (2013)	Performance Evaluation of CALINE 4 Dispersion Model for an Urban Highway Corridor in Delhi	Vehicular emission, CO	CALINE 4 model used to predict the CO Conc. Using ARAI and CPCB emission factors. Conc. was found to be 12% higher in case of ARAI.
Sarath et al. (2013)	Receptor model-based source apportionment of particulate pollution in Hyderabad, India.	Ambient air quality, Particulate matter	The receptor modelling results indicated that the PM pollution is dominated by the direct vehicular exhaust and road dust (more than 60 %). PM with higher propensity to enter the human respiratory tracks, has mixed sources of vehicle exhaust, industrial coal combustion, garbage burning, and secondary PM.

Author/ Year	Objective of Study	Constructs	Outcome
Sathe Yogesh et al. (2013)	Urban Air Quality Modelling and Simulation: A Case Study of Kolhapur	Air quality; Air quality models	This paper evaluates the performance of Danish Operational Street Pollution Model under Indian traffic conditions. Comparison between predicted and observed concentrations was performed using both quantitative and statistical methods.
Dubey Bhawna et al. (2013)	Assessment of Vehicular Pollution in Dhanbad City Using CALINE 4 Model	CALINE 4, CO, Vehicular Exhaust	CALINE 4 has several advantages over other line source models and was used as a base model for the Dhanbad city to predict CO concentration from various categories of vehicles.
Ahmad Kafeel (2013)	Physical Simulation of Automobile Exhausts Dispersion at an Urban Intersection – Part II: Traffic Induced Effects	Urban Intersection, Model Vehicle Movement System, Line Source Dispersion, Traffic Induced Effects.	Traffic induced turbulence coupled with natural air motions become an important variable affecting the dispersion of exhaust emissions, especially under low wind conditions.
Shrivastava R. K. et al. (2013)	Air Pollution Due to Road Transportation in India: A Review on Assessment and Reduction Strategies	Air pollution, Transport modeling, PM_{10}	The present study is a review of an assessment model for emitted pollutants and effective strategies to reduce air pollution due to road transport.
Singh Richa & Sharma (2012)	Assessment of emission from transport sector in Delhi.	Transport Sector, Emission Factor	The study presents emission of different pollutants from transport sector in Delhi.

Author/ Year	Objective of Study	Constructs	Outcome
Sonawane et al. (2012)	Health benefit modelling and optimization of vehicular pollution control strategies.	CO, NOx, particulate matter	An integrated model was developed which can be used as a tool for optimal prioritization of various pollution management strategies. The model estimates health benefits associated with specific control strategies.
Satsangi et al. (2011)	Measurement of PM_{10} and $PM_{2.5}$ aerosols in Agra, a semiarid region of India.	PM_{10} and $PM_{2.5}$	Measurement of PM_{10} and $PM_{2.5}$ was done at 3 locations and $PM_{2.5}/PM_{10}$ ratio indicated that 40-71% of PM_{10} are made of $PM_{2.5}$.
Majumdar et al. (2010)	To assess vehicular pollution in Kolkata, India, using CALINE 4 model	Carbon monoxide, vehicular pollution	CALINE 4 model with suitable correction factors should serve as guide for proper air quality management.
Prajapati, Tripathi & Pathak (2009)	To monitor horizontal and vertical distribution of traffic-related pollutants within the street canyons in Varanasi, India	CO and SO_2	Horizontal distribution of pollutants was uniform but vertical concentration of both pollutants decreased with height
Ziauddin (2009)	To study the vehicular air pollution with regards to carbon monoxide emission.	Vehicular emission, carbon monoxide	In this paper an attempt was made to highlight carbon monoxide emission by vehicles during peak hours of the day.
Gurung, S. (2008)	Modelling the dispersion of vehicular carbon-	Carbon dioxide	CO concentration was predicted using CALINE 4 model. Ninety receptor points were taken.

Author/ Year	Objective of Study	Constructs	Outcome
	monoxide (CO) pollution in Kathmandu valley, Nepal: A CALINE4 approach combined with GIS Techniques		Root mean square error method is carried out to evaluate the model performance. The RMSE value found to be 0.77 and the accuracy of the model performance as 74%.
Sharma, Jain & Khan (2008)	To study particulate polycyclic aromatic hydrocarbons profiles in urban air of Delhi during different seasons	Polycyclic aromatic hydrocarbons, diesel engines, gasoline engines	Average concentration was maximum in winter and minimum during monsoon
Hamdi et al. (2008)	To study the impact diesel powered vehicular and industrial emissions on urban air quality	SO_2, NO_2, CO, particulate matter, sulphur, diesel	Key pollutants measured were higher in commercial, residential and industrial areas than permissible limit.
Agrawal, Maitra, Ghose (2007)	To develop a methodology for incorporating spatial data in GIS environment for assessing air pollution impact of a highway project	Vehicular traffic, air pollutants	Increased vehicular traffic caused due to highway development is a major source of air pollution.
Chelani & Devotta (2007)	To assess Air quality in Delhi before and after implementation of CNG as a fuel	Particulate matter, SO_2, NO_2	CO & NO_2 concentration levels in ambient air are found to be associated with mobile sources.

Author/ Year	**Objective of Study**	**Constructs**	**Outcome**
Mohan and Kandya (2007)	To analyse the Annual and Seasonal Trends of Air Quality Index of Delhi	Air Quality Index, NO_2	Air Quality has slightly improved in some areas of Delhi because of continued rigorous efforts in this direction
Fang (2007)	To monitor atmospheric aerosol particles and metallic concentrations, ionic species at the Experimental harbour of Taichung sampling site.	Particulate matter in TSP, $PM_{2.5}$, $PM_{2.5-10}$	Meteorological conditions have high co-correlation at largest particulate concentrations for TSP at TH sampling site for this study
Manab et al.(2006)	Distribution of $PM_{2.5}$ and $PM_{10-2.5}$ in PM_{10} fraction in Ambient Air due to Vehicular Pollution in Kolkata Megacity	$PM_{2.5}$, $PM_{10-2.5}$, PM_{10}, Ambient Air quality	The average 24h PM_{10} concentration was 304µg/m^3, which is 3 times more than the Indian National Ambient Air Quality Standards (NAAQS) and higher PM_{10} concentration was due to fine fraction ($PM_{2.5}$ released by vehicular exhaust.
Karar et al. (2006)	To investigate seasonal and spatial variations of PM (particulate matter) and TSP (Total Suspended Particulate Matter) of an Indian metropolis	Particulate matter (PM), Total Suspended Particulate Matter (TSPM), populations density, industrial	Higher particulate pollution at industrial area may be attributed due to re-suspension of road dust, soil dust, and automobile traffic and nearby industrial emissions.

Author/ Year	Objective of Study	Constructs	Outcome
		pollution	
Shukla (2006)	To study the traffic impact on ambient air quality in Lucknow city. The study was undertaken with an aim to establish some relationship between the transport aspects and air pollution.	Vehicular pollutants and traffic count	The deterioration of urban air in arterial streets due to vehicular traffic exhaust and its interaction with the environment is causing a perceivable discomfort in daily life.
Ravindra, K. et al. (2006)	To assess air quality after the implementation of Compressed Natural Gas (CNG) in public transport in Delhi, India	SPM, PM_{10}, CO, SO_2, NOx and organic pollutants such as benzene, toluene, xylene (BTX) and polycyclic aromatic hydrocarbons	A decreasing trend was found for PAHs, SO_2, CO concentrations while NOx level was increased in comparison to those before implementation of CNG
Lone (2005)	To study the dust pollution caused by vehicles in Aligarh city	Dust pollution	The dust pollution was maximum on Kanpur road (46.44 gm/m^2/month) followed by Agra road (38.94 gm/m^2/month) and Delhi road (34.52 gm/m^2/month). The least dust pollution was recorded on Anoopshahar road (20.10 gm/m^2/month). The average dust fall rate per unit area was estimated to be

Author/ Year	Objective of Study	Constructs	Outcome
			about 35 gm/m^2/month in Aligarh city.
Gadgil (2004)	To study the concentration of SPM, NO_2 and SO_2 at 13 important traffic intersections in Pune city.	Vehicular pollutants, oxides of nitrogen and sulphur do-oxide	In order to study the contribution of these pollutants from motor vehicles, attention was focused on the roadside, street-level concentration. The statistical analysis of the sampling results indicated that there was not only high correlation between SPM and NO_2 but also the levels of these pollutants were above the National Ambient Air Quality Standards (NAAQS) laid down by the Central Pollution Control Board (CPCB), India. The SO_2 concentrations were found to be well below the NAAQS.
Mahendra (2003)	To assess the air pollution concentration from road traffic in Bangalore.	CO, NOx, SO_2 and SPM	Traffic flows and air pollution concentrations of CO, NOx, SO_2 and SPM were measured simultaneously. It was evident that the traffic generated CO concentrations in the study intersections were high and exceeding the permissible standards prescribed by the CPCB. This may be attributed to the interrupted flow of traffic near the intersection due to frequent 'stop' and 'go' situations. Measures to reduce vehicular pollution were also discussed.
Goyal (2002)	To study the role that meteorology plays in dispersion of air pollutants emitted	NO_2, $SO_{2,}$	In order to study these variations, impact of SO_2 emissions emitted from multiple point sources of an industry located in northern India was predicted using

Author/ Year	Objective of Study	Constructs	Outcome
	from elevated point sources and the resultant predicted ground level concentrations (GLCs)		Industrial Source Complex (ISC) air quality model under different meteorological scenarios. Cumulative effect of all the meteorological parameters in the present study indicated the occurrence of maximum GLCs in monsoon season, followed by post monsoon, summer and winter seasons, indicating that winter season need not necessarily be the critical season as generally considered from air pollution point of view under a given set of conditions.
Senthilnathan (2002)	To elucidate the Analysis of four of the five major pollutants namely SO_2, NO_x, PM_{10} and SPM present in air by using air pollution indexing technique and offered a software solution for computation of AQI.	SO_2, NO_x, PM_{10} and SPM	He found that the air pollution indexing is a scheme that transforms the (weighted) values of individual air pollution related parameters for various pollutants into a single number or set of numbers called the Air Quality Index (AQI).
Shishir, L. and Patil, R.S. (2001)	To monitor Atmospheric Behaviour of NO_x from Vehicular Traffic	NO_x, NO, NO_2, vehicular traffic	Larger the distance from the road the level of NO decreases but the level of NO_2 which is very harmful remains the same

Author/ Year	Objective of Study	Constructs	Outcome
Ramamurthy (2001)	To study the various pollutants emitted from vehicles	Vehicular pollutants: CO, oxides of nitrogen, sulphur di-oxide	The results showed that CO is the primary pollutant and very toxic one. From the study, it is proved that the CO level is closely related to the density of motor vehicles plying on the roads. With increase in number of motor vehicles CO levels also increases, which pollutes the roadside environment severely in future.
Mondal (2000)	To measure ground-level concentration of NOx at 19 important traffic intersection points within the city of Calcutta	NOx, vehicular traffic	Results indicate that the NO_x concentration level has a seasonal variation. Maximum average concentration of 222g/m^3 was observed during winter and minimum average concentration of 55g/m^3 was observed during peak monsoon.
Mohanty (2000)	To monitor the ambient air quality at 11 monitoring stations in and around Koraput district at monthly intervals.	Air quality index, air pollutants	Air quality index and standard deviation at different sampling points were calculated. The results show a comparative study of the air quality in different areas of Koraput. The study identifies the potential sources for effective pollution control measures to improve the air quality in Koraput district in future.
Kulandi (2000)	To predict the concentration level of suspended particulate matter (SPM) in the ambient air of	Ambient air quality, suspended particulate matter	The meteorological parameters were measured during sampling. Background SPM concentration and Kerbside SPM concentrations were estimated. A comparison was made between actual and predicted concentration of SPM.

Author/ Year	Objective of Study	Constructs	Outcome
	Madurai using existing street canyon model popularly known as Johnson air quality model,		
Jayshree (2000)	To identify the various types of pollutants emitted by automobiles in Thiruvananthapuram city.	Vehicular emissions, air quality	It was found that air pollution was a major environmental problem faced by many Indian cities. One important factor that brings air pollution is automotive emissions. Low speed limit in the city and various operating modes of vehicles influence the amount of pollutants released by them.
Dayal (2000)	To study the vehicular pollution as one of the main sources of air pollution in Bangalore city.	Suspended particulate matter, nitrogen and sulphur oxides,	A study of the ambient air was carried out for 10 congested areas in the city for a period of 14 days, in each place. The results indicated that in six of the 10 congested areas, the SPM values were above the limit. While both nitrogen oxides and sulphur dioxides were within the prescribed limit in all the areas, the concentration of nitrogen oxides was found nearing the World Health Organisation (WHO) limit in some places.
Joshi (2000)	To estimate the total suspended particulate matter and respirable dust	Suspended particulate matter, respirable dust	High particulate matter concentration, both respirable and non respirable, were found to exceed the permissible limits at most of the locations. The bad road

Author/ Year	Objective of Study	Constructs	Outcome
	concentration in the ambient air from the roadsides of Indore city.		conditions and high density of vehicular movement are the main causal factors for high concentrations of particulates which gradually builds up due to high rise buildings on either sides of the road in the city area in contrast to open areas located in the outskirts of the city.
Pandey et al., (1999)	To monitor air quality status of different sites in Lucknow city.	Vehicular pollutants, black soot	The results showed that the Lucknow city has witnessed a tremendous increase in two wheeler and three wheeler populations. They are the main source of visible pollution because they emit a lot of black soot from the exhaust. This black soot creates eye irritation, breathing trouble and is deposited on clothes.
Srinivas (1999)	To study at the spatial patterns of air pollution in Delhi, for sulphur dioxide (SO_2), oxides of nitrogen (NOx), and suspended particulate matter (SPM).	Sulphur dioxide (SO_2), oxides of nitrogen (NOx), and suspended particulate matter (SPM)	The SPM levels at a few places in Delhi often exceed national ambient air quality standards with the highest average values of SPM concentrations in various seasons in Delhi were always above 380 $\mu g/m^3$. Some strategies to reduce air pollution in the city of Delhi were suggested.
Joshi (1998[a,b])	To study the ambient air quality with reference to suspended particulate matter, Sulphur dioxide and	Suspended particulate matter, oxides of nitrogen and sulphur di-oxide	The change in concentration of these parameters for a period of five years from 1991 to 1995 was monitored and various causal factors were discussed. The values of suspended particulate matter exceeded the prescribed standards for commercial

Author/ Year	Objective of Study	Constructs	Outcome
	oxides of Nitrogen at Indore, Madhya Pradesh.		and residential areas for most of the time, while they were mostly within limits in the Industrial areas.
Panwar (1997)	To study the annual average ambient air quality data for three pollutants, namely suspended particulate matter (SPM), sulphur dioxide (SO_2) and oxides of nitrogen, (NOx) were analysed for 62 cities/towns in India and to represent the same on the map of India using GIS tools.	suspended particulate matter (SPM), sulphur dioxide (SO_2) and oxides of nitrogen, (NOx)	The air quality levels were compared against the prescribed standards to draw inferences regarding the pollutant (s) of concern and the severity of the problem at various cities/towns in the country. Analysis of the data reveals the prevalence of high SPM pollution levels in most of the cities, while only a few of them have high SO_2 or NOx problem.
Das (1997)	To study the rapid assessment of air quality in Jaipur city and to identify critical zones for evolving a proper environmental management strategy.	NO_2, SO_2, CO	Repeat measurements of SO_2 were made on a Sunday at 5 locations to enunciate the difference between the concentration levels on week days and Sunday due to lesser number of traffic and any other unknown sources. The concentration of gaseous pollutants, i.e. SO_2, NO_2, CO have been presented and analysed. The measurements were made only during the peak traffic hours (3. 30 PM to 5. 30 PM) which gave the maximum concentration

Author/ Year	Objective of Study	Constructs	Outcome
			observed in a day.
Chandrasekaran (1997)	To investigate the quality of air in Bangalore city at selected sites.	Ambient air quality pollutants, Lead	It was noticed that except for lead levels at Bapuji Nagar, no other pollutants exceeded the ambient air quality standards. It was due to the presence of large number of trees and other vegetation and existing pucca roads in Bangalore.
Bansal (1996)	To study the NO_2 concentration in commercial, industrial and residential areas of Bhopal (MP).	NO_2	In the commercial areas maximum NO_2 was recorded as 96.4 µg/m^3. Corresponding value in the industrial area as 66.3 µg/m^3 and 53.5 µg/m^3 in the residential area. Monthly average values were well below the prescribed standards.
Saini (1994)	To study the atmospheric concentrations of the SPM in the Chandigarh city and its industrial area	Suspended particulate matter	The data was measured from April to December 1993. The data collected was investigated and its statistical distribution, the weekly, daily and monthly variations was studied. On the whole a resident of city was exposed to over the maximum desirable level of 200 µg/m^3 for about 126 day whereas a person in the industrial area was exposed to over the stipulated limit of 500 µg/m^3 for about 13 day.

CHAPTER – 3

RESEARCH METHODOLOGY

3.1 DESCRIPTION OF STUDY REGION

As a matter of fact due to urbanization activities in the metropolitan cities it is seen that a number of satellite towns starts emerging around the city. In India among the States and Union Territories, the National Capital Territory of Delhi (NCT) is the most urbanized comprising of 93% urban population. National Capital Region Planning Board (NCRPB) was formulated in 1985 to plan for National Capital Territory (NCT) and the region surrounding NCT i.e. National Capital Region. The Nation Capital Region (NCR) of Delhi has grown rapidly in the past two decades. It now covers an estimated area of 900 Sq. km that includes new satellite towns of Gurgaon and Noida. In 2007, the population of NCR was estimated at 16 million. It is expected to reach 22.5 million in 2025.

Due to urbanization activities in and around Delhi, the satellite towns like Gurgaon, Faridabad, Noida, Ghaziabad, Jhajjar and Sonipat emerged as new centers. Among these newly created satellite towns, Gurgaon due to its proximity to Indira Gandhi International Airport has become an important commercial hub.

A brief history of Gurgaon is detailed below:

The Gurgaon town has been the headquarters of Gurgaon district since 1816, and has exhibited spectacular and steady growth after partition. Gurgaon started as a notified Area Committee for the Hidayatpur Chhaoni estate in 1899-1900. It was in 1950 that Class II Municipal Committee was set up for Gurgaon and in 1969, it was transformed into the Class I Municipal Committee.

The development Plan for Gurgaon was published in 1971 for an estimated population of 1.25 lakhs. Later in 1977 and 1982 it was revised for a projected population of 2.25 and 10 lakhs respectively. The NCR Regional plan has proposed that the population of Gurgaon could grow upto 16.5 lakhs by 2021. However due to increase commercial activities in last decade the population has increased many folds. Keeping in view this tremendous increase it is expected to reach a population of around 32.0 lakhs or higher as projected by Department of Town and Country Planning, Government of Haryana.

3.1.1 ENVIRONMENTAL CONCERNS FOR GURGAON

Gurgaon is the fastest growing city of Haryana and NCR and has a high attraction for many multinational companies as an ideal investment destination, especially in IT sector and automobile industry and at the same time, a better quality of life. This coupled with its proximity to National Capital and International Airport has added to its attraction. Similar to other large growing cities in India, Gurgaon is confronted with complex urban environmental problems due to its phenomenal growth during the last few decades.

The major emphasis regarding the monitoring of air quality is confined to the metropolitan cities or state capitals; however the satellite towns which also face the population loads are often neglected. The Central Pollution Control Board (CPCB) is regularly monitoring the air quality of many cities including Delhi. Gurgaon, which is a fast growing commercial hub in the National Capital Region of Delhi, has been chosen as the study area, because due to increased commercial activities the vehicular traffic has increased many fold and more over the transport facilities could not cope up with the growing demand and have deteriorated the environment quality over the years. Also, CPCB at present is not monitoring the air quality at Gurgaon which is a matter of concern due to deteriorating air quality. Hence, there is a need to study the impacts of vehicular pollution on ambient air quality in the city of Gurgaon.

3.1.2 ROAD NETWORK IN GURGAON

There are four major traffic corridors in Gurgaon city. The most important corridor is National Highway-8, which, traverse in the north-south direction along the length of Gurgaon city and divides the city into two parts. The second important road corridor is Mehrauli – Gurgaon (M.G.) Road (recently declared as NH-236) which starts from Mehrauli (in Delhi) and ends at Delhi/Gurgaon border, while the M.G. Road section in Gurgaon continues and after bisecting NH-8 it ends near ISBT (Gurgaon). The third major road corridor is Gurgaon-Sohna road, which, is an important State Highway and finally the fourth major road corridor is Gurgaon-Faridabad (another important State Highway) which connects cities of Gurgaon and Faridabad. In addition, arterial and sub-arterial roads cover the entire Gurgaon urban area.

Approximately 250 km of roads are present with in urban areas of Gurgaon. About 65% of the road lengths have right of way (RoW) more than 20 m i.e. land width available. This width is sufficient to develop six lane roads. However, presently only 34% of road length has carriageway widths of less than two lanes and 25% of road length have carriageway of more than four lanes. Medians are present in only 30% of the road length whereas only 18% of the roads have service roads. Ninety nine percent (99%) of the total road length has bitumen surfacing.

3.1.3 VEHICULAR GROWTH AND TRAVEL DEMAND IN GURGAON

The transport demands forecast within Gurgaon are summarized in **Table 3.1.** It may be observed that Gurgaon city would experience an estimated 39 lakhs trips out of which 15.6 lakh are expected to be within Gurgaon in the year 2021. A total of 23.6 lakh trips are expected to be performed by public transport system (intra + inter-city).

Table 3.1: Summary of Transport Demand Forecast

Parameters	2004	2011	2021
Population (lakh)	4.79	10.78	19.03
Employment (lakh)	1.76	3.91	6.91
PCTR (Vehicle) within Gurgaon	0.62	0.72	0.82
Total Vehicular Trips (lakh)	11.0	21.5	39.4
Intra City Trips (lakh) within Gurgaon	3.0	7.8	15.6
Inter-City Trips (lakh) Total _____ Within Delhi _____ With other areas_____	 8.0 5.8 2.2	 13.7 11.0 2.7	 23.8 20.2 3.6
Modular Split (Public Transport intra-study area trips) %	37	50	60
Total Public Transport Trips (Intra + inter-city) (lakh)	3.3	10.7	23.6

Source: DMRC Traffic Survey Report

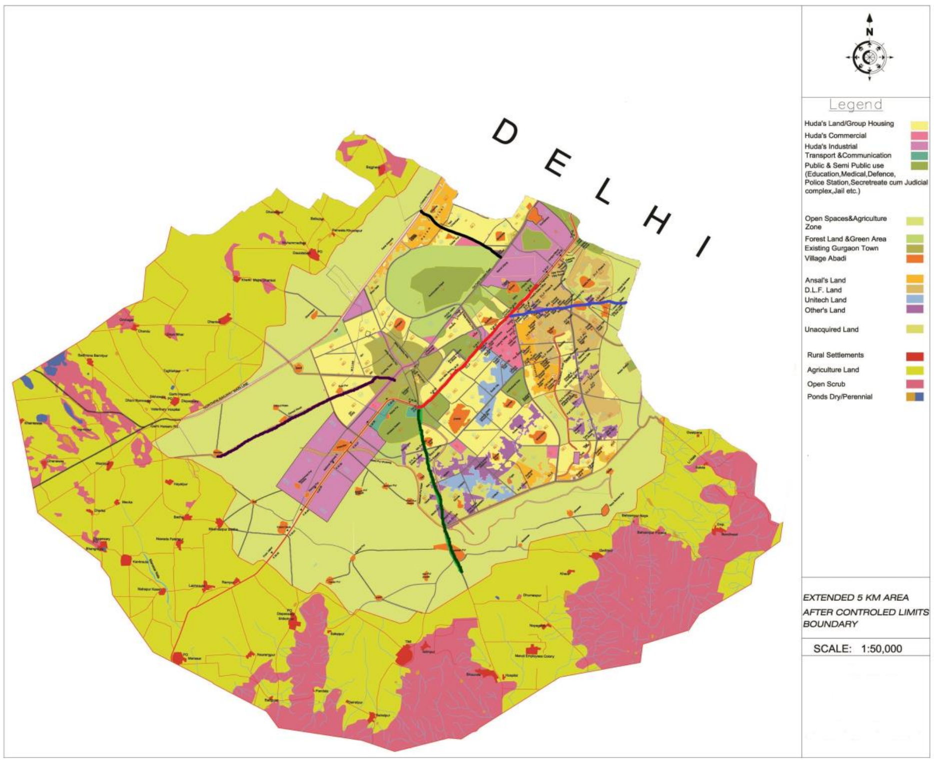
Analysis of the modal split of vehicular traffic of Gurgaon city reveals private modes of transport i.e. two-wheelers and cars occupy the major share i.e. 56%. This can be attributed to the inadequacy of public modes of transport. However, some busses and auto rickshaws operated by private and public operators ply within city limits.

National Highway- 8, Mehrauli - Gurgaon road and Gurgaon – Sohna road are three major roads which accounts for major incoming and outgoing traffic movement in the city. All three road corridors are considered as hot spots and have been included in the present study. The other corridors which have been selected represent semi urban and residential areas.

3.1.4 THE AREA OF THE PRESENT STUDY

National Highway- 8, Mehrauli - Gurgaon road and Gurgaon – Sohna road are important roads which account for major incoming and outgoing traffic movement in the city. All three road corridors which represent different land-use patterns (high traffic zone, major commercial area and a rural area) have been chosen for the present study. The other road corridors which have been selected represents other land-use pattern i.e. semi urban and residential areas.

Unlike other urban cities Gurgaon town and its vicinity has been divided into number of spatial zones. In order to study the effect of vehicular pollution on ambient air quality, all five road corridors passing through different land use were identified. The five road corridors selected for the study are as follows (**Ref. Figure 3.1**):



Road Corridor 1	**Road Corridor 2**	**Road Corridor 3**	**Road Corridor 4**	**Road Corridor 5**

Figure 3.1: Selected Road Corridors on Map of Gurgaon

Corridor 1 - National Highway Number 8, near IFFCO Chowk, a zone which experiences very high volume of traffic because of inter-city traffic

Corridor 2 – Mehrauli - Gurgaon Road near Sikandpur, a major commercial hub;

Corridor 3 - Sohna Road near village Badshahpur, a rural area;

Corridor 4 - Pataudi Road, a semi-urban area with commercial and residential mix; and

Corridor 5 - Palam Vihar Road, a residential area

In all the above selected road corridors field measurements were collected for assessing the traffic characteristics and ambient air quality using characteristics given in the section below:

3.2 FIELD SURVEY

Traffic generated air pollution is one of the prime environmental concerns. As motor vehicles are the major contributor to urban air pollution, controlling strategies are required to minimize these environmental impacts. Vehicular dispersion models represent essential computational tools for predicting the air quality impacts of emissions from road traffic and are widely used in urban and municipal planning.

Following field surveys/ parameters were conducted for the research study:

i. Classified Traffic Volume Count Survey (4 hourly traffic volume, composition: two wheelers, three wheelers, car/jeeps, buses, trucks and tractors).

ii. Ambient Air Quality Monitoring Survey (4 hourly data collection for PM_{10}, $PM_{2.5}$, SO_X, NO_X & CO.

iii. Fuel Station Survey (Fuel used in vehicle & Age of vehicle)

iv. Road Geometry Survey (carriageway width, median width)

v. Meteorological Data

3.2.1 CLASSIFIED TRAFFIC VOLUME COUNT SURVEY

Four hourly classified traffic volume count survey has been conducted at all the five road corridor for period of 16 hours from 6.00 am to 10.00 pm on normal working days covering both morning peak hours and evening peak hours. The traffic volume data has been collected on 4 hourly basis for the periods 06.00 to 10.00 hours; 10.00 to 14.00 hours; 14.00 to 18.00 hours and from 18.00 to 22.00 hours during two seasons - monsoon (in the month of August 2010) and pre-monsoon (in the month of March 2011). While hourly data for 24 hours was collected for the month of December, 2010 for modeling purpose.

The traffic survey has been done by manual counting of vehicles for different categories of vehicles two wheelers, three wheelers, car/van/jeep/sumo, mini bus/ bus, trucks, tractors and others. The Survey format used in collection of traffic volume data is given in **Appendix 3.1**.

3.2.2 AMBIENT AIR QUALITY MONITORING SURVEY

Ambient air quality monitoring survey has also been conducted simultaneously at all the five road corridors using a Respirable Dust Sampler in respect of the following parameters – Particulate Matter10 (PM_{10}) & Particulate Matter 2.5 ($PM_{2.5}$); Sulphur dioxide (SO_2); Oxides of Nitrogen (NOx) and Carbon monoxide (CO). Four hourly data for period of 16 hours from 06.00 to 10.00 hours; 10.00 to 14.00 hours; 14.00 to 18.00 hours and from 18.00 to 22.00 hours was collected during two seasons - monsoon (in the month of August 2010) and pre-monsoon (in the month of March 2011). While hourly data for 24 hours was collected for the month of December, 2010 for modeling purpose.

The sampling of air pollutants was done as per method prescribed in IS:5182 (Part II, IV and VI). The Survey format used in collection of Ambient Air Quality Monitoring data is given in **Appendix 3.2**.

3.2.3 FUEL STATION SURVEY

It is not possible to ascertain the percentage of two and four vehicles in two wheeler category and to know the type of the fuel used in the four wheelers during manual traffic count. Further, it is not possible to know the vintage (i.e. year of manufacture) of each vehicle counted in the traffic survey. To take care of all the above, a fuel station survey at nearest petrol pump at each road corridor have been carried out. There was no gas filling station on any of the above road corridor hence the fuel station survey at the nearest gas filling station in sector 29 was also carried out. The average results of the fuel station survey has been extended to the traffic survey, assuming that the vehicles plying on the road can be represented by vehicles coming to the fuel stations for filling up of the fuel. The fuel station survey were carried out at nearest fuel stations to know the vintage of the vehicles plying on the road as well as the percentage of two stroke and four stroke vehicles in two wheeler category and also to know the percentage of petrol, diesel and CNG driven vehicles in four wheelers (i.e. passenger car) category. It was assumed that the vehicles coming to the fuel stations are truly reflective of the vehicles plying on the road. The survey format used in collection of traffic vintage data from fuel station survey is given in **Appendix 3.3**.

3.2.4 ROAD GEOMETRY SURVEY

The road geometry surveys were carried out at the entire five road corridor to collect the information about road geometry. The information collected is as follows:

- Laning of the road
- Carriageway width
- Median width

The survey format used in collection of road geometry data from selected five road corridor is given in **Appendix 3.4**.

3.2.5 METEOROLOGICAL DATA

Since the study was to cover the three seasons (pre-monsoon, monsoon and post monsoon) hence, the meteorological data have been collected from secondary source i.e. Indian Meteorological Department. The monthly average meteorological data for Gurgaon city was collected for the parameters like wind speed, wind direction, humidity, and temperature for two seasons - monsoon (in the month of August 2010) and pre-monsoon (in the month of March 2011), while hourly data on two additional parameters stability class and mixing height was collected for the month of December, 2010 for modeling purpose. Summary of the meteorological data collected in August 2010 and March 2011 is shown in **Table 3.2**, while data collected in December 2010 is shown in **Table 3.3**.

Table 3.2: Meteorological Parameters in August 2010 and March 2011

From	To	August 2010				March 2011			
		Wind Speed (m/s)	Wind Direction	Temp. (^{O}C)	Humidity (%)	Wind Speed (m/s)	Wind Direction	Temp. (^{O}C)	Humidity (%)
6:00	7:00	2.1	SW	30	100	2.1	SW	17.5	83
7:00	8:00	2.1	W	31.8	100	1.5	WSW	18.0	83
8:00	9:00	2.6	W	31.9	100	2.1	W	19.0	78
9:00	10:00	2.6	W	31.9	89	2.1	SW	19.5	64
10:00	11:00	1.5	SSW	32.9	84	2.6	VARIABLE	20.5	51
11:00	12:00	calm	CALM	33.7	79	1.0	WSW	21.0	42
12:00	13:00	3.1	WSW	36.8	75	4.1	SW	21.5	27
13:00	14:00	2.6	W	36.8	75	3.6	SW	22.5	27
14:00	15:00	4.1	W	36.8	67	3.1	WSW	23.2	28
15:00	16:00	2.6	W	36.9	75	3.1	SW	22.5	28
16:00	17:00	2.6	WNW	35.5	71	2.6	SW	22.0	26
17:00	18:00	2.1	W	34.0	66	2.1	SSW	22.0	26
18:00	19:00	1.5	W	33.9	66	2.6	S	21.0	29
19.00	20.00	1.5	W	33.6	75	2.6	SSE	20.7	31
20:00	21:00	4.6	ENE	32.6	75	3.1	S	19.5	30
21:00	22:00	2.1	E	31.9	89	3.1	SSE	19.0	39
22:00	23:00	2.6	ESE	30.7	94	4.1	SSE	19.0	45
23:00	0:00	calm	CALM	30.7	94	2.6	WSW	18.8	53
0:00	1:00	calm	CALM	30.7	94	calm	CALM	18.5	57
1:00	2:00	calm	CALM	30.6	94	calm	CALM	18.3	65
2:00	3:00	calm	CALM	30.6	94	calm	CALM	18.2	73
3:00	4:00	calm	CALM	29.4	100	calm	CALM	17.9	78
4:00	5:00	calm	CALM	29.4	100	calm	CALM	17.8	78
5:00	6:00	calm	CALM	29.4	100	calm	CALM	17.5	83

Table 3.3: Meteorological Parameters in December 2010

From	To	Wind Speed (m/s)	Wind Direction	Temp. (^{O}C)	Humidity (%)	Mixing Height (m)	Stability Class (P-G)
6:00	7:00	1.8	WSW	8	94	55	D
7:00	8:00	1.5	WSW-SW	8	88	60	D
8:00	9:00	2.3	WSW-SW	9.5	82	75	C
9:00	10:00	3	WSW-W	12	72	130	C
10:00	11:00	2.8	W	15	67	250	C
11:00	12:00	3.1	W	18	63	440	C
12:00	13:00	3.6	W	19.5	49	630	C
13:00	14:00	4.3	W	20.5	43	725	C
14:00	15:00	4.6	W	21	37	775	C
15:00	16:00	4.6	W	21	35	840	C
16:00	17:00	3.6	W	20.5	32	860	D
17:00	18:00	2.3	W	19	34	800	D
18:00	19:00	2.6	W-WNW	17.5	36	725	D
19.00	20.00	2.2	WNW	16	42	550	D
20:00	21:00	1	WNW	15.5	48	300	D
21:00	22:00	1	WNW	14.5	51	150	D
22:00	23:00	1	WNW	13.5	54	85	D
23:00	0:00	1	W	12	72	55	D
0:00	1:00	1	SW	11	72	35	D
1:00	2:00	2.1	SW	11	72	25	D
2:00	3:00	2.4	SW-WSW	10.5	77	15	D
3:00	4:00	2.8	WSW-W	9.5	87	10	D
4:00	5:00	2	WSW-W	8.5	94	20	D
5:00	6:00	1.5	WSW	8	94	40	D

The wind speed at 10m above Ground Level has been found out by using velocity power law equation given below:

$$U_1/U_2 = (Z_1/Z_2)^{0.33}$$

The value corresponding to urban terrain conditions have been taken as 0.33. Since, in any air basin, observed mixing heights do not change much during particular seasons/ months. The wind data collected at approximately 3m above ground level (GL) was extrapolated to find the wind speed at 10m height above GL by using the velocity power law with the power law exponent ‘α=0.33’, corresponding to the urban/semi urban area, corresponding to outskirt area of large cities (like Delhi) (Ref. **Table 3.4**). The wind speed (at 10m) and mixing height were used to calculate the hourly ventilation coefficient (ventilation coefficient = mixing height X average wind speed).

Table 3.4: Values of 'α' and 'δ' for Different Types of Terrain (Counihan, 1975)

Type of terrain	α	δ (m)
Rural terrain	0.143 – 0.167	
Suburban terrain	0.21 – 0.23	
Urban terrain	0.28	600
Grassland, Prairie, Desert	0.133	275
Farmland with scattered trees and buildings	0.154	305
Open field with walls and hedges, scattered trees and buildings	0.1818	335
Scattered two-storey buildings, scattered wind brakes of trees	0.2222	366
Forest, Scrubs, Parkland	0.266	412
Towns, Suburbs, Outskirts of large cites	0.333	457
Centre of large cities	0.40 – 0.66	550

The hourly stability classes viz., A-F (Pasquill and Gilford; P-G) were obtained by the Turner Scheme (Turner, 1964) (Ref. **Table 3.5**). In the present study stability class D, which represents neutral class has been used.

Table 3.5: Pasquill Stability Categories

Surface wind speed (m/s) (at 10m height)	Day – time Insolation			Night- time	
	Strong	Moderate	Slight	Thin overcast or ≥ 4/8 cloudiness	≤ 3/8 cloudiness
< 2	A	A-B	B		
2	A-B	B	C	E	F
4	B	B-C	C	D	E
6	C	C-D	D	D	D
> 6	C	D	D	D	D

A – Extremely unstable B – Moderately unstable C – Slightly unstable

D – Neutral E – Slightly stable F- Moderately stable

3.3 AIR QUALITY PREDICTION CALINE 4 MODEL

CALINE 4 was introduced in 1984 which is the latest version in the CALINE series of models for predicting concentration of CO, NOx and aerosols (Robet, 2002). CALINE 4 is the fourth version simple line source Gaussian plume dispersion model. It employs a mixing zone concept to characterized pollutant dispersion over the roadway. Its purpose is to help planners protect public health from the adverse effects of excessive CO exposure.

The main purpose of the model is to assess air quality impacts near transportation facilities. The CALINE 4 can predict the pollutant concentrations for receptors located within 500 meters of the roadway under given traffic and meteorological conditions of road/highway. The important input parameters required for CALINE 4 model include, classified traffic volume (number of vehicles per hour). Meteorological parameters (wind speed, wind direction, ambient temperature, mixing height and stability class), emission parameters (weighted emission factor, WEF), road geometry, (road width, median width, road elevation), type of terrain (rural or urban), background CO concentration (ppm or $\mu g/m^3$) at pre-identified receptor locations along the road corridors.

In the present study CALINE 4 model has been used to predict the CO concentrations along road corridor 1 as it has highest concentration of carbon monoxide and highest traffic volume. A brief description about CALINE 4 model is provided in Appendix 3.5. The details of model setup is provided below in section 3.3.1, while a brief about the data input used in the model are described in below sections.

3.3.1 MODEL SETUP

In order to predict air concentrations of Carbon monoxide CALINE4 model was used to predict the concentration of CO emitted from vehicle exhaust under standard meteorological conditions. The model was run for 24-hour period during winter season. Hourly weighted emission factors were calculated using the hourly traffic data recorded on study corridors. As the road corridor 1 (near IFFCO Chowk on NH-8) recorded the significantly higher traffic volumes in comparison to other road corridors, the modeling was performed for the corridor 1. The CO being major indicator pollutant for vehicular activities was chosen for the present study and hence the modeling was performed for CO only. For the present project, the model was used to predict 1-hour CO concentration for standard meteorological conditions.

The WEF (input parameter for CALINE 4) is a function of vehicle emission factor (as a function of vehicle category, type, fuel type, age profile, vintage etc.) and vehicle activity (traffic volume). The methodology used for calculation of WEF is given below:

WEF= [$\sum$ (i) $\sum$ (ky) N (j.ky), EF (i,j,ky)]/ Total No. of Vehicles ………. (Eqn. 4.1)

Where,

WEF = Weighted emission factor (g/kg)

N (j.ky) = No. of vehicles of a particular type j and age ky in year y (average daily traffic

EF (i,j,ky) = Emission factor for component I for the vehicle type j and age ky in year y (g/kg)

I = Pollutant component (viz., CO)

J = Type of vehicle [i.e. 2W, 3W, cars, bus, truck etc.]

Ky = Age if vehicle in year y

3.3.2 INPUT PARAMETERS

Various input parameters such as traffic data, weighted emission factor, terrain type, mixing zone width and meteorological and recorded CO concentration were used in CALINE 4 model. The details of such parameters are provided in **Table 3.6** below:

Table 3.6: Input Parameters Used in CALINE 4

S.No.	Parameters	Values/ Units	Source
1	Traffic Data (24 hour)	24 hourly	Manual Count
2	Weighted Emission Factors (WEF)	g/miles	Calculated
3	Terrain Type	Urban	Physically observed
4	Mixing Zone width (Carriage width + 3 m on both sides)		Physically measured
a	Road Alignment	Straight	Google Map
b	Road Type	At-Grade	Assumed
5	Meteorological Data		
a	Wind Speed	m/s	IMD
b	Wind Direction	Degree	IMD
c	Mixing Height	m	Atlas, IMD
d	Stability Class	A,B,C,D,E or F	Pasquill (P-G) Stability Class
6	Monitored CO Conc.	$\mu g/m^3$	Recorded

3.3.3 TRAFFIC DATA

Under standard meteorological condition, the CALINE4 model predicts the pollutant concentration in the prevailing wind direction; hence hourly concentration values at predetermined receptor locations were obtained. CO predictions have been done for year 2010 and for next five years thereafter i.e. for year 2015. The hourly traffic data at corridor I (near IFFCO Chowk on NH-8) recorded in December 2010 (winter season) was used. The traffic projections five years down the line (i.e. for year 2015) has been done based on annual growth projections in NCR in near past. The projected traffic volume has been calculated with an annual rise of 8% for first 3 years and 7% for 4th and 5th year.

For air pollution modeling purpose, the traffic data was reclassified in 5 broad categories wiz. two wheelers, three wheelers, Cars, LCVs and HCVs. The reclassification of different vehicles is performed as per **Table 3.7** below:

Table 3.7: Reclassification of Different Vehicles

New Category / Class of Vehicle	Old Category of Vehicles
Two Wheelers	All Two Wheelers
Three Wheelers	All Three Wheelers
Cars	Car / Van / Jeep / Sumo
LCVs	10% of all minibus/buses All Tractors
HCVs	90% of all minibus/buses All Trucks

Based on the average results of the fuel station survey the same results has been extended to the traffic survey, assuming that the vehicles plying on the road are being represented by vehicles coming to the fuel stations for filling up of the fuel. The vintage of the vehicles plying on the road as well as the percentage of petrol, diesel and CNG vehicles plying on the corridor are given below in **Table 3.8**:

Table 3.8: Composition of Traffic / Age of Vehicle (%)

Age of Vehicle	2W (2 Stroke) 30%	2W (4 Stroke) 70%	3W (Petrol) 90%	3W (CNG) 10%	Passenger Cars (Petrol) 55%	Passenger Cars (Diesel) 45%	LCV	HCV / BUS
1991-1995	5	0	5	-	5	5	5	5
1996-2000	15	10	15	-	20	20	15	15
2001-2005	50	30	40	100	35	35	40	40
2006-2010	30	60	40		40	40	40	40

* Tractors are assumed in the category of LCV

* As buses and mini buses are counted as same; hence, it is assumed that mini buses account for 10% share

3.3.4 WEIGHTED EMISSION FACTOR

One of the important requirements for CALINE4 model is the input for emission factor for vehicles. In the present study, the emission factors specified by the ARAI and CPCB have been used for calculation of weighted emission factors. These emission factors have been expressed for various pollutants and vehicle types, year of manufacturing and type of fuel used (petrol or diesel). The improvement in engine technology, resulting in reduced emission factors are reflected in these standard emission factors. Since, there is only one input requirement for total no. of vehicles in the CALINE 4 model, whereas, there are different categories of vehicles (viz. cars, LCVs and HCVs) with different manufacturing year and fuel type, it is essential that a single value representing the equivalent emission factors for all the vehicles is calculated. Thus, Weighted Emission Factor expressed in g/mile has been calculated for the present study.

$$\text{WEF}=\frac{\sum_i (No.of\ Vehicles\ X\ Emission\ Factor\ X\ Detoriation\ Factor)}{\sum_i (No.of\ Vehicles)}$$

In the present study, the emission factors specified by the Automotive Research Association of India (ARAI 2007) and Central Pollution Control Board (CPCB, 2000) has been used for calculation of weighted emission factors. With increased age of the vehicles, there is further deterioration in the emission generated by vehicles, hence with age deterioration factor is also considered in calculation of WEF as given below in **Table 3.9**.

Table 3.9: CPCB Deterioration Factor (gm/km) for Different Category of Vehicles

Age of Vehicles (years)	Passenger Cars		LCVs	HCVs
	Petrol	Diesel		
10-15	1.17	1.085	1.1	1.475
5-10	1.28	1.14	1.125	1.33
0-5	1.097	1.05	1.095	1.17

3.3.5 ROAD PARAMETERS

The road alignment is considered straight and at grade. Surface roughness length equal to 200 cm, relevant for centers of large town or cities has been used for modelling.

3.3.6 METEOROLOGICAL DATA

The hourly meteorological data with regards to temperature, wind speed, wind direction, mixing height and stability class for December 2010 has been obtained from IMD. The meteorological data corresponding to that hour which has maximum emission load has been used for the modelling purpose.

3.3.7 RECEPTOR POINTS

The 18 receptor points (9 points on each side of the road corridor) was selected at pre-identified receptor location with a specified distance from the edge of the mixing zone width (road width + 3 m on each side of the corridor) i.e. 1 m, 5m, 10m, 20m, 30m, 50m, 75m, 100m and 150m from the edge of the road on both the side. The predicted CO Concentrations at all 18 receptor points was calculated both for year 2010 and 2015.

The detailed mathematical calculations and predicted CO results are provided in section 4.3.

3.4 SENSITIVITY ANALYSIS

The sensitivity analysis of the CALINE 4 model has been performed in the study to identify the most influential input variable among the various input variables. Almost all input parameters act independently within the model, interaction between two or more variables were presumed to be insignificant. Hence, for sensitivity analysis effect of each input variable was seen by changing one input variable at a time keeping other variable constant.

Sensitivity analysis was done for following meteorological and traffic parameters input variables:

Meteorological parameters:

- Wind Angle
- Wind Speed

Traffic parameters:

- Road Width
- Median Width

The Sensitivity analysis of CALINE 4 model was done for corridor I. Two receptor points on either side (LHS & RHS) of road corridor at a distance of 1 m from the mixing zone were chosen. The following site variables/link variables which have been used in sensitivity analysis are shown below in **Table 3.10**:

Table 3.10: Site and Link Variables

Site variables		Link Variables	
Stability Class	4 (D)	Emission Factor	4.8
Mixing Height	550 m		
Surface Roughness	200cm		
Temperature	$16^{0}C$		
Altitude	235 m		

To study the sensitivity of wind angle, the wind angle was varied from 0 to 360 degree at an interval of 15 degree. The concentrations of CO on both the receptor points were recorded for each wind angle and most critical effect on the receptor was studied. Similarly to study the sensitivity of wind speed, the wind speed was varied from 0.5 m/s to 5.0 m/s. The concentrations of CO on both the receptor points were recorded and analyzed.

The presently road corridor I is 6 lane divided carriageway and has a road width of 21 m (10.5 m on LHS and 10.5 m on RHS). For the sensitivity analysis, highway width was varied to 8 lane (28m), 10 lane (35m) and 12 lane (42 m) carriageway width configurations. The model was run for different road widths and concentrations of CO on both the receptors were studied. Similarly to study the sensitivity with regards to median width, the median width was varied from 1m to 5m width at 1m interval and concentrations of CO on both the receptors were recorded and analyzed.

The detailed results due to change in each variables and effect on CO Concentration levels at both receptor points are provided in section 4.4.

3.5 ENVIRONMENTAL MANAGEMENT PLAN

In order to prepare an Environmental Management Plan it was necessary to identify the probable cumulative impacts due to different air pollutants on all the road corridors. In the present study the environmental monitoring was carried out for all

5 road corridors in Gurgaon town as per latest Central Pollution Control Board 2009 guidelines. The monitored results were analyzed and compared with National Ambient Air Quality Standards (NAAQS). To study the cumulative effect of concentration of individual pollutants in ambient air a single value was required and was expressed through Air Quality Index. The probable risks in terms of Air Quality Index (AQI) for all 5 road corridors were calculated using excel based AQI Calculator for Delhi (SIM air working paper No. 34).

The Air Quality Index (AQI) is an "index" determined by calculating the degree of pollution in the urban area or at the monitoring point and includes main pollutants - particulate matter, ground-level ozone, sulphur dioxide, carbon monoxide and nitrogen dioxide. Each of these pollutants has an air quality standard which is used to calculate the AQI. In numbers, AQI is represented between 0 to 500 with 0 representing good air and 500 representing hazardous air. For better understanding and presentation, the AQI is broken down into six categories, each color coded with the number scale. (**Ref. Table 3.11**)

Table 3.11: AQI Categories

0 - 50	Good	This AQI value between 0 and 50 is considered satisfactory and air pollution poses little or no risk. No cautionary actions are prescribed to the general public.
51 - 100	Moderate	This AQI value between 51 and 100 considered is acceptable for general public. However, unusually sensitive people should consider limiting prolonged outdoor stays.
101 - 150	Unhealthy for sensitive group	This AQI value between 101 and 150 is considered borderline unhealthy, particularly for members of sensitive groups. This means they are likely to be affected at lower levels than the general public. For example, children and adults who are active outdoors and people with respiratory disease are at greater risk from exposure to PM and ozone, while people with heart disease are at greater risk from CO. Some people may be sensitive to more than one pollutant.
151 – 200	Unhealthy	This AQI value between 151 and 200 is considered for most of the public where everyone may begin to

		experience some level of discomfort. Active children and adults, and people with respiratory disease, such as asthma, should avoid prolonged outdoor stays.
201 - 300	Very Unhealthy	This AQI value between 201 and 300 can trigger a health alert, meaning everyone may experience more serious health effects. Active children and adults, and people with respiratory disease, such as asthma, should avoid all outdoor stays.
301 - 500	Hazardous	This AQI value of over 300 trigger health warnings of emergency conditions. The entire population is likely to be affected. This could be due to a combination of the pollutants or a single pollutant such as PM.

The monitored values of air pollutants - PM_{10}, $PM_{2.5}$, SO_X, NO_X and CO during three season's viz. August 2010, December, 2010 and March 2011 was feed in the excel based system and AQI values were calculated for each road corridor in 3 different seasons. An average of two worst AQI values was obtained for each road corridor. The road corridors with critical AQI were identified and an Environmental Management Plan has been suggested meeting the requirements of Ministry of Environment Forests and Climate Change (MoEF & CC), Government of India.

An Environmental Management Plan is a site or project specific plan developed to ensure that appropriate environmental management practices are followed during execution phase. An effective Environmental Management Plan should ensure:

- Application of best environmental management practices
- Compliance with environmental legislations
- The associated environmental risks are properly managed.

The Environmental Management Plan suggested will help the local district administration in planning developmental activities in near future. A site specific environmental management plan has been suggested for the road corridors where ambient air quality is exceeding NAAQS. In addition to this a generic environmental management plan has also been suggested which could be applicable for other road corridors in Gurgaon town. Finally an environmental monitoring plan has also been suggested so that future environmental risks associated with these road corridors could be monitored and managed properly. The details are provided in section 4.5.

CHAPTER 4

RESULTS AND DISCUSSION

In this chapter the results of the objectives have been discussed for each objective separately. In objective 1 the baseline traffic was established in terms of traffic volume for all 5 road corridors representing different land-use pattern and baseline transport scenario was established in terms of traffic composition for all the 5 road corridors. Further to understand the trends with regards to seasonal variation was studied. In objective 2 an effort has been made to establish the relation between total vehicles and air pollutants and also between various pollutants and meteorological attributes. In objective 3 prediction of concentration of Carbon monoxide was done using CALINE 4 model for next 5 years. In objective 4 the sensitivity analysis was carried out on the predicted concentrations of CO with different combination of meteorological and traffic parameters and finally based on the outcome of the results a suggestive remedial measures in form of Environmental Management Plan has been proposed. The detailed results and discussions against each objective are given below:

4.1 Objective I: To Establish A Baseline Traffic in Terms of Traffic Volume and Transport Scenario in Terms of Traffic Composition to Understand Its Impact on Ambient Air Quality With Seasonal Variation Within The Urban Limits of Gurgaon.

The parameters related to traffic composition and traffic flow affect the environmental pollution through vehicle exhaust emissions. Therefore, to establish a baseline traffic and transport scenario a four hourly classified traffic volume count survey was conducted at five different road corridor for period of 16 hours from 0600 to 2200 hours on normal working days covering both morning peak hours and evening peak hours. The traffic volume data has been collected on 4 hourly basis for the time periods 0600 to 1000 hours; 1000 to 1400 hours; 1400 to 1800 hours and from 1800 to 2200 hours during two seasons -

monsoon (in the month of August 2010) and pre-monsoon (in the month of March 2011). While hourly data for 24 hours was collected for the month of December, 2010 for modeling purpose.

4.1.1 TRAFFIC VOLUME COUNT AND COMPOSITION AT ROAD CORRIDOR 1

The results of Traffic Volume Count conducted in three different seasons monsoon period (August, 2010), post monsoon (December, 2010) and pre monsoon(March, 2011) for Corridor – I are given below in **Table 4.1**, **Table 4.2** and **Table 4.3** respectively, while the traffic composition is given in graphical representation in **Figure 4.1**, **Figure 4.2** and **Figure 4.3** respectively.

Table 4.1: Traffic Volume Count at Corridor 1 (August, 2010)

Time (hours)	Two Wheelers	Three Wheelers	Car/Van/ Jeep/Sumo	Mini Bus/Bus	Trucks	Tractors	Total
06:00 to10:00	11362	3409	30311	1769	6727	204	**53782**
10:00 to 14:00	8663	2762	30798	1819	1676	275	**45993**
14:00 to 18:00	8018	2096	31417	1499	2358	212	**45600**
18:00 to 22:00	13217	2916	41022	2299	14726	243	**74423**
Total	**41260**	**11183**	**133548**	**7386**	**25487**	**934**	**219798**

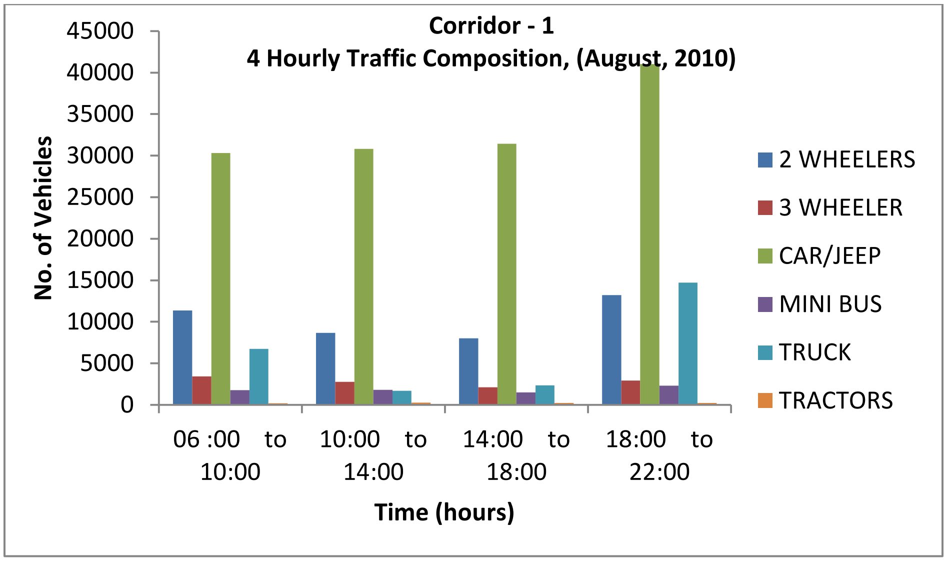


Figure 4.1: Four Hourly Traffic Composition, Corridor 1, August 2010

Table 4.2: Traffic Volume Count at Corridor 1 (December, 2010)

Time (hours)	Two Wheelers	Three Wheelers	Car/Van/ Jeep/Sumo	Mini Bus/Bus	Trucks	Tractors	Total
06:00 to10:00	13161	3077	35000	1760	8171	293	**61462**
10:00 to 14:00	10495	3037	38114	1892	2517	441	**56496**
14:00 to 18:00	10474	2376	34042	1502	3058	365	**51817**
18:00 to 22:00	15666	3053	38281	2285	21119	324	**80728**
Total	**49796**	**11543**	**145437**	**7439**	**34865**	**1423**	**250503**

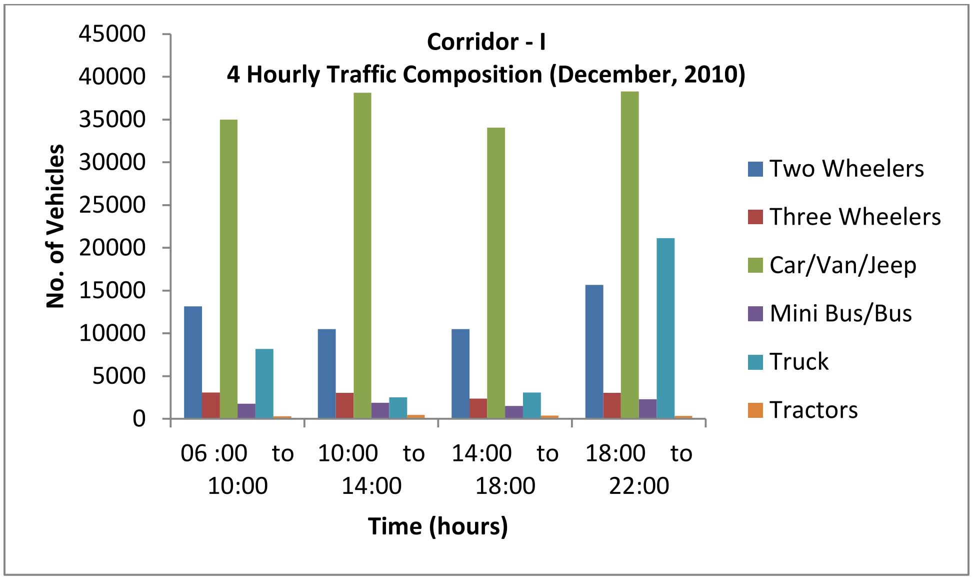


Figure 4.2: Four Hourly Traffic Composition, Corridor 1, December 2010

Table 4.3: Traffic Volume Count at Corridor 1 (March, 2011)

Time (hours)	Two Wheelers	Three Wheelers	Car/Van/ Jeep/Sumo	Mini Bus/Bus	Trucks	Tractors	Total
06:00 to10:00	14662	3297	30106	1766	8284	303	**58418**
10:00 to 14:00	10025	2915	32005	1912	2188	408	**49453**
14:00 to 18:00	10149	2207	31594	1397	2809	334	**48490**
18:00 to 22:00	16597	2857	39751	2354	21038	313	**82910**
Total	**51433**	**11276**	**133456**	**7429**	**34319**	**1358**	**239271**

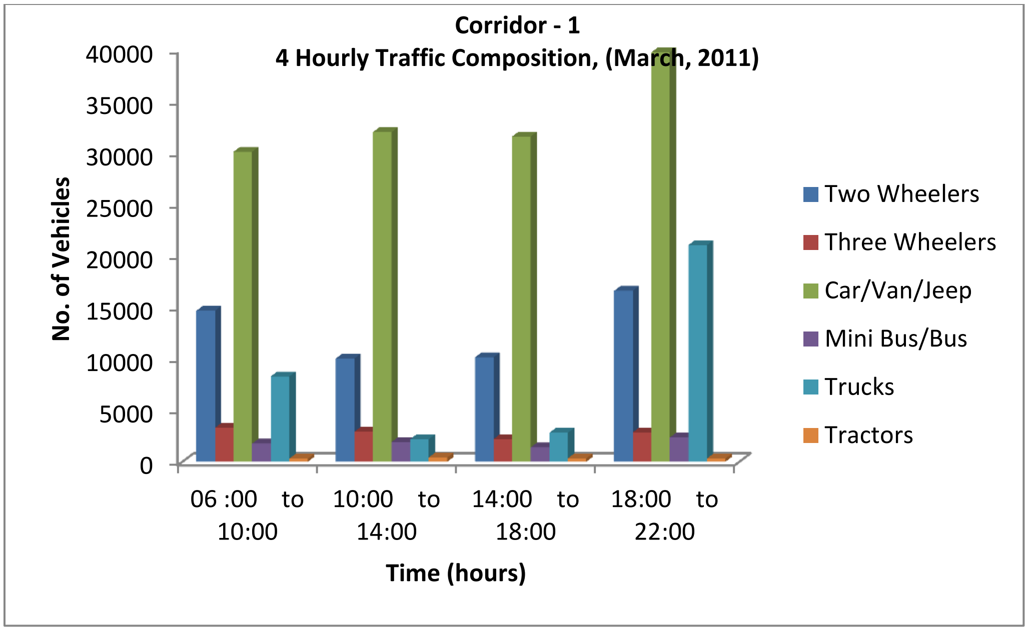


Figure 4.3: Four Hourly Traffic Composition, Corridor 1, March 2011

4.1.2 DISCUSSION FOR ROAD CORRIDOR 1

The road corridor 1 which represents a National Highways recorded a very high traffic volume of over 2 lakhs vehicles. The traffic volume recorded was 219798; 250503 and 239271 in the month of August 2010, December 2010 and March 2011 respectively.

The above data with regards to total traffic composition highlights that the major proportion of traffic is contributed by cars/jeeps followed by two-wheelers, the reason for the same may be since Gurgaon is part of National Capital Region, and a major industrial hub with a large population working in industries and corporates hence ownership of cars/jeeps is very high. Similar results were quoted in a previous research by Sachdeva (2010) which states that out of the total composition of traffic on National Highway 8 between Delhi and Gurgaon, 48 per cent traffic is constituted by cars.

Presently, the Gurgaon city has inadequate public transport facilities in relation to large working population, thus more and more people are dependent on personalized vehicles. From the data it is also evident that the maximum traffic is concentrated between 1800 to 2200 hours. The traffic constituted by trucks is maximum during night, the main reason for that is the entry of trucks in Delhi are only allowed after 8 pm, hence the same gets highlighted in traffic composition data.

As far as seasonal variations are concerned, maximum traffic was observed in December followed by March and least was in august. The reason for the same may be that since climate of North India is such that it is more comfortable to move out during winters, office traffic as well as leisure traffic contribute towards higher concentration in these seasons

4.1.3 TRAFFIC VOLUME COUNT AND COMPOSITION AT ROAD CORRIDOR 2

The results of Traffic Volume Count conducted in three different seasons monsoon period (August, 2010), post monsoon (December, 2010) and pre monsoon (March, 2011) for Corridor – 2 are given below in **Table 4.4**, **Table 4.5** and **Table 4.6** respectively, while the traffic composition is given in graphical representation in **Figure 4.4**, **Figure 4.5** and **Figure 4.6** respectively.

Table 4.4: Traffic Volume Count at Corridor 2 (August, 2010)

Time (hours)	Two Wheelers	Three Wheelers	Car/Van/ Jeep/Sumo	Mini Bus/Bus	Trucks	Tractors	Total
06:00 to10:00	5556	1830	16241	520	1000	275	**25422**
10:00 to 14:00	6644	1812	16615	725	647	417	**26860**
14:00 to 18:00	6658	1416	16541	654	696	293	**26258**
18:00 to 22:00	5325	1937	19296	466	1121	291	**28436**
Total	**24183**	**6995**	**68693**	**2365**	**3464**	**1276**	**106976**

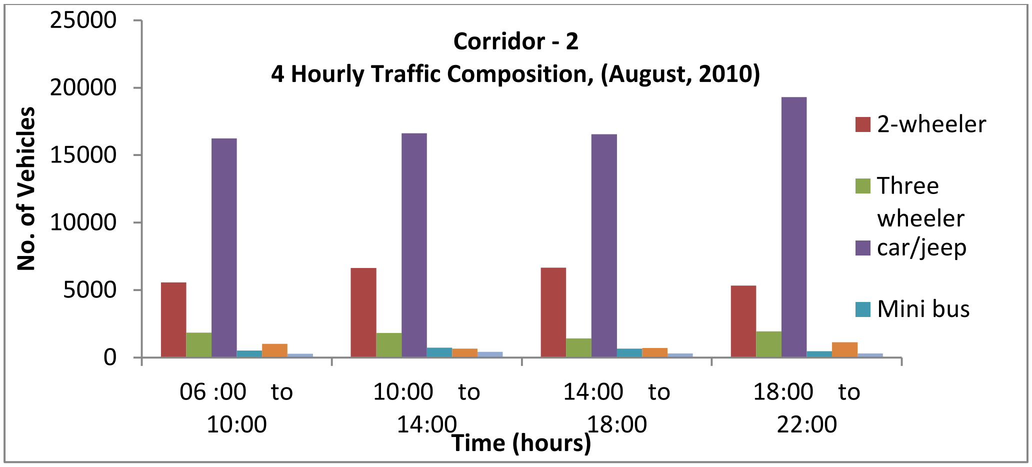


Figure 4.4: Four Hourly Traffic Composition, Corridor 2, August 2010

Table 4.5: Traffic Volume Count at Corridor 2 (December, 2010)

Time (hours)	Two Wheelers	Three Wheelers	Car/Van/ Jeep/Sumo	Mini Bus/Bus	Trucks	Tractors	Total
06:00 to10:00	7031	2000	17344	552	1000	257	**28184**
10:00 to 14:00	9493	2269	18913	821	721	454	**32671**
14:00 to 18:00	8671	1686	18814	744	729	335	**30979**
18:00 to 22:00	6469	1961	21451	521	1152	272	**31826**
Total	**31664**	**7916**	**76522**	**2638**	**3602**	**1318**	**123660**

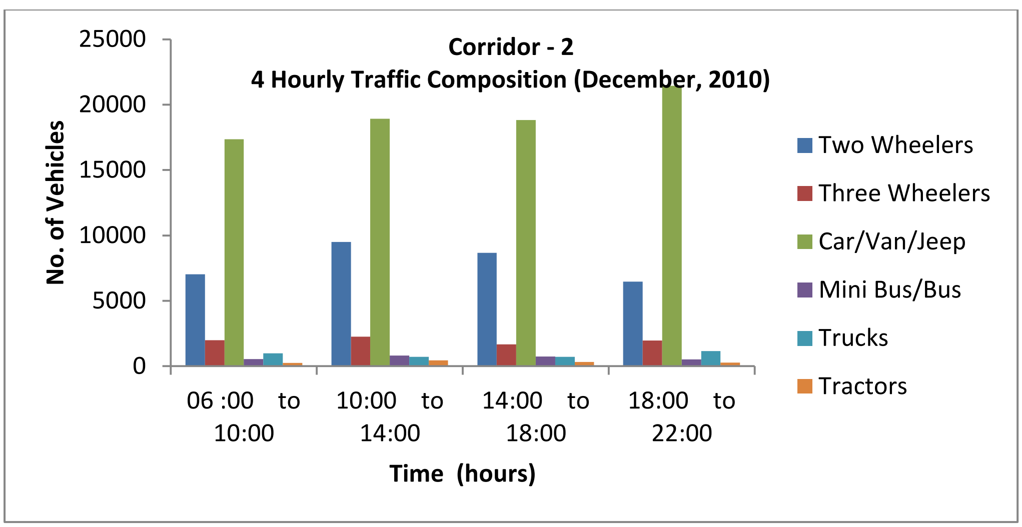


Figure 4.5: Four Hourly Traffic Composition, Corridor 2, December 2010

Table 4.6:Traffic Volume Count at Corridor 2 (March, 2011)

Time (hours)	Two Wheelers	Three Wheelers	Car/Van/ Jeep/Sumo	Mini Bus/Bus	Trucks	Tractors	Total
06:00 to10:00	7203	2175	17776	557	1008	276	**28995**
10:00 to 14:00	9077	2160	17872	791	722	386	**31008**
14:00 to 18:00	8373	1431	18209	719	725	325	**29782**
18:00 to 22:00	6413	2001	21222	521	1079	306	**31542**
Total	**31066**	**7767**	**75079**	**2588**	**3534**	**1293**	**121327**

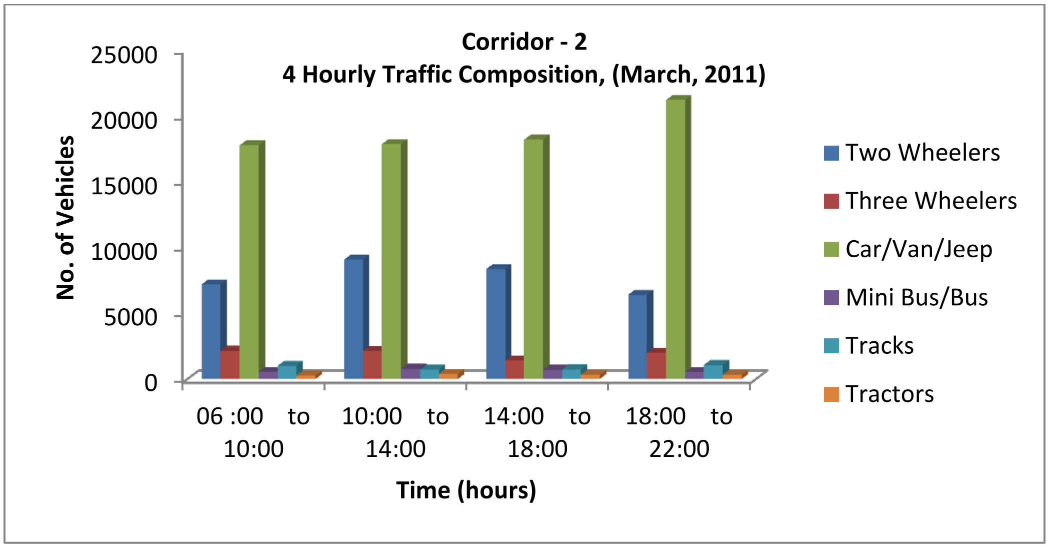


Figure 4.6: Four Hourly Traffic Composition, Corridor 2, March 2011

4.1.4 DISCUSSION FOR ROAD CORRIDOR 2

The road corridor 2 which also represents a National Highways also recorded a high traffic volume of over 1 lakhs vehicles, but less than that of Corridor 1. The traffic volume recorded was 106967; 123660 and 121327 in the month of August 2010, December 2010 and March 2011 respectively.

As far as traffic composition is concerned, maximum contribution to total traffic was by cars/jeeps followed by 2-wheelers and the highest traffic concentration was observed between 1800 to 2200 hours followed by 1000 to 1400 hours, which definitely coincides with the start and finish of office hours as well as this the area where commercial activities are concentrated. Again the seasonal variation highlights more traffic in December followed by March and least in August and the reasons are same as quoted in discussion for road corridor 1.

4.1.5 TRAFFIC VOLUME COUNT AND COMPOSITION AT ROAD CORRIDOR 3

The results of Traffic Volume Count conducted in three different seasons monsoon period (August, 2010), post monsoon (December, 2010) and pre monsoon(March, 2011) for Corridor – 3 are given below in **Table 4.7**, **Table 4.8** and **Table 4.9** respectively, while the traffic composition is given in graphical representation in **Figure 4.7**, **Figure 4.8** and **Figure 4.9** respectively.

Table 4.7:Traffic Volume Count at Corridor 3 (August, 2010)

Time (hours)	Two Wheelers	Three Wheelers	Car/Van/ Jeep/Sumo	Mini Bus/Bus	Trucks	Tractors	Total
06:00 to10:00	1906	304	1316	221	1467	181	**5395**
10:00 to 14:00	2937	277	2220	214	765	92	**6505**
14:00 to 18:00	2276	226	1777	190	1531	109	**6109**
18:00 to 22:00	1619	208	1547	136	2333	126	**5969**
Total	**8738**	**1015**	**6860**	**761**	**6096**	**508**	**23978**

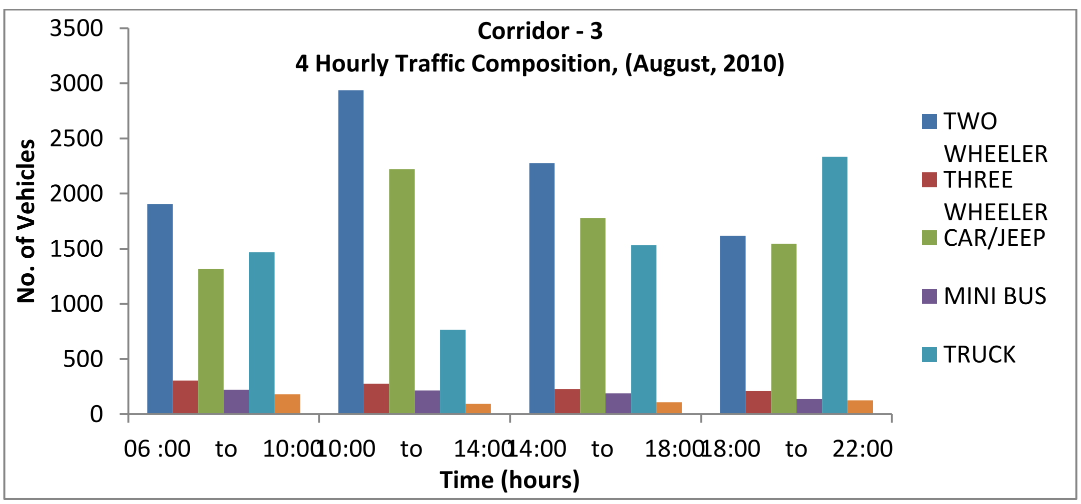


Figure 4.7: Four Hourly Traffic Composition, Corridor 3, August 2010

Table 4.8:Traffic Volume Count at Corridor 3 (December, 2010)

Time (hours)	Two Wheelers	Three Wheelers	Car/Van/ Jeep/Sumo	Mini Bus/Bus	Trucks	Tractors	Total
06:00 to10:00	1715	310	1500	254	1645	175	**5599**
10:00 to 14:00	4004	366	2710	257	974	130	**8441**
14:00 to 18:00	2887	299	2165	251	1978	144	**7724**
18:00 to 22:00	1997	257	1949	162	2799	167	**7331**
Total	**10603**	**1232**	**8324**	**924**	**7396**	**616**	**29095**

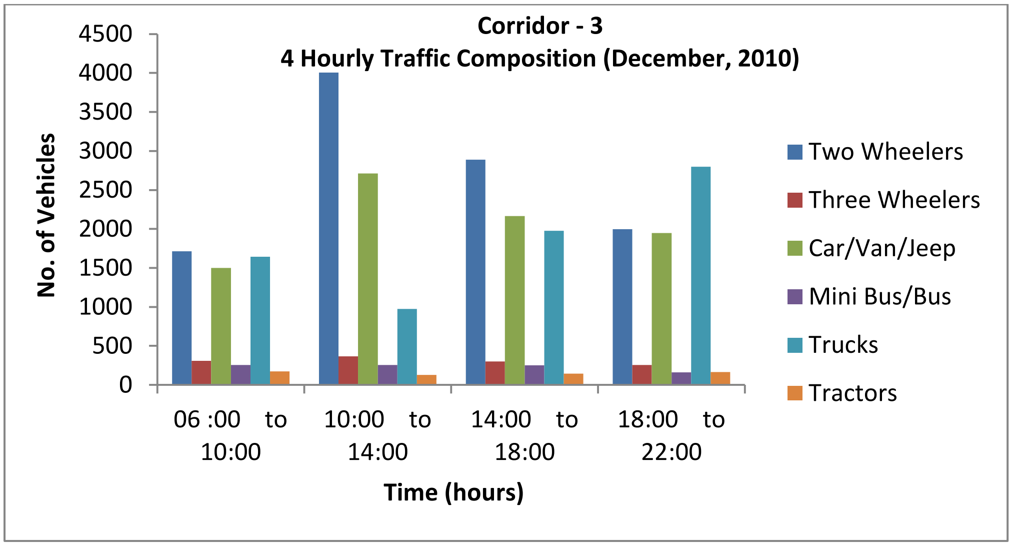


Figure 4.8: Four Hourly Traffic Composition, Corridor 3, December 2010

Table 4.9: Traffic Volume Count at Corridor 3 (March, 2011)

Time (hours)	Two Wheelers	Three Wheelers	Car/Van/ Jeep/Sumo	Mini Bus/Bus	Trucks	Tractors	Total
06:00 to10:00	2382	342	1731	267	1691	221	**6634**
10:00 to 14:00	3568	315	2535	239	887	109	**7653**
14:00 to 18:00	2498	262	2202	224	1869	120	**7175**
18:00 to 22:00	1860	279	1625	169	2744	149	**6826**
Total	**10308**	**1198**	**8093**	**899**	**7191**	**599**	**28288**

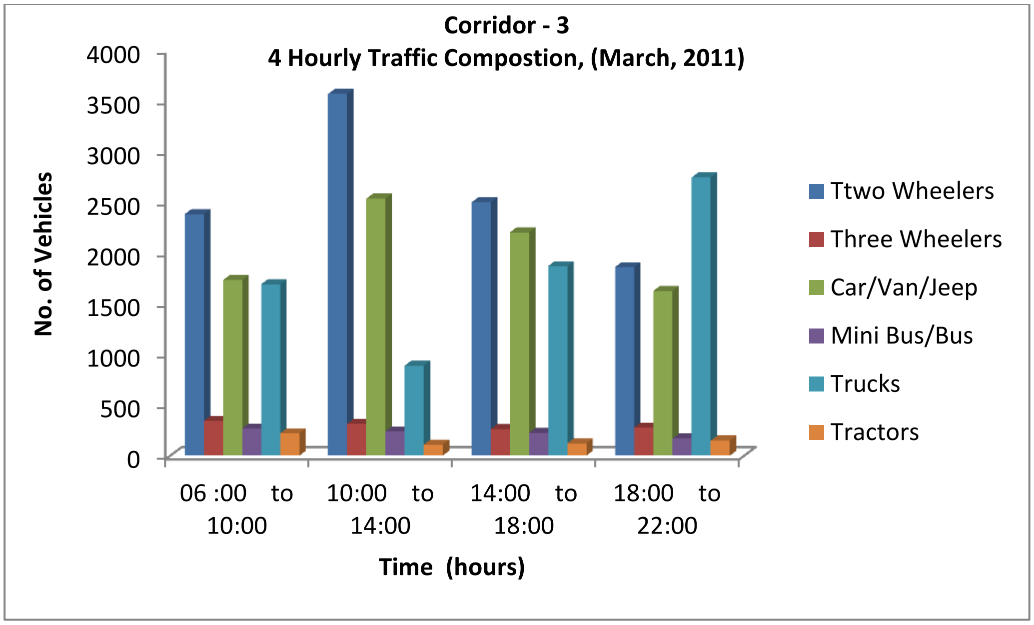


Figure 4.9: Four Hourly Traffic Composition, Corridor 3, March 2011

4.1.6 DISCUSSION FOR ROAD CORRIDOR 3

The road corridor 3 represents a rural area on a state highway. Although it was a rural area but activities in this corridor are increasing at a very rapid pace. The traffic volume recorded was 23987; 29095 and 28288 in the month of August 2010, December 2010 and March 2011 respectively. Data for Corridor 3 has indicated a higher proportion of two-wheeler traffic followed by cars/jeeps and then trucks. The reason for higher concentration of two-wheelers commuting may be that people in nearby rural areas come for employment daily and go back in the evening. The concentration of traffic flow was found to be highest between 1000 to 1400 hours followed by 1400 to 1800 hours. The reason for difference may be because of the locality and income group of people staying in the locality. More number of middle and lower-middle income group families stay near to this corridor hence the personalized mode of transport used is majorly two-wheelers followed by cars/jeeps. But seasonal variation in traffic flow was same as for Corridor 1 and 2, with highest in December followed by March and least in August. The reason for the same is that they fall in same geographical location.

4.1.7 TRAFFIC VOLUME COUNT AND COMPOSITION AT ROAD CORRIDOR 4

The results of Traffic Volume Count conducted in three different seasons monsoon period (August, 2010), post monsoon (December, 2010) and pre monsoon(March, 2011) for Corridor – 4 are given below in **Table 4.10**, **Table 4.11** and **Table 4.12** respectively, while the traffic composition is given in graphical representation in **Figure 4.10**, **Figure 4.11** and **Figure 4.12** respectively.

Table 4.10: Traffic Volume Count at Corridor 4 (August, 2010)

Time (hours)	Two Wheelers	Three Wheelers	Car/Van/ Jeep/Sumo	Mini Bus/Bus	Trucks	Tractors	Total
06:00 to 10:00	881	215	783	37	559	42	**2517**
10:00 to 14:00	1280	234	1080	41	296	24	**2955**
14:00 to 18:00	1242	234	1075	33	274	27	**2885**
18:00 to 22:00	1125	196	961	17	505	34	**2838**
Total	**4528**	**879**	**3899**	**128**	**1634**	**127**	**11195**

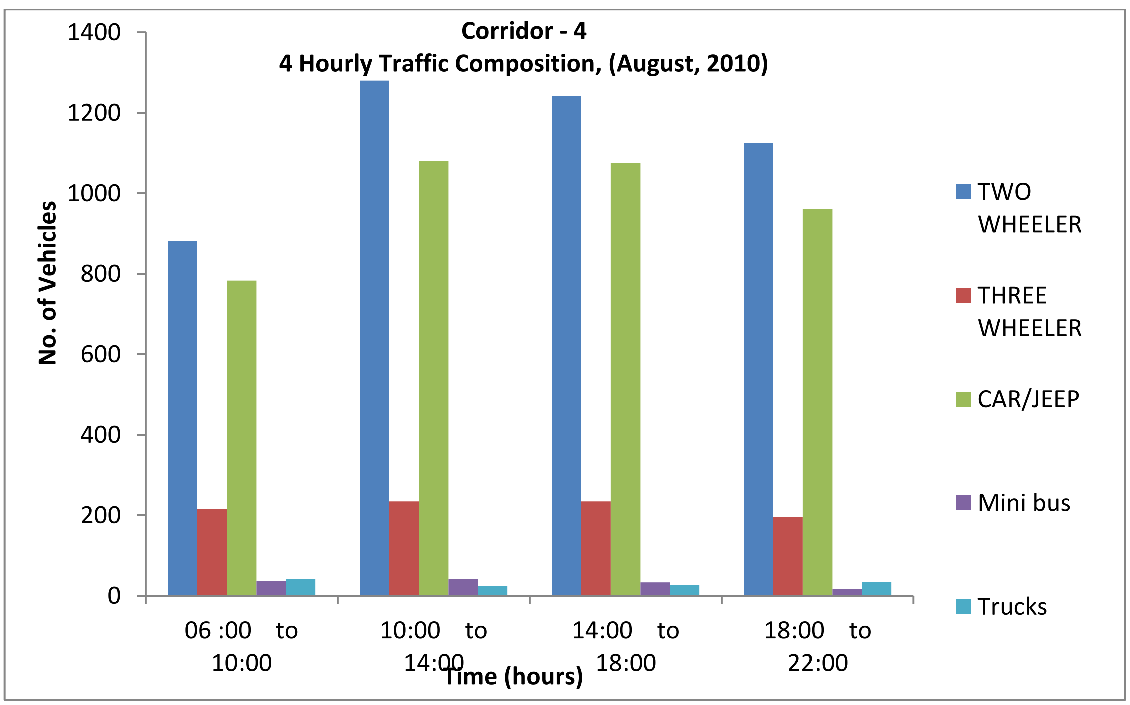


Figure 4.10: Four Hourly Traffic Composition, Corridor 4, August 2010

Table 4.11: Traffic Volume Count at Corridor 4 (December, 2010)

Time (hours)	Two Wheelers	Three Wheelers	Car/Van/ Jeep/Sumo	Mini Bus/Bus	Trucks	Tractors	Total
06:00 to 10:00	1079	287	795	40	615	45	**2861**
10:00 to 14:00	1503	266	1353	49	394	29	**3594**
14:00 to 18:00	1431	244	1345	38	302	37	**3397**
18:00 to 22:00	1245	225	1035	22	588	35	**3150**
Total	**5258**	**1022**	**4528**	**149**	**1899**	**146**	**13002**

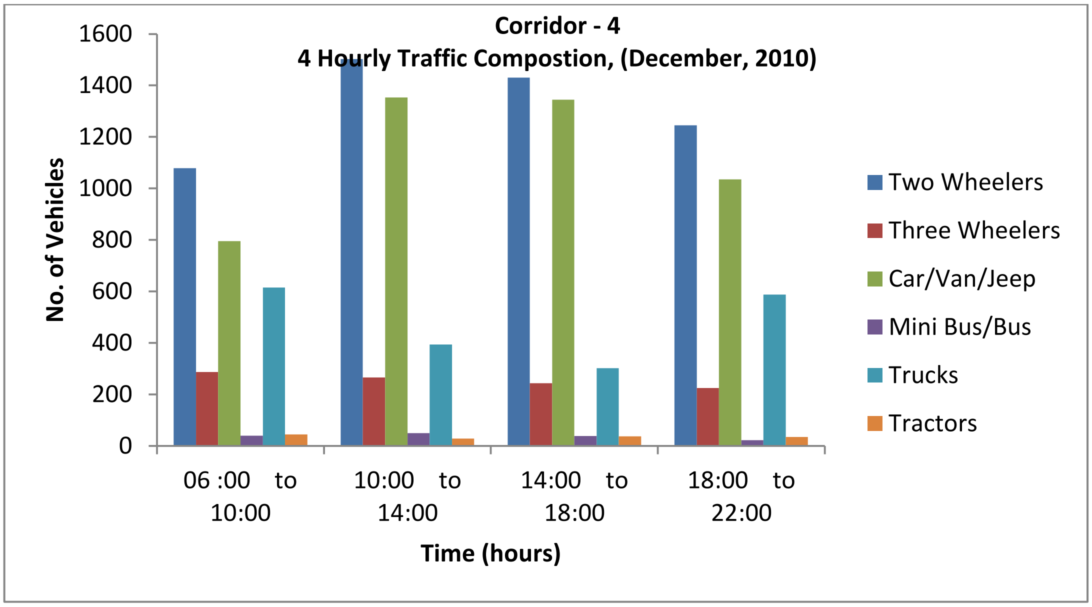


Figure 4.11: Four Hourly Traffic Composition, Corridor 4, December 2010

Table 4.12: Traffic Volume Count at Corridor 4 (March, 2011)

Time (hours)	Two Wheelers	Three Wheelers	Car/Van/ Jeep/Sumo	Mini Bus/Bus	Trucks	Tractors	Total
06:00 to 10:00	976	252	843	39	598	43	**2751**
10:00 to 14:00	1410	260	1197	44	296	25	**3232**
14:00 to 18:00	1327	235	1187	35	298	32	**3114**
18:00 to 22:00	1156	199	966	20	566	35	**2942**
Total	**4869**	**946**	**4193**	**138**	**1758**	**135**	**12039**

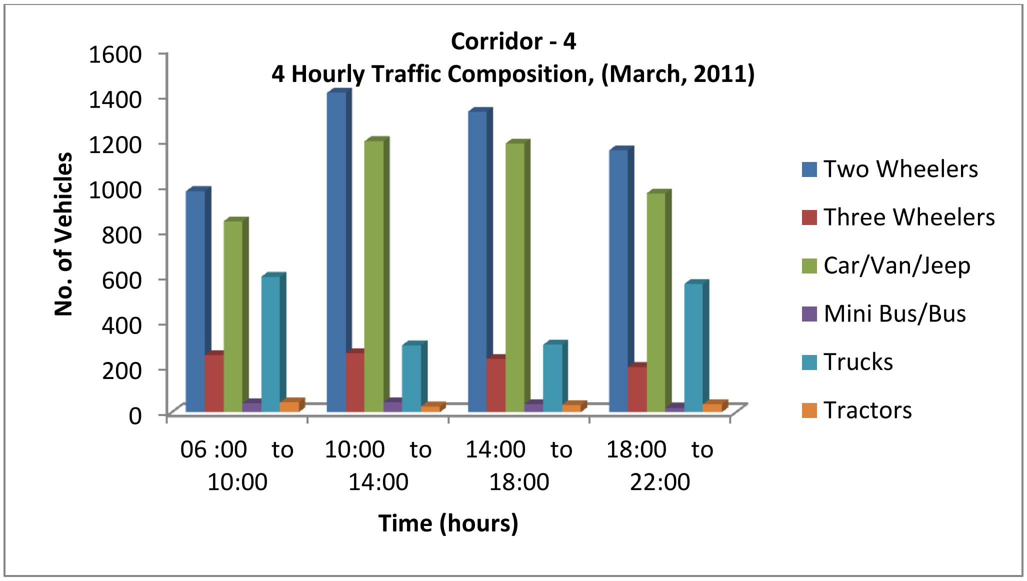


Figure 4.12: Four Hourly Traffic Composition, Corridor 4, March 2011

4.1.8 DISCUSSION FOR ROAD CORRIDOR 4

The traffic volume recorded at road corridor 4 was 11195; 13002 and 12039 in the month of August 2010, December 2010 and March 2011 respectively. The results for Corridor 4 are similar to Corridor 3, being in near proximity to each other, and people of similar socio-economic background live there. Hence, two-wheeler population is highest followed by cars/jeeps. Again the traffic concentration is highest between 1000 to 1400 hours, followed by 1400 to 1800 hours, the reason may be these areas are occupied by people who are majorly small traders or shop-owners and hence they come out of their respective households little later than the office going population and also reach back home later in the evening.

4.1.9 TRAFFIC VOLUME COUNT AND COMPOSITION AT ROAD CORRIDOR 5

The results of Traffic Volume Count conducted in three different seasons monsoon period (August, 2010), post monsoon (December, 2010) and pre monsoon(March, 2011) for Corridor – 5 are given below in **Table 4.13**, **Table 4.14** and **Table 4.15** respectively, while the traffic composition is given in graphical representation in **Figure 4.13**, **Figure 4.14** and **Figure 4.15** respectively.

Table 4.13: Traffic Volume Count at Corridor 5 (August, 2010)

Time (hours)	Two Wheelers	Three Wheelers	Car/Van/ Jeep/Sumo	Mini Bus/Bus	Trucks	Tractors	Total
06:00 to 10:00	545	8	1112	12	42	3	**1722**
10:00 to 14:00	638	14	1378	12	9	13	**2064**
14:00 to 18:00	379	6	824	10	10	8	**1237**
18:00 to 22:00	622	9	949	11	54	2	**1647**
Total	**2184**	**37**	**4263**	**45**	**115**	**26**	**6670**

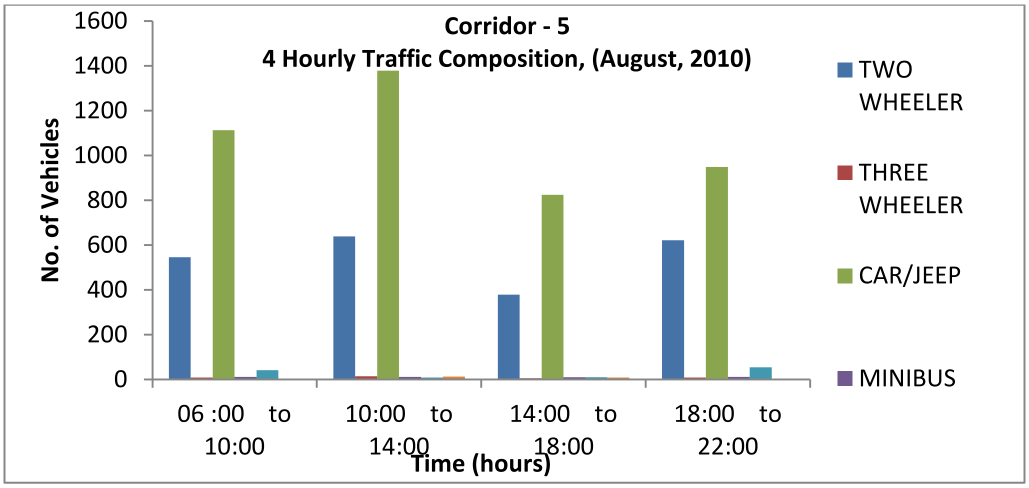


Figure 4.13: Four Hourly Traffic Composition, Corridor 5, August 2010

Table 4.14: Traffic Volume Count at Corridor 5 (December, 2010)

Time (hours)	Two Wheelers	Three Wheelers	Car/Van/ Jeep/Sumo	Mini Bus/Bus	Trucks	Tractors	Total
06:00 to 10:00	650	7	1231	18	51	8	**1965**
10:00 to 14:00	830	15	1717	18	20	21	**2621**
14:00 to 18:00	352	9	1138	9	17	26	**1551**
18:00 to 22:00	606	7	1224	12	60	4	**1913**
Total	**2438**	**38**	**5310**	**57**	**148**	**59**	**8050**

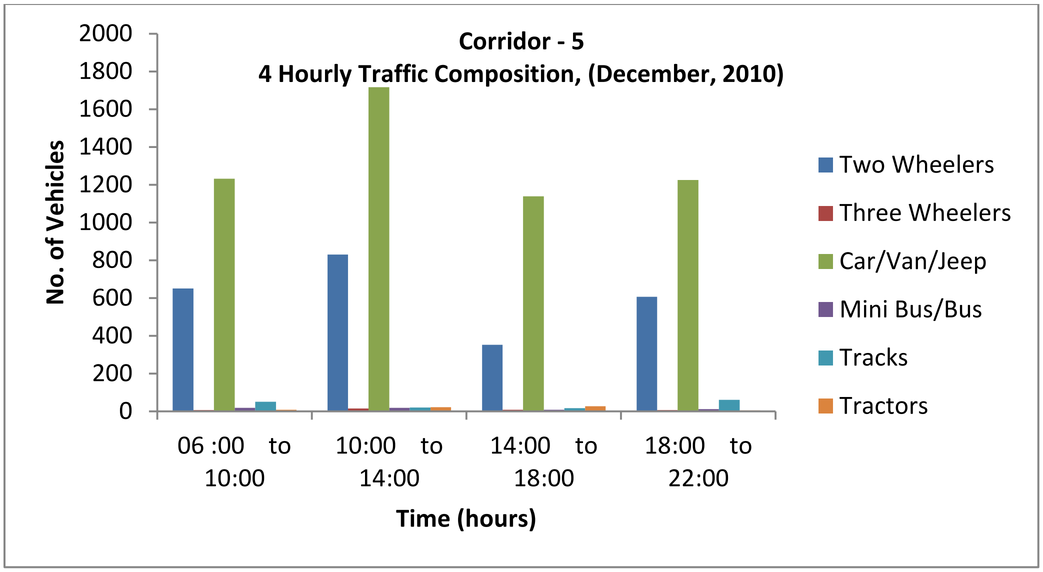


Figure 4.14: Four Hourly Traffic Composition, Corridor 5, December 2010

Table 4.15:Traffic Volume Count at Corridor 5 (March, 2011)

Time (hours)	Two Wheelers	Three Wheelers	Car/Van/ Jeep/Sumo	Mini Bus/Bus	Trucks	Tractors	Total
06:00 to 10:00	695	22	1322	12	55	11	**2117**
10:00 to 14:00	648	22	1536	14	8	22	**2250**
14:00 to 18:00	455	9	1022	10	11	33	**1540**
18:00 to 22:00	706	16	1286	16	57	7	**2088**
Total	**2504**	**69**	**5166**	**52**	**131**	**73**	**7995**

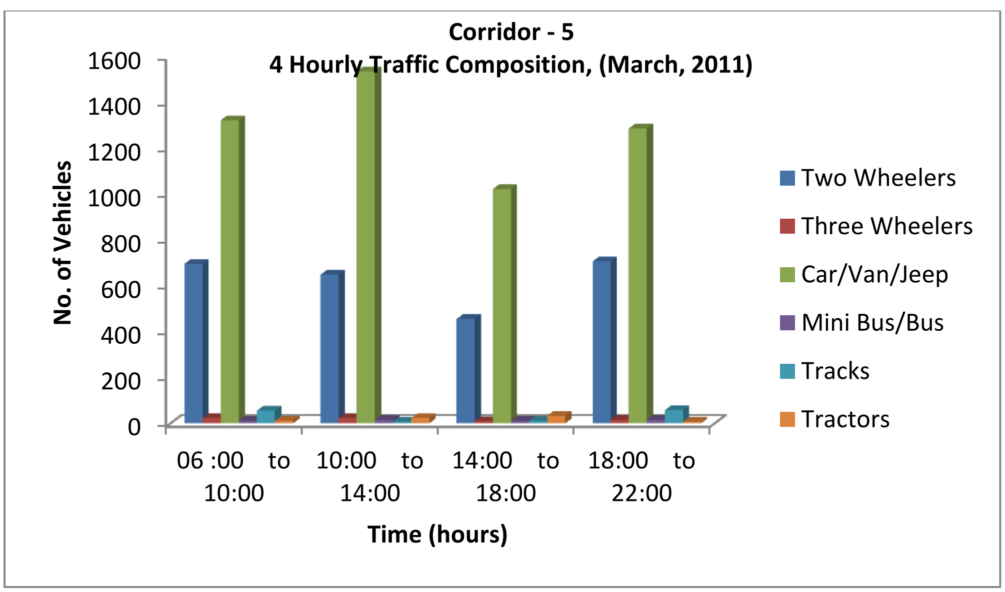


Figure 4.15: Four Hourly Traffic Composition, Corridor 5, March 2011

4.1.10 DISCUSSION FOR ROAD CORRIDOR 5

The traffic volume recorded at road corridor 5 was 6670; 8050 and 7995 in the month of August 2010, December 2010 and March 2011 respectively. Data from Corridor 5 indicates that this area is relatively less densely populated and hence the cumulative traffic flow figures are low since being an only residential area and commercial activities are very limited.

4.1.11 SUMMARY OF DISCUSSION FOR ALL ROAD CORRIDORS

Corridor 1, a National Highway, has very high traffic volume followed by Corridor 2 which is a major commercial hub. The lowest traffic was observed in Corridor 5, a residential area. As per seasonal variations the highest traffic was observed in December (Winter) followed by March and least during the August (Monsoon)

At Corridor 1, 2 and 5 maximum traffic composition was attributed by cars/jeeps followed by two-wheelers, while at Corridor 3 and 4, maximum traffic composition was attributed by two-wheelers followed by cars/jeeps.

4.2 Objective II: To Establish The Relation Between Total Vehicles and Air Pollutants at Selected Corridors and To Study The Relation Between Various Air Pollutants and Meteorological Attributes at Selected Corridors.

4.2.1 RELATION BETWEEN TOTAL VEHICLES AND AIR POLLUTANTS

4.2.1.1 Relation between Total Vehicles and PM_{10}

Previously, the data on 4 hourly traffic volume counts in all five Corridors were studied and presented. We now present data on 4 hourly variation of total vehicles and the air pollutants, such as PM_{10}, SOx and NOx. 4 hourly variation of PM_{10} at different corridors in August, December and March are represented in **Figure 4.16**, **Figure 4.17** and **Figure 4.18** respectively.

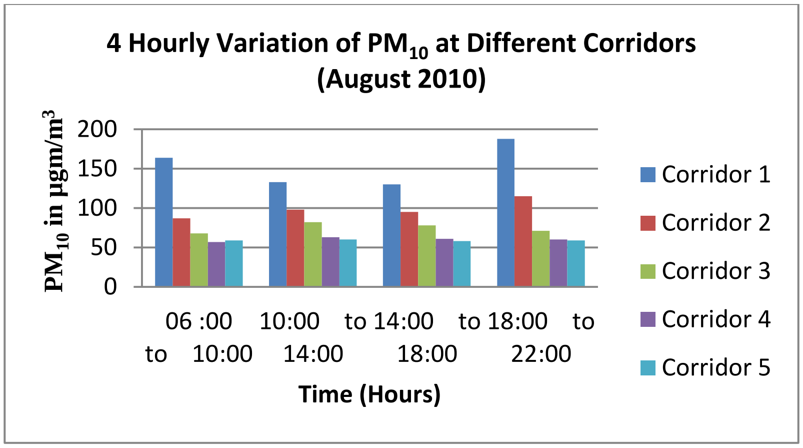


Figure 4.16: Four Hourly Variation of PM_{10}, August 2010

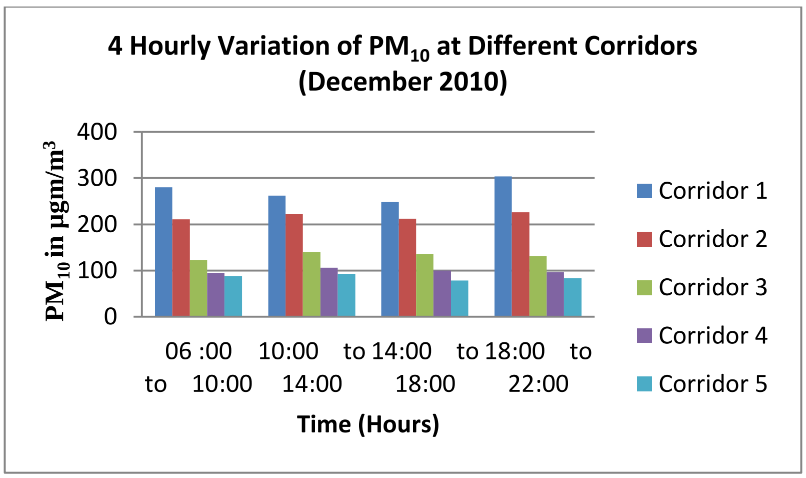


Figure 4.17: Four Hourly Variation of PM_{10}, December 2010

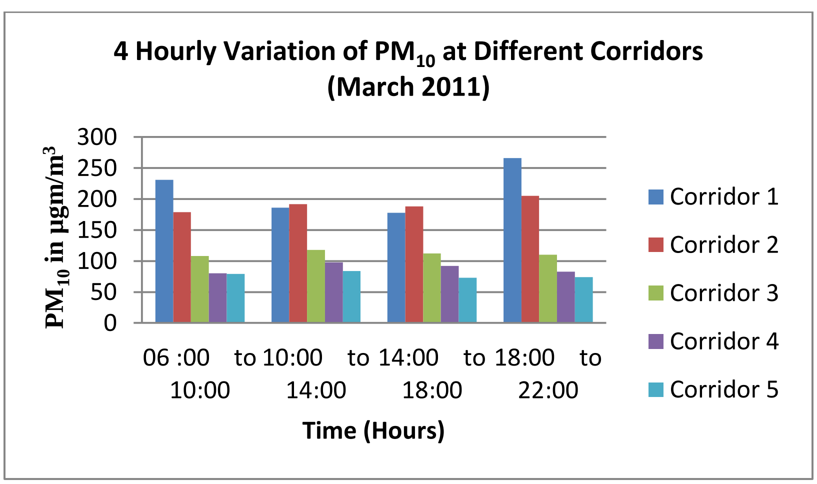


Figure 4.18: Four Hourly Variation of PM_{10}, March 2011

Further, regression analysis has been undertaken between these air pollutants and total vehicles for all locations separately. Linear regression models developed in the study have been scrutinized using R^2 values. The details of regression analysis and scatter plot for all corridors are given from **Figure 4.19** to **Figure 4.33**.

PM_{10} Analysis for Corridor 1

PM_{10} variation at Corridor 1, high traffic volume zone, indicates that the peak hour traffic at this location was highest during 1800 hrs to 2200 hrs in all three seasons i.e. August, December and March, and at the same time PM_{10} levels were also found to be maximum during the same time of the day, in the total data set. This shows a good relationship between traffic and air pollutant parameters. Regression analysis of PM_{10} also indicates a very good co-relation with the total number of vehicles with observed R^2 values of 0.91, 0.94 and 0.90 for August, December and March observations respectively.

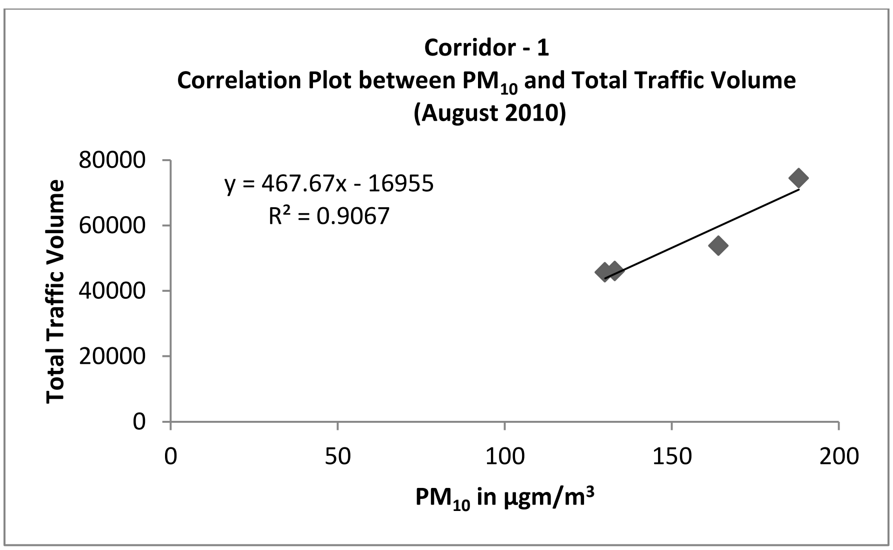


Figure 4.19: Correlation Plot between PM_{10} and Total Traffic Volume, Corridor – 1 (August 2010)

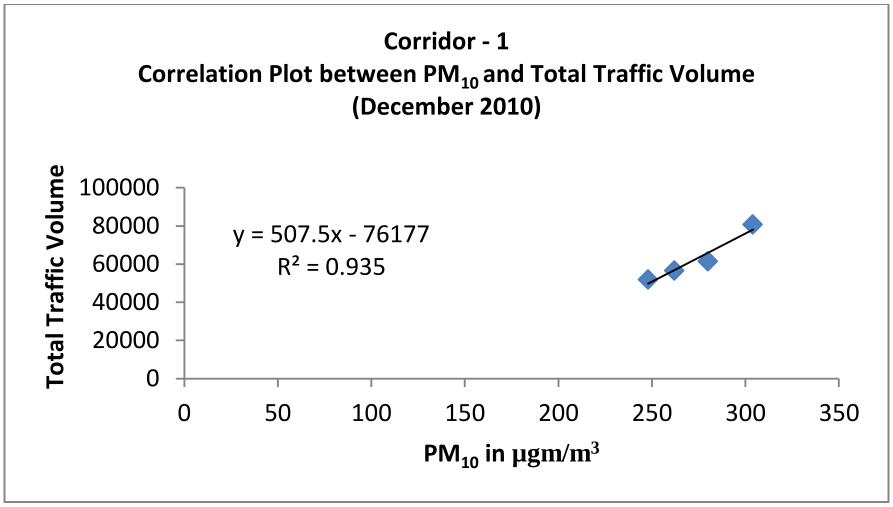


Figure 4.20: Correlation Plot between PM_{10} and Total Traffic Volume, Corridor – 1 (December 2010)

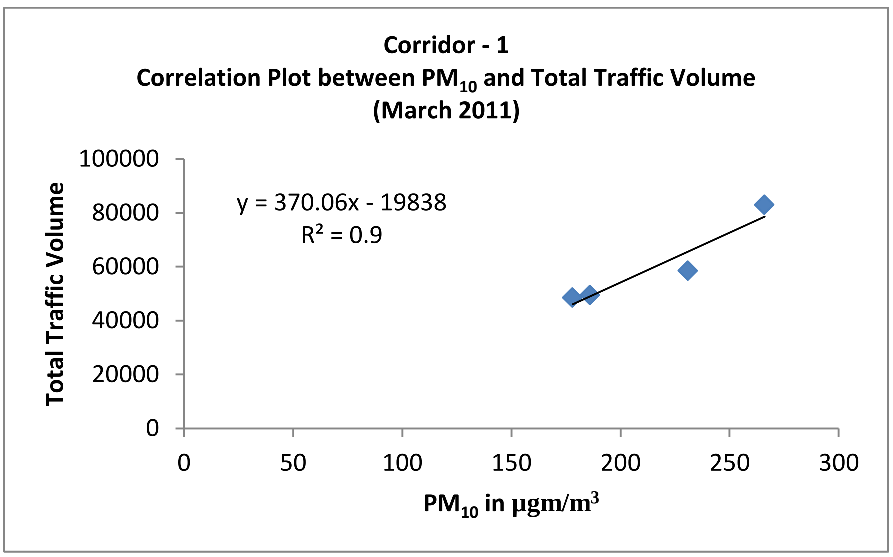


Figure 4.21: Correlation Plot between PM_{10} and Total Traffic Volume, Corridor – 1 (March 2011)

The data also highlights a variation in total concentration of PM_{10} during different parts of the year, i.e. PM_{10} levels were found to be high during December (Post Monsoon/Winter) where the concentration ranged from 248 – 304 µgm/m^3, in the same Corridor 1, followed by March, where the values observed were, 178 – 266 µgm/m^3 and least concentration was observed during August (Monsoon period) with the values, 130 – 188 µgm/m^3. The reason for the same can be attributed to meteorological conditions, wherein maximum concentration of pollution is found during winters due to temperature inversions. Temperature inversion is a phenomenon when cold stratum of air at ground level gets covered by lighter warmer air at higher level, due to which vertical air movement is stopped and pollution stays concentrated beneath the inversion layer. Similarly, in August since it is a rainy season in North India, rainfall exerts a two-fold cleansing action on the pollutants discharged into the atmosphere by accelerating the deposition of particulate matter on the ground hence its removal from atmosphere. The gaseous pollutants which are soluble in water are removed from the atmosphere; hence we found that during August, level of PM_{10} has fallen down as compared to December and August for same Corridor. And during pre-monsoon season (March) since wind speed is higher it results in drift and diffusion of air pollutants which get carried away from source at higher speed hence observed values for PM_{10} level during March is lower as compared to December but higher than that of August.

PM_{10} Analysis for Corridor 2

PM_{10} variation at Corridor 2, a major commercial hub, indicates that the peak hour traffic at this location was also highest during 1800 hrs to 2200 hrs in all three seasons i.e. August, December and March, and at the same time PM_{10} levels were also found to be maximum during the same time of the day, in the total data set. This again shows a good relationship between traffic and air pollutant parameters. Regression analysis of PM_{10} also indicates a very good co-relation with the total number of vehicles with observed R^2 values of 0.99, 0.60 and 0.89 for August, December and March observations respectively.

PM_{10} levels in Corridor 2, were also found to be high during December(Post Monsoon/Winter) where the concentration ranged from 211–226 µgm/m^3, followed by March, where the values observed were, 179 – 205 µgm/m^3 and least concentration was observed during August (Monsoon period) with the values, 87 – 115 µgm/m^3 .

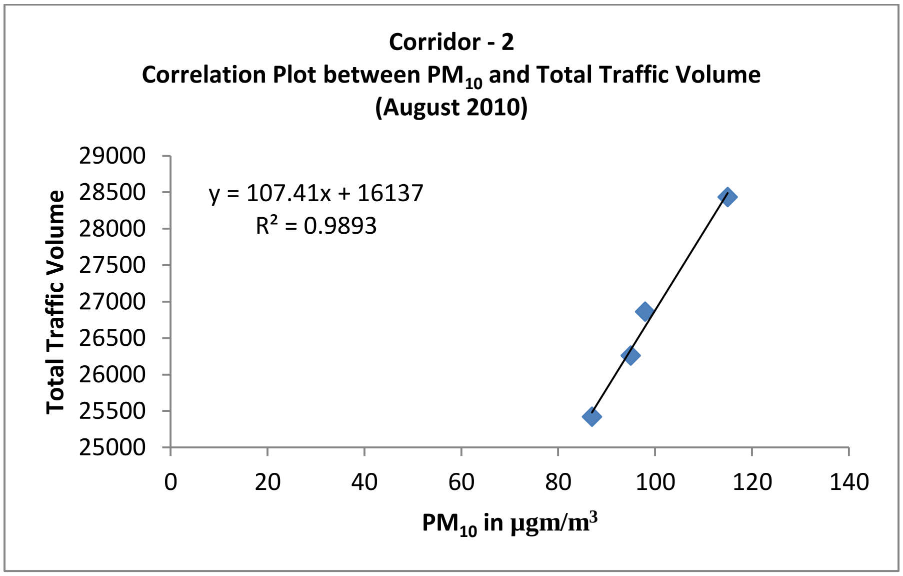


Figure 4.22: Correlation Plot between PM_{10} and Total Traffic Volume, Corridor – 2 (August 2010)

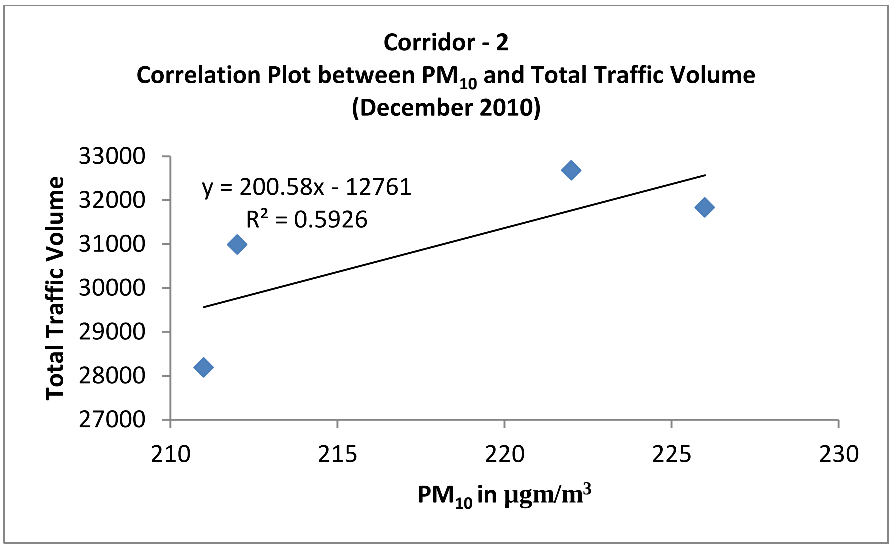


Figure 4.23: Correlation Plot between PM_{10} and Total Traffic Volume, Corridor – 2 (December 2010)

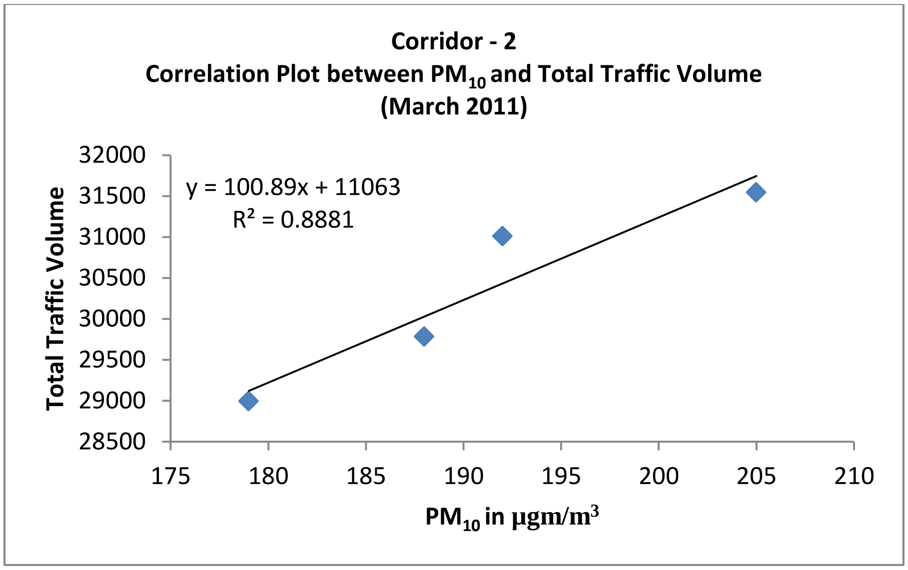


Figure 4.24: Correlation Plot between PM_{10} and Total Traffic Volume, Corridor – 2 (March 2011)

PM_{10} Analysis for Corridor 3

PM_{10} variation at Corridor 3, a rural area, indicates that the peak hour traffic at this location was highest during 1000 hours to 1400 hours followed by 1400 hours to 1800 hours in all three seasons i.e. August, December and March, and at the same time PM_{10} levels were also found to be maximum during the same time of the day, in the total data set. This again shows a good relationship between traffic and air pollutant parameters. Regression analysis of PM_{10} also indicates a very good co-relation with the total number of vehicles with observed R^2 values of 0.87, 0.97 and 0.98 for August, December and March observations respectively.

PM_{10} levels in Corridor 3, were also found to be high during December(Post Monsoon/Winter) where the concentration ranged from 123 – 140 µgm/m^3, followed by March, where the values observed were, 108 – 118 µgm/m^3 and least concentration was observed during August (Monsoon period) with the values, 68 – 82 µgm/m^3.

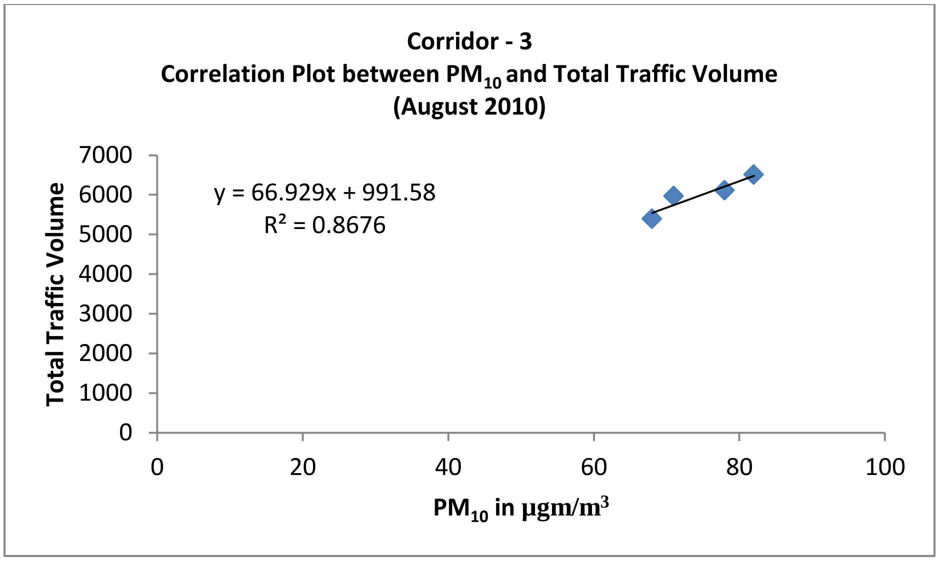


Figure 4.25: Correlation Plot between PM_{10} and Total Traffic Volume, Corridor – 3 (August 2010)

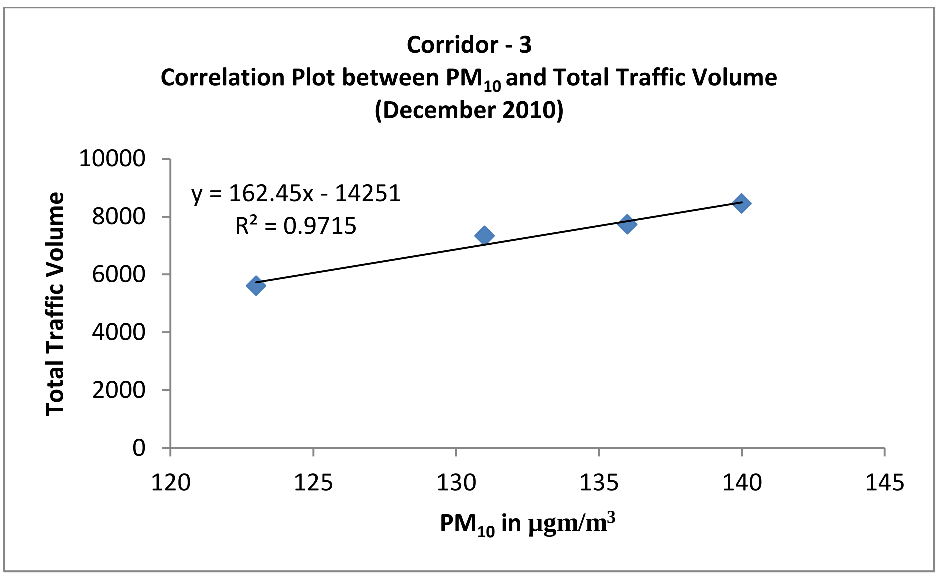


Figure 4.26: Correlation Plot between PM_{10} and Total Traffic Volume, Corridor – 3 (December 2010)

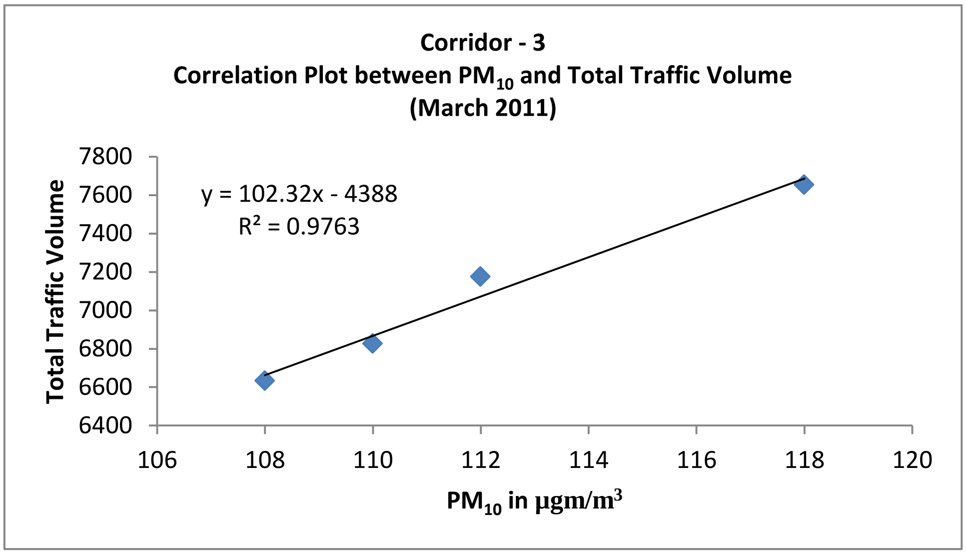


Figure 4.27: Correlation Plot between PM_{10} and Total Traffic Volume, Corridor – 3 (March 2011)

PM_{10} Analysis for Corridor 4

PM_{10} variation at Corridor 4, a semi-urban area with commercial and residential mix, indicates that the peak hour traffic at this location was highest during 1000 hours to 1400 hours followed by 1400 hours to 1800 hours in all three seasons i.e. August, December and March, and at the same time PM_{10} levels were also found to be maximum during the same time of the day, in the total data set. This again shows a good relationship between traffic and air pollutant parameters. Regression analysis of PM_{10} also indicates a very good co-relation with the total number of vehicles with observed R^2 values of 0.93, 0.86 and 0.94 for August, December and March observations respectively.

PM_{10} levels in Corridor 4, were also found to be high during December(Post Monsoon/Winter) where the concentration ranged from 95 – 106 µgm/m^3, followed by March, where the values observed were, 80 – 98 µgm/m^3 and least concentration was observed during August (Monsoon period) with the values, 57 – 63 µgm/m^3.

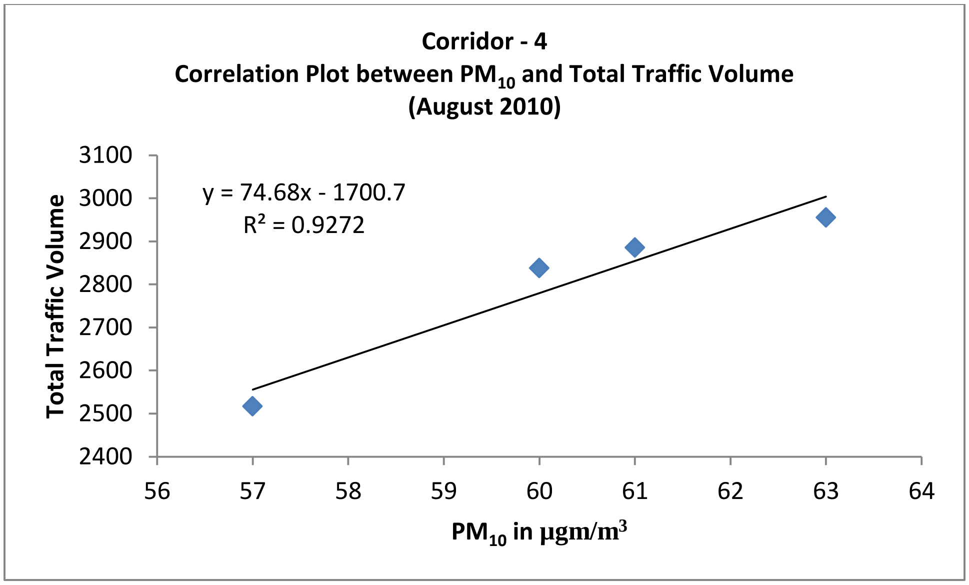


Figure 4.28: Correlation Plot between PM_{10} and Total Traffic Volume, Corridor – 4 (August 2010)

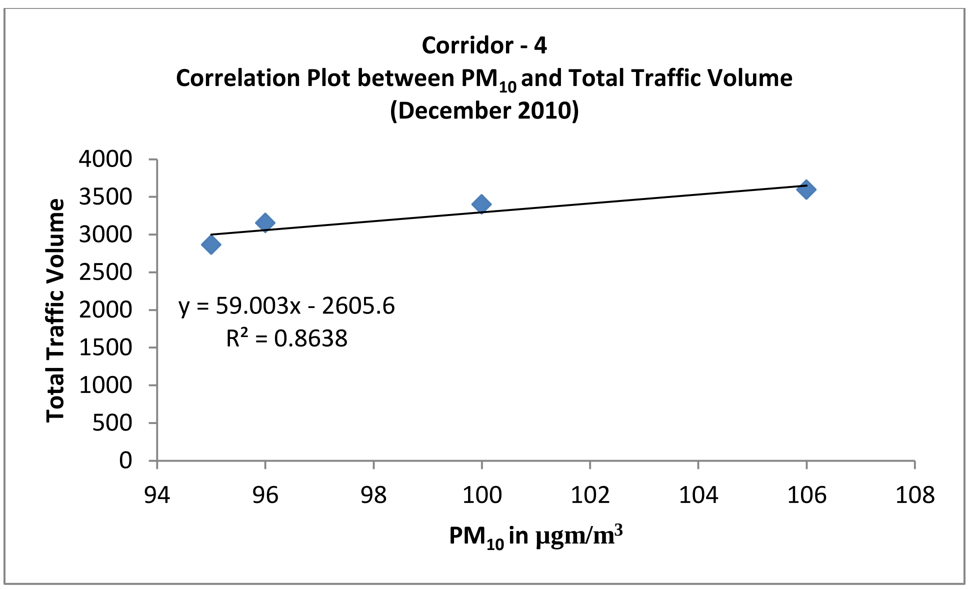


Figure 4.29: Correlation Plot between PM_{10} and Total Traffic Volume, Corridor – 4 (December 2010)

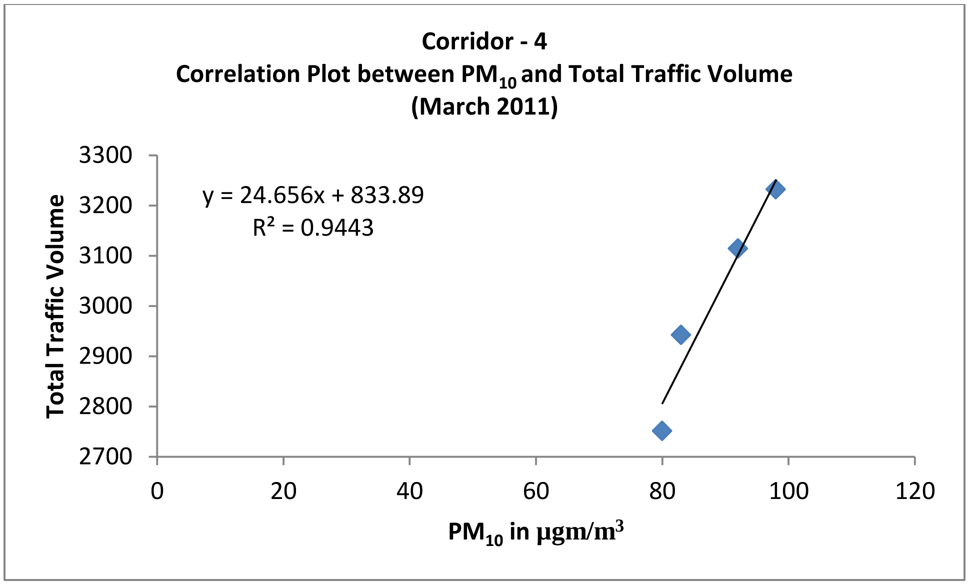


Figure 4.30: Correlation Plot between PM_{10} and Total Traffic Volume, Corridor – 4 (March 2011)

PM_{10} Analysis for Corridor 5

PM_{10} variation at Corridor 5, a residential area, indicates that the peak hour traffic at this location was highest during 1000 hours to 1400 hours in all three seasons i.e. August, December and March, and at the same time PM_{10} levels were also found to be maximum during the same time of the day, in the total data set. This again shows a good relationship between traffic and air pollutant parameters. Regression analysis of PM_{10} also indicates a very good co-relation with the total number of vehicles with observed R^2 values of 0.99, 0.89 and 0.56 for August, December and March observations respectively.

PM_{10} levels in Corridor 5, were also found to be high during December(Post Monsoon/Winter) where the concentration ranged from 78 – 93 µgm/m^3, followed by March, where the values observed were, 73 – 84 µgm/m^3 and least concentration was observed during August (Monsoon period) with the values, 58 – 60 µgm/m^3, for the reasons mentioned above.

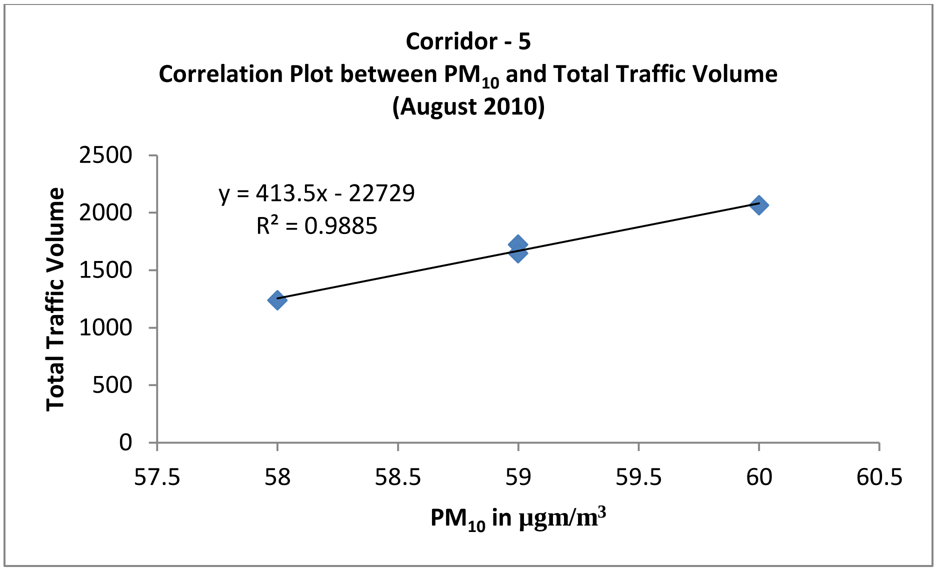


Figure 4.31: Correlation Plot between PM_{10} and Total Traffic Volume, Corridor – 5 (August 2010)

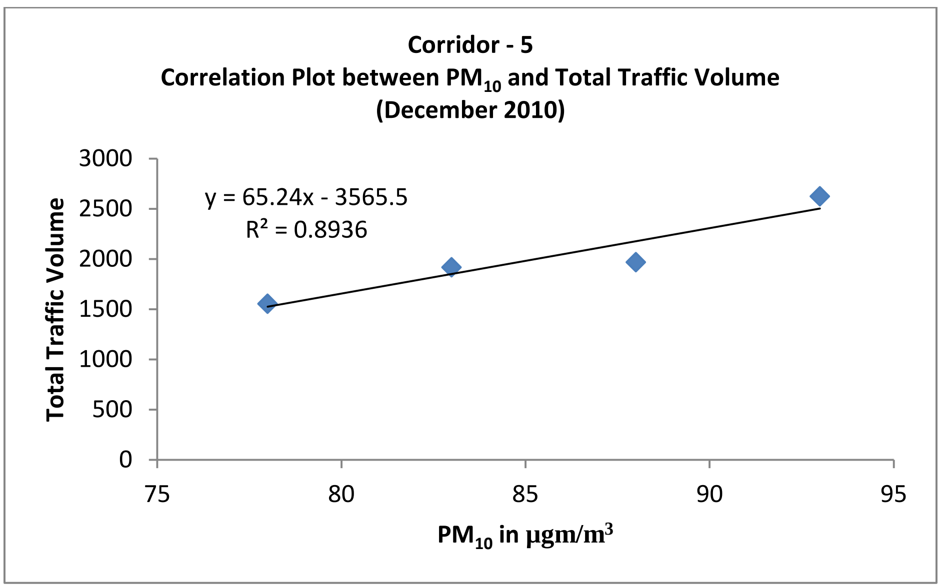


Figure 4.32: Correlation Plot between PM_{10} and Total Traffic Volume, Corridor – 5 (December 2010)

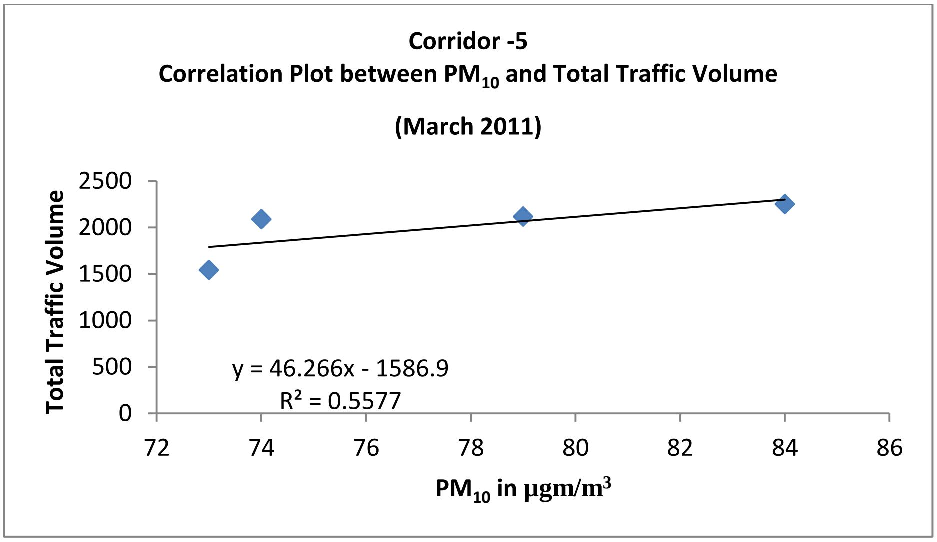


Figure 4.33: Correlation Plot between PM_{10} and Total Traffic Volume, Corridor – 5 (March 2011)

4.2.1.2 Relation between Total Vehicles and SO_X

Four hourly variation of SO_X at different corridors in August, December and March are represented in **Figure 4.34**, **Figure 4.35** and **Figure 4.36** respectively.

Further, regression analysis has been undertaken between SO_X and total vehicles for all locations separately. Linear regression models developed in the study have been scrutinized using R^2 values. The details of regression analysis and scatter plot for all corridors are given from **Figure 4.37** to **Figure 4.51**.

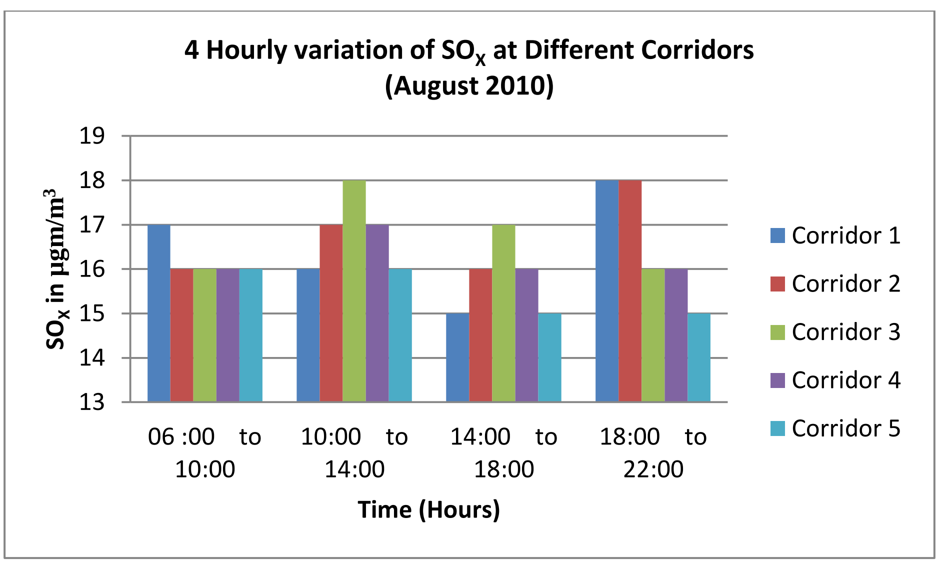


Figure 4.34: Four Hourly Variation of SO_X, August 2010

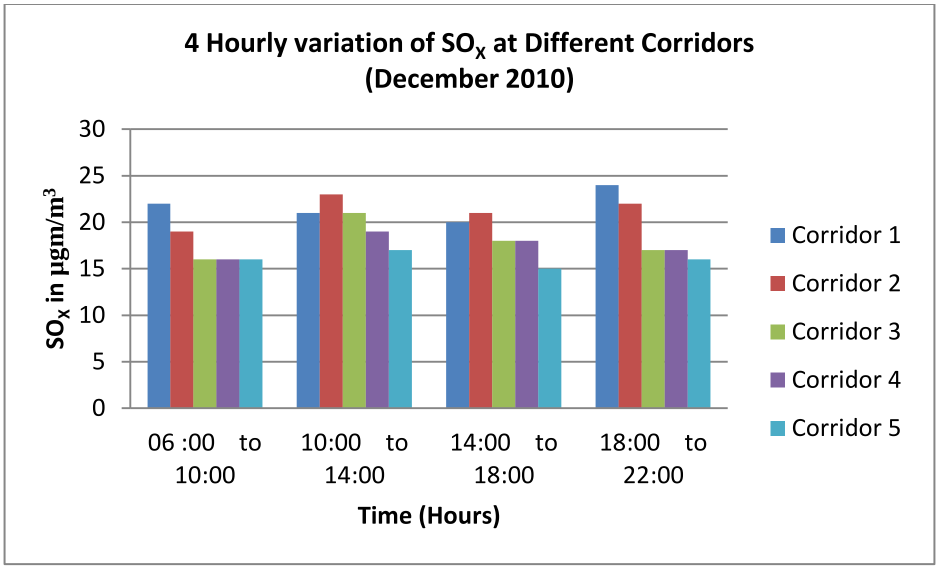


Figure 4.35: Four Hourly Variation of SO_X, December 2010

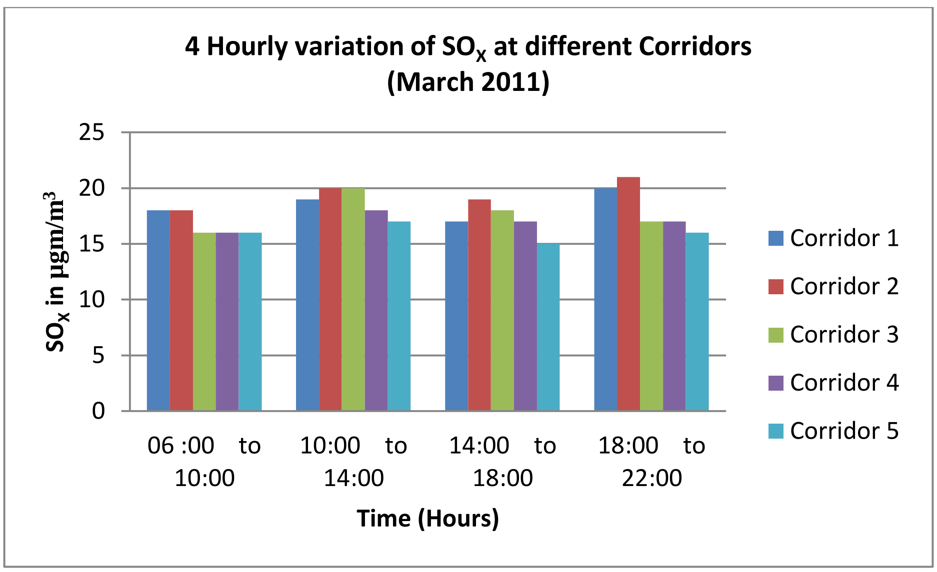


Figure 4.36: Four Hourly Variation of SO_X, March 2011

Analysis for SO_X for Corridor 1

SO_X variation at Corridor 1, a high traffic volume zone, indicates that the peak hour traffic at this location was also highest during 1800 hrs to 2200 hrs in all three seasons i.e. August, December and March, and at the same time SO_X levels were also found to be maximum during the same time of the day, in the total data set. This shows a good relationship between traffic and air pollutant parameters.

Regression analysis of SO_X also indicates a very good co-relation with the total number of vehicles with observed R^2 values of 0.81, 0.97 and 0.58 for August, December and March observations respectively.

SO_X levels in Corridor 1, were also found to be high during December(Post Monsoon/Winter) where the concentration ranged from 20-24 µgm/m^3, followed by March, where the values observed were, 17-20 µgm/m^3 and least concentration was observed during August (Monsoon period) with the values, 15 - 18 µgm/m^3 .

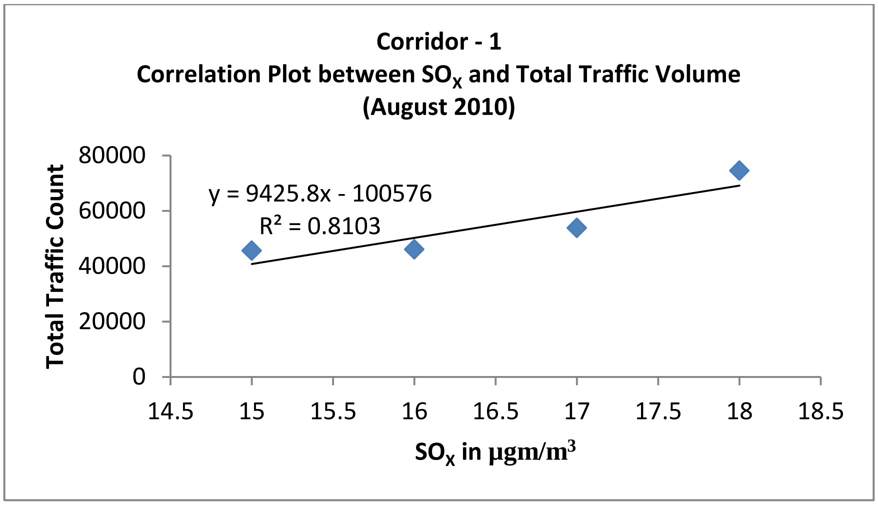


Figure 4.37: Correlation Plot between SO_X and Total Traffic Volume, Corridor – 1 (August 2010)

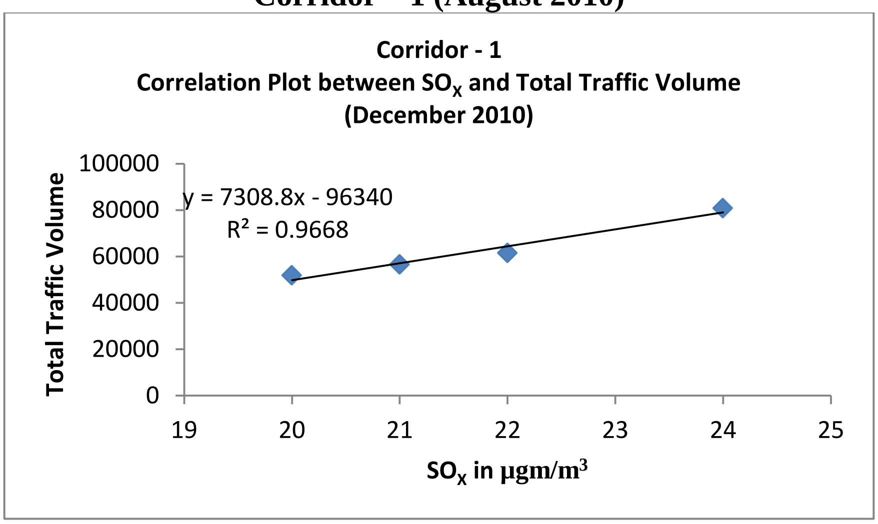


Figure 4.38: Correlation Plot between SO_X and Total Traffic Volume, Corridor – 1 (December 2010)

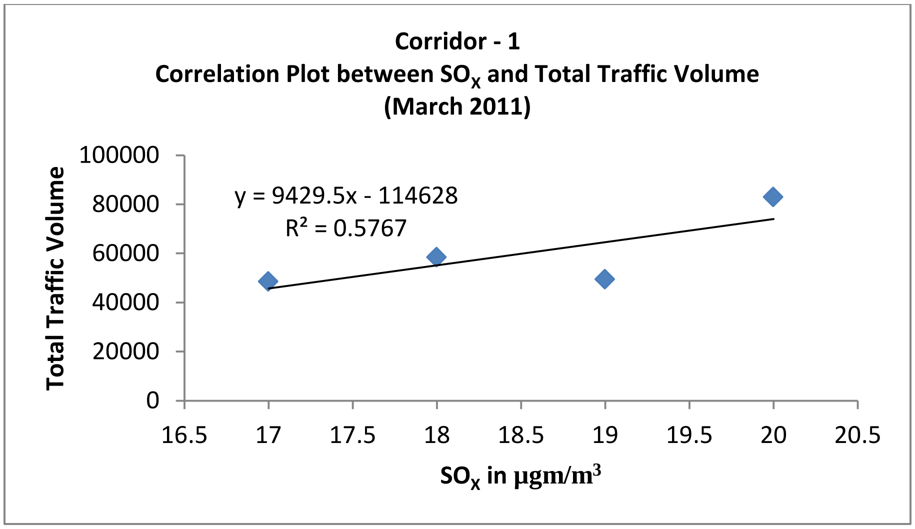


Figure 4.39: Correlation Plot between SO_X and Total Traffic Volume, Corridor – 1 (March 2011)

SO_X Analysis for Corridor 2

SO_X variation at Corridor 2, a major commercial hub, indicates that the peak hour traffic at this location was highest during 1800 hrs to 2200 hrs in August and March seasons while in December traffic volume was maximum during 1000 hrs – 1400 hrs, and at the same time SO_X levels were also found to be maximum during the same time of the day respectively, in the total data set. This again shows a good relationship between traffic and air pollutant parameters. Regression analysis of SO_X also indicates a very good co-relation with the total number of vehicles with observed R^2 values of 0.92, 0.98 and 0.98 for August, December and March observations respectively.

SO_X levels in Corridor 2, were also found to be high during December (Post Monsoon/Winter) where the concentration ranged from 19 -23 µgm/m^3, followed by March, where the values observed were, 18 -21 µgm/m^3 and least concentration was observed during August (Monsoon period) with the values, 16 - 18 µgm/m^3.

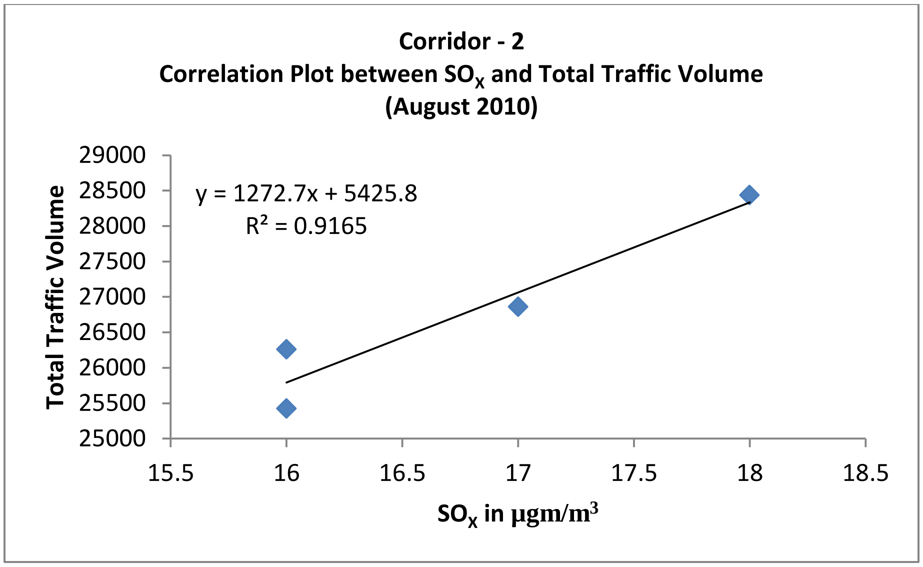


Figure 4.40: Correlation Plot between SO_X and Total Traffic Volume, Corridor – 2 (August 2010)

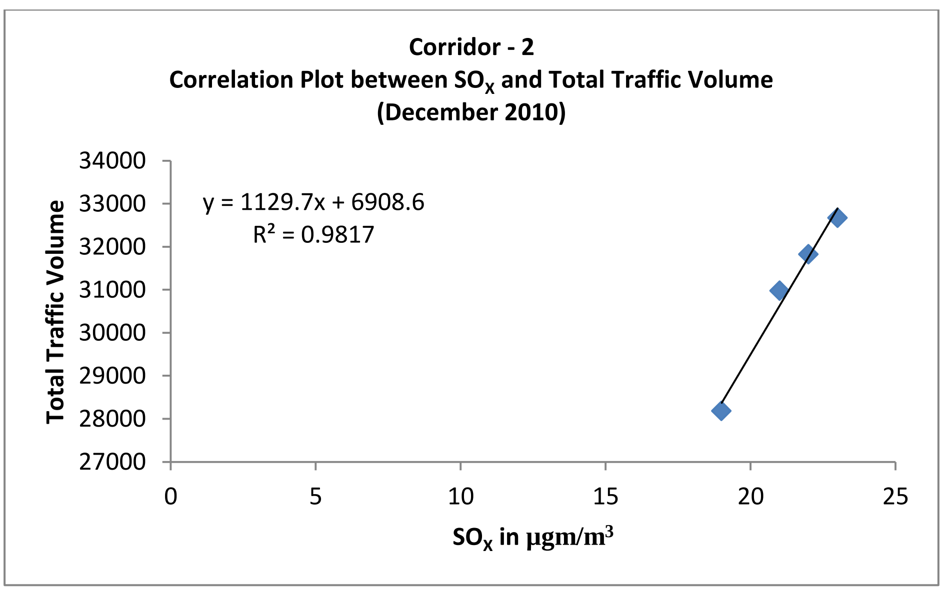


Figure 4.41: Correlation Plot between SO_X and Total Traffic Volume, Corridor – 2 (December 2010)

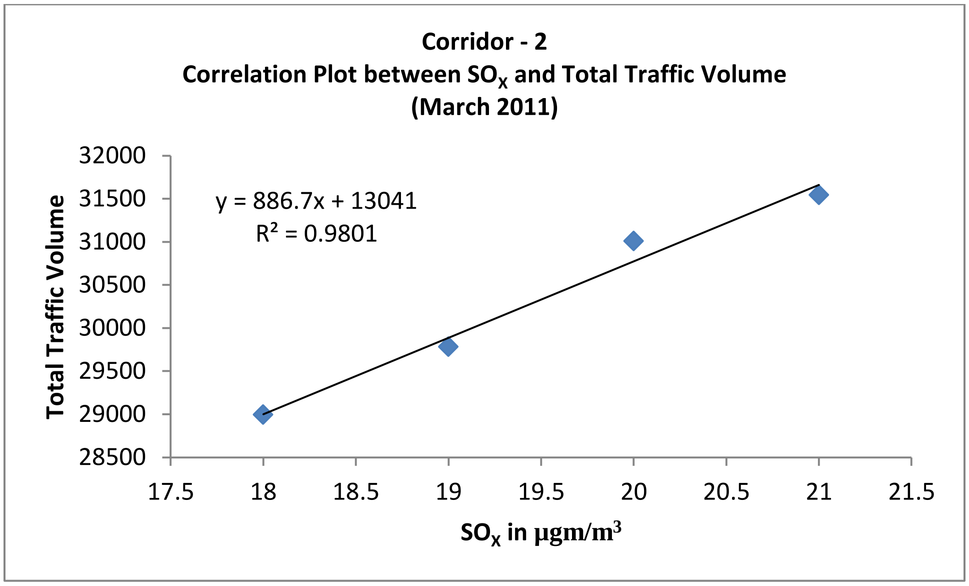


Figure 4.42: Correlation Plot between SO_X and Total Traffic Volume, Corridor – 2 (March 2011)

SO_X Analysis for Corridor 3

SO_X variation at Corridor 3, a major commercial hub, indicates that the peak hour traffic at this location was highest during 1000 hrs to 1400 hrs in all three seasons i.e. August, December and March, and at the same time SO_X levels were also found to be maximum during the same time of the day, in the total data set. This again shows a good relationship between traffic and air pollutant parameters. Regression analysis of SO_X also indicates a very good co-relation with the total number of vehicles with observed R^2 values of 0.74, 0.75 and 0.99 for August, December and March observations respectively.

SO_X levels in Corridor 3, were also found to be high during December (Post Monsoon/Winter) where the concentration ranged from 16 - 21 µgm/m^3, followed by March, where the values observed were, 16 - 20 µgm/m^3 and least concentration was observed during August (Monsoon period) with the values, 16 – 18 µgm/m^3 .

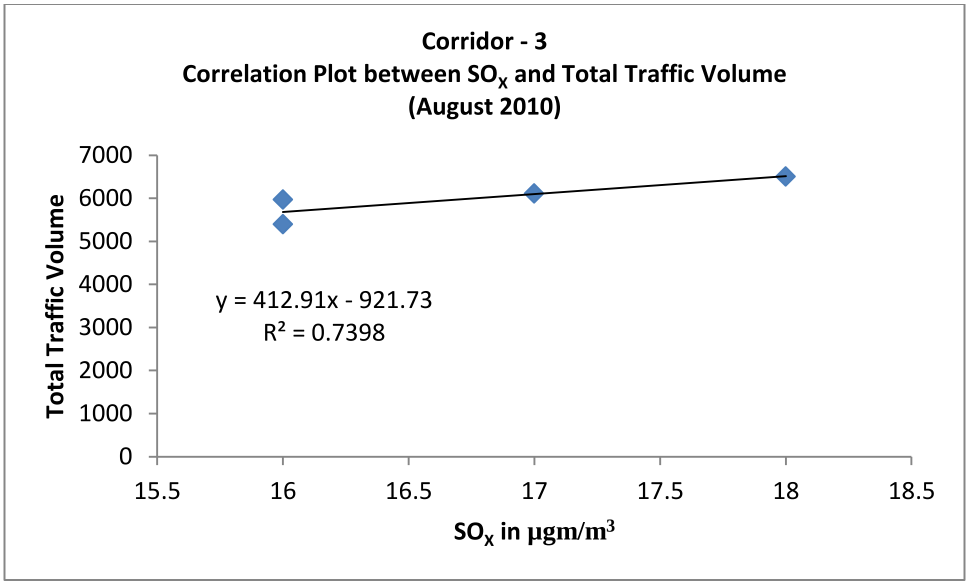


Figure 4.43: Correlation Plot between SO_X and Total Traffic Volume, Corridor – 3 (August 2010)

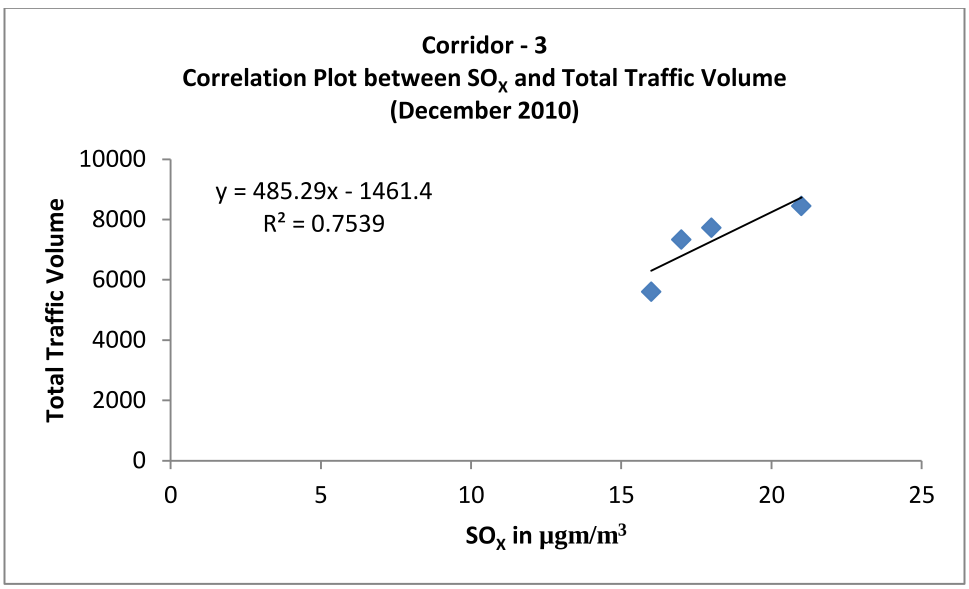


Figure 4.44: Correlation Plot between SO_X and Total Traffic Volume, Corridor – 3 (December 2010)

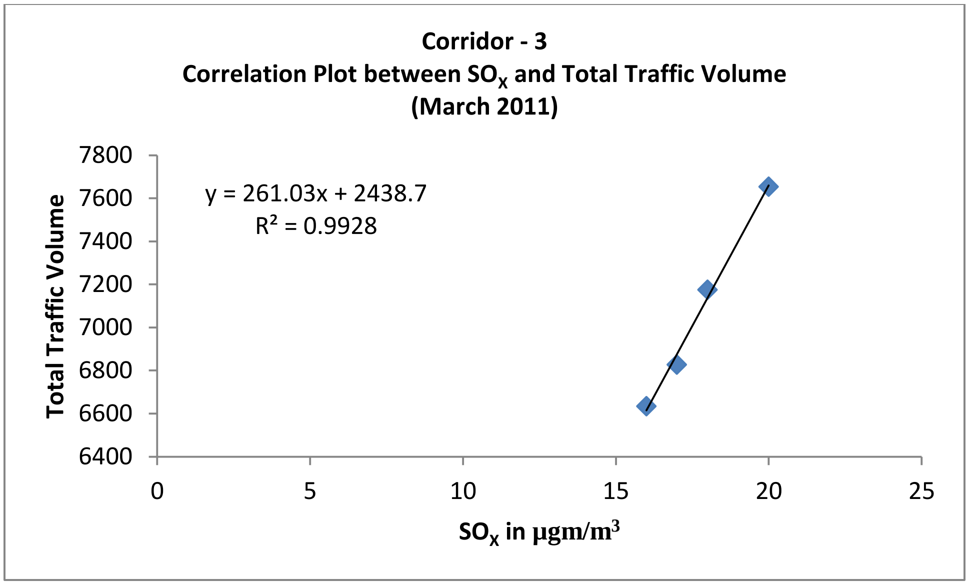


Figure 4.45: Correlation Plot between SO_X and Total Traffic Volume, Corridor – 3 (March 2011)

SO_X Analysis for Corridor 4

SO_X variation at Corridor 4, a semi-urban area with commercial and residential mix, indicates that the peak hour traffic at this location was highest during 1000 hrs to 1400 hrs followed by 1400 hrs to 1800 hrs in all three seasons i.e. August, December and March, and at the same time SO_X levels were also found to be maximum during the same time of the day, in the total data set. This again shows a good relationship between traffic and air pollutant parameters. Regression analysis of SO_X also indicates a very good co-relation with the total number of vehicles with observed R^2 values of 0.59, 0.99 and 0.88 for August, December and March observations respectively.

SO_X levels in Corridor 4, were also found to be high during December (Post Monsoon/Winter) where the concentration ranged from 16 - 19 µgm/m^3, followed by March, where the values observed were, 16 - 18 µgm/m^3 and least concentration was observed during August (Monsoon period) with the values, 16 – 17 µgm/m^3.

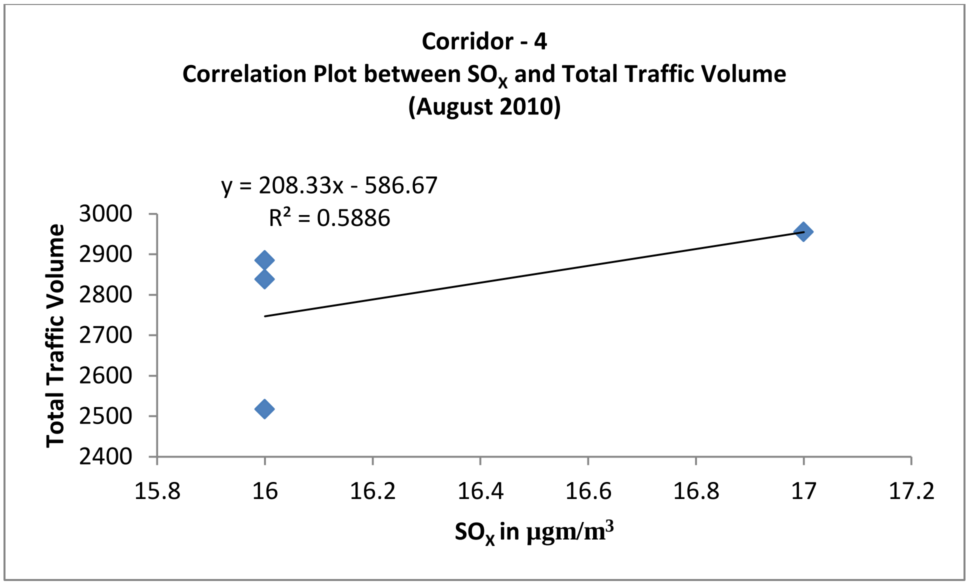


Figure 4.46: Correlation Plot between SO_X and Total Traffic Volume, Corridor – 4 (August 2010)

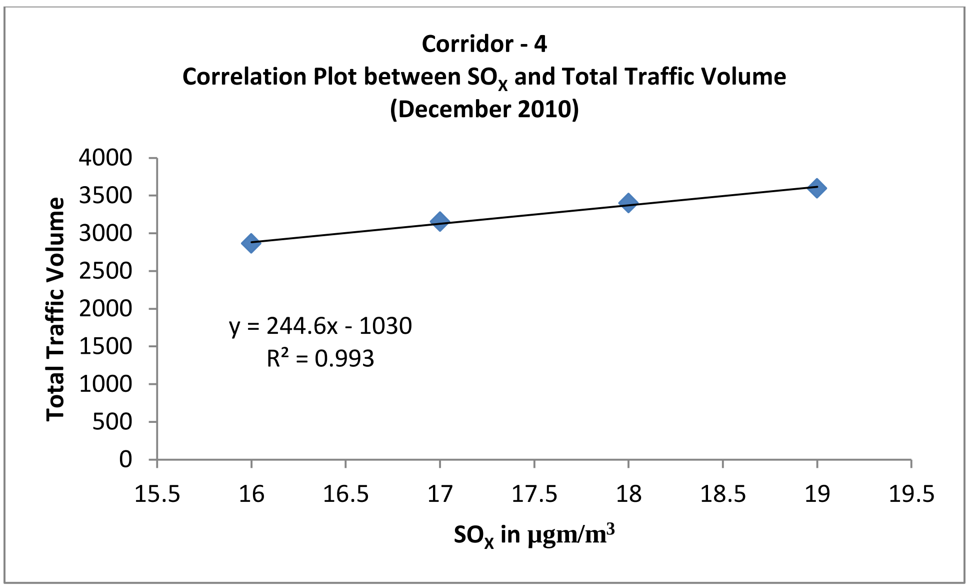


Figure 4.47: Correlation Plot between SO_X and Total Traffic Volume, Corridor – 4 (December 2010)

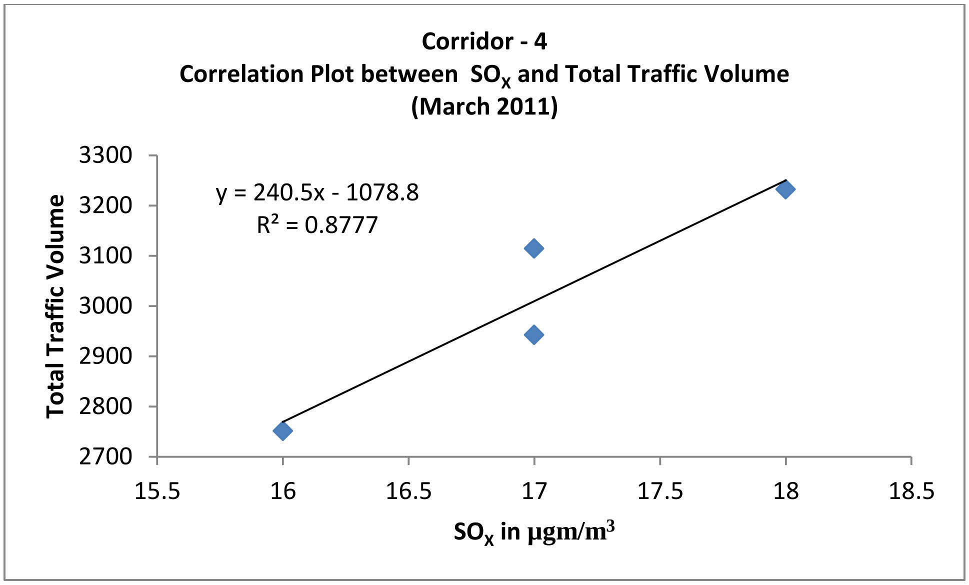


Figure 4.48: Correlation Plot between SO_X and Total Traffic Volume, Corridor – 4 (March 2011)

SO_X Analysis for Corridor 5

SO_X variation at Corridor 5, a residential area, indicates that the peak hour traffic at this location was highest during 1000 hrs to 1400 hrs in all three seasons i.e. August, December and March, and at the same time SO_X levels were also found to be maximum during the same time of the day, in the total data set. This again shows a good relationship between traffic and air pollutant parameters. Regression analysis of SO_X also indicates a very good co-relation with the total number of vehicles with observed R^2 values of 0.59, 0.96 and 0.85 for August, December and March observations respectively.

SO_X levels in Corridor 5, were also found to be high during December(Post Monsoon/Winter) where the concentration ranged from 15 - 17 µgm/m^3, followed by March, where the values observed were, 15 - 17 µgm/m^3 and least concentration was observed during August (Monsoon period) with the values, 15 – 16 µgm/m^3, for the reasons mentioned above.

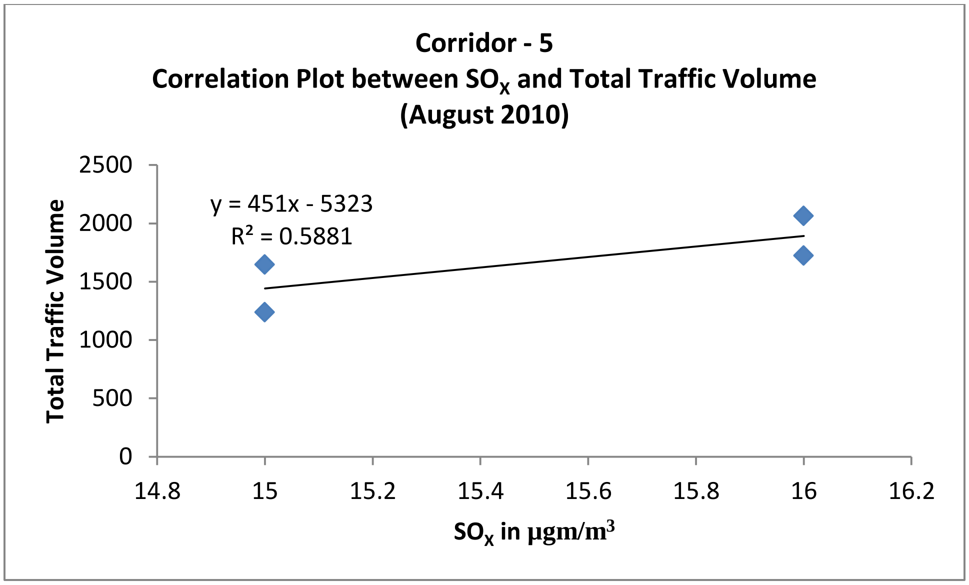


Figure 4.49: Correlation Plot between SO_X and Total Traffic Volume, Corridor – 5 (August 2010)

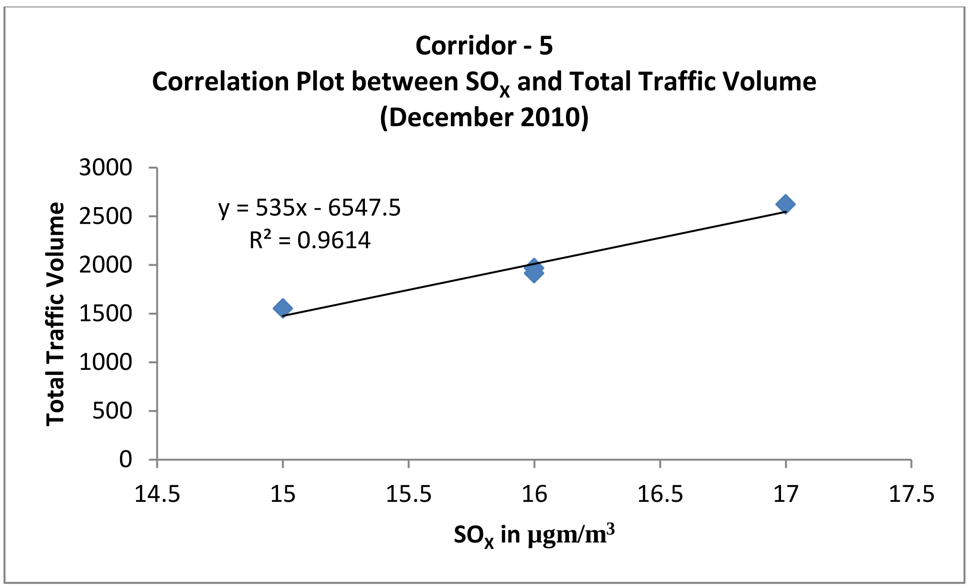


Figure 4.50: Correlation Plot between SO_X and Total Traffic Volume, Corridor – 5 (December 2010)

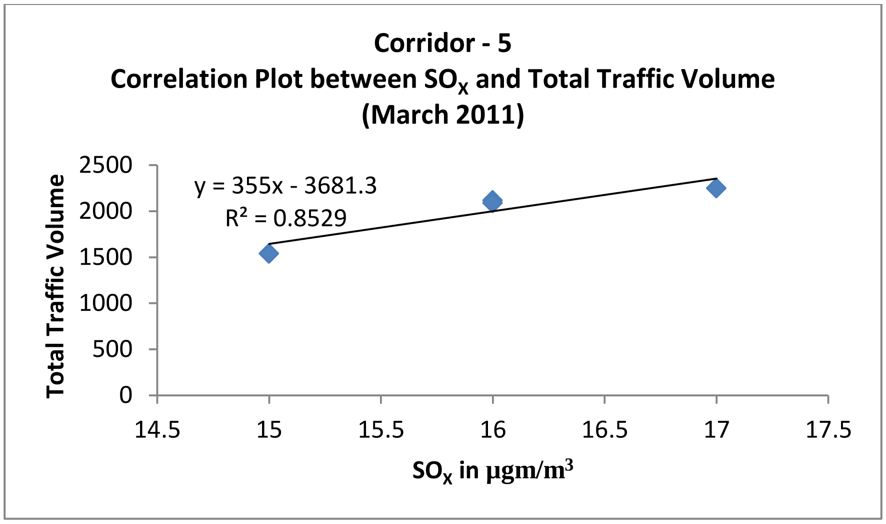


Figure 4.51: Correlation Plot between SO_X and Total Traffic Volume, Corridor – 5 (March 2011)

4.2.1.3 Relation between Total Vehicles and NO_X

Four hourly variation of NO_X at different corridors in August, December and March are represented in **Figure 4.52**, **Figure 4.53** and **Figure 4.54** respectively. Further, regression analysis has been undertaken between NO_X and total vehicles for all locations separately. Linear regression models developed in the study have been scrutinized using R^2 values. The details of regression analysis and scatter plot for all corridors are given from **Figure 4.55** to **Figure 4.69**.

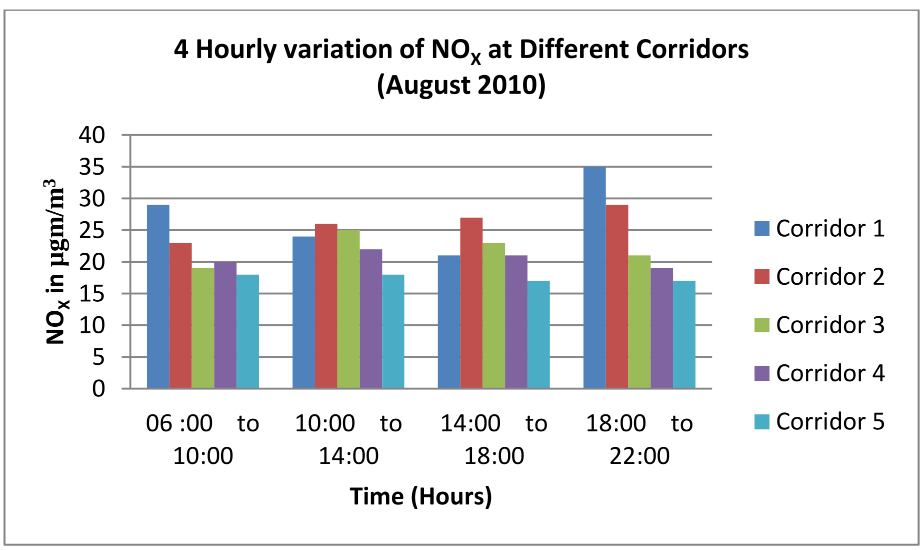


Figure 4.52: Four Hourly Variation of NO_X, August 2010

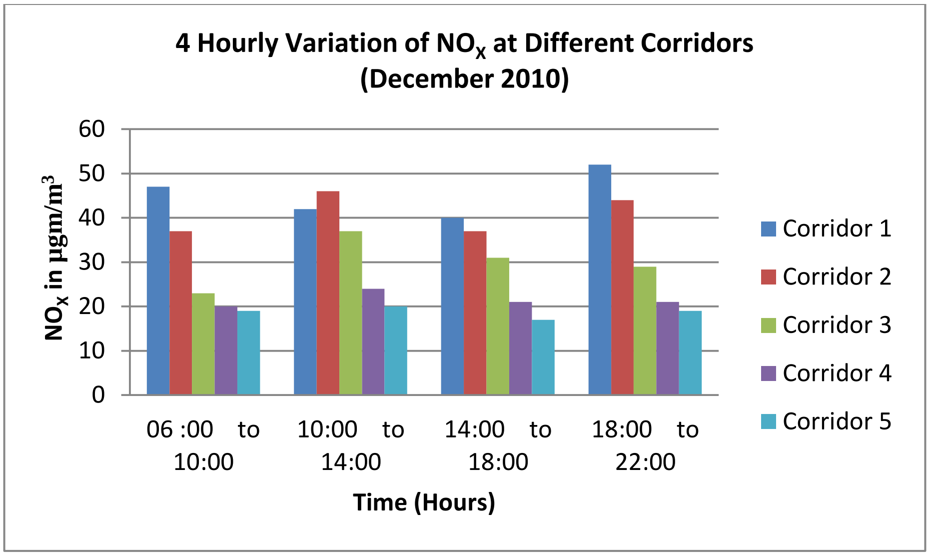


Figure 4.53: Four Hourly Variation of NO_X, December 2010

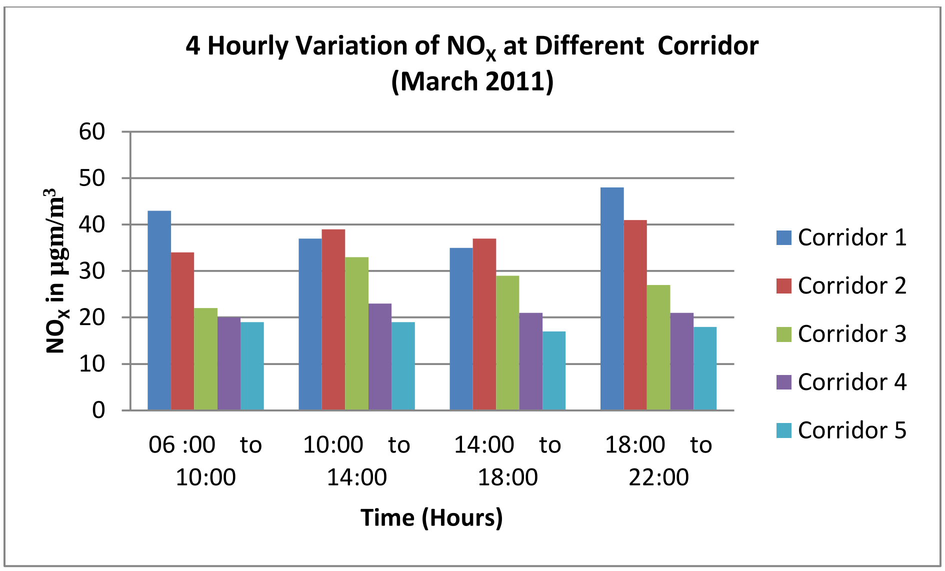


Figure 4.54: Four Hourly Variation of NO_X, March 2011

Analysis for NO_X for Corridor 1

NO_X variation at Corridor 1, high traffic volume zone, indicates that the peak hour traffic at this location was highest during 1800 hrs to 2200 hrs in all three seasons i.e. August, December and March, and at the same time NO_X levels were also found to be maximum during the same time of the day, in the total data set. This shows a good relationship between traffic and air pollutant parameters.

Regression analysis of NO_X also indicates a very good co-relation with the total number of vehicles with observed R^2 values of 0.90, 0.92 and 0.89 for August, December and March observations respectively.

NO_X levels in Corridor 1, were also found to be high during December (Post Monsoon/Winter) where the concentration ranged from 40 - 52 µgm/m^3, followed by March, where the values observed were, 35 - 48 µgm/m^3 and least concentration was observed during August (Monsoon period) with the values, 21 - 35 µgm/m^3 .

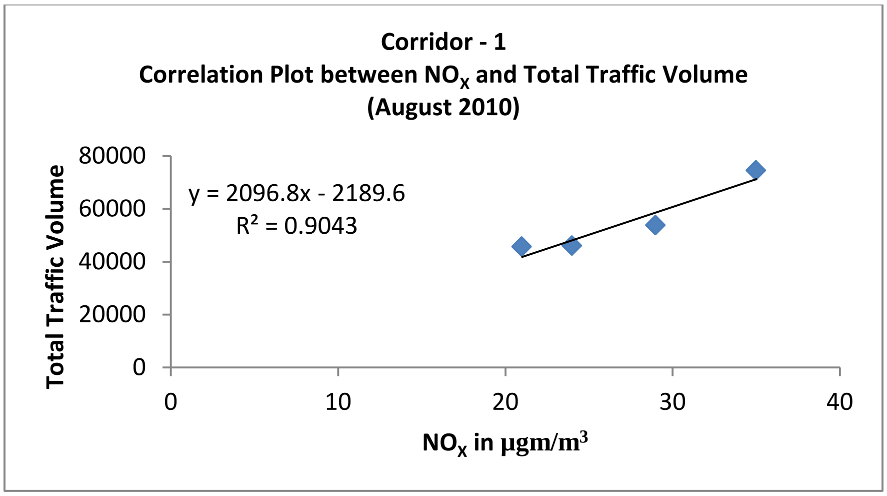


Figure 4.55: Correlation Plot between NO_X and Total Traffic Volume, Corridor – 1 (August 2010)

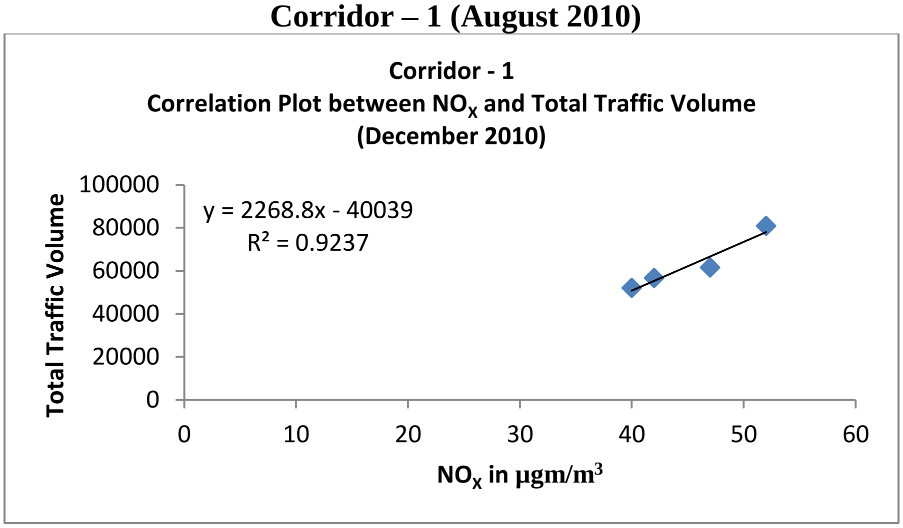


Figure 4.56: Correlation Plot between NO_X and Total Traffic Volume, Corridor – 1 (December 2010)

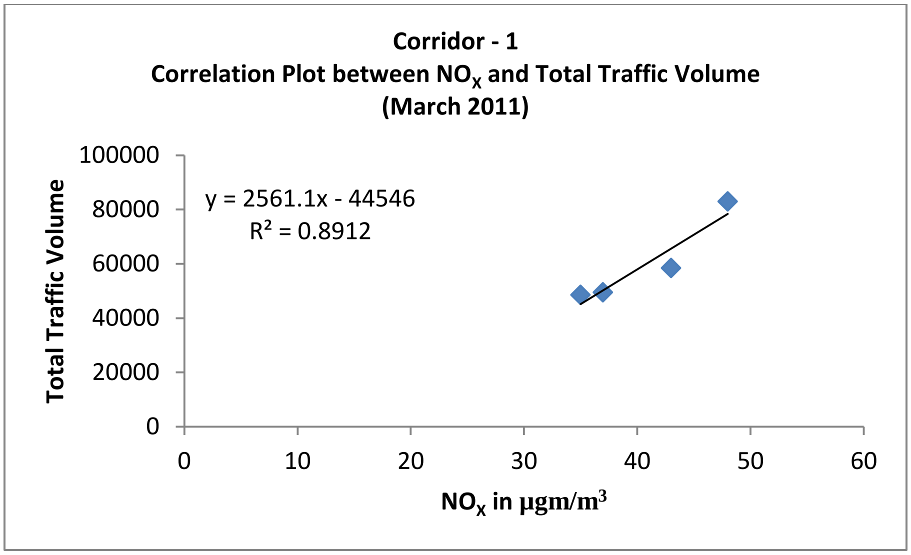


Figure 4.57: Correlation Plot between NO_X and Total Traffic Volume, Corridor – 1 (March 2011)

NO_X Analysis for Corridor 2

NO_X variation at Corridor 2, a major commercial hub, indicates that the peak hour traffic at this location was also highest during 1000 hrs to 1400 hrs in December while in August and March maximum traffic was observed during 1800 hrs – 2200 hrs, and NO_X levels were also found to be maximum during the same time of the day respectively, in the total data set. This again shows a good relationship between traffic and air pollutant parameters. Regression analysis of NO_X also indicates a very good co-relation with the total number of vehicles with observed R^2 values of 0.80, 0.66 and 0.97 for August, December and March observations respectively.

NO_X levels in Corridor 2, were also found to be high during December(Post Monsoon/Winter) where the concentration ranged from 37 -46 µgm/m^3, followed by March, where the values observed were, 34 -41 µgm/m^3 and least concentration was observed during August (Monsoon period) with the values, 23 - 29 µgm/m^3 .

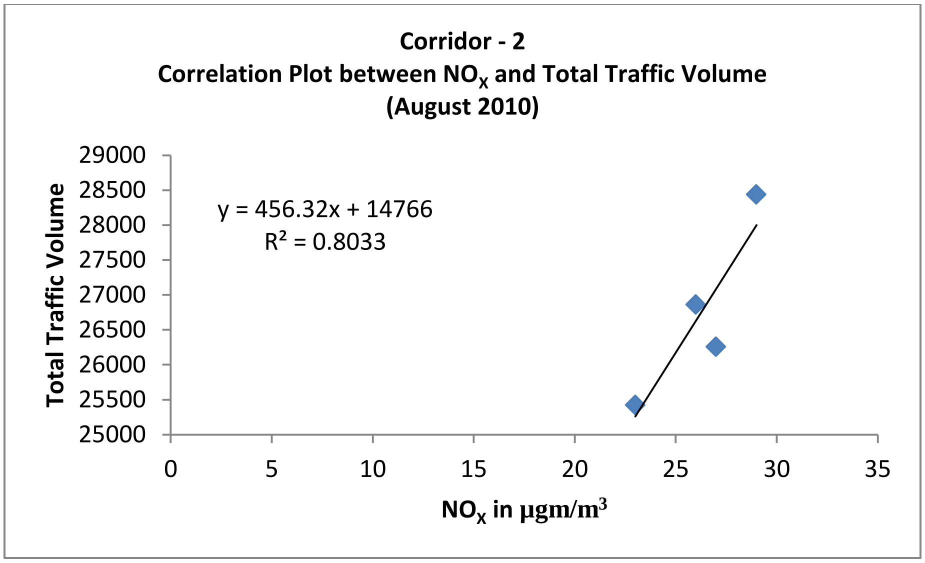


Figure 4.58: Correlation Plot between NO_X and Total Traffic Volume, Corridor – 2 (August 2010)

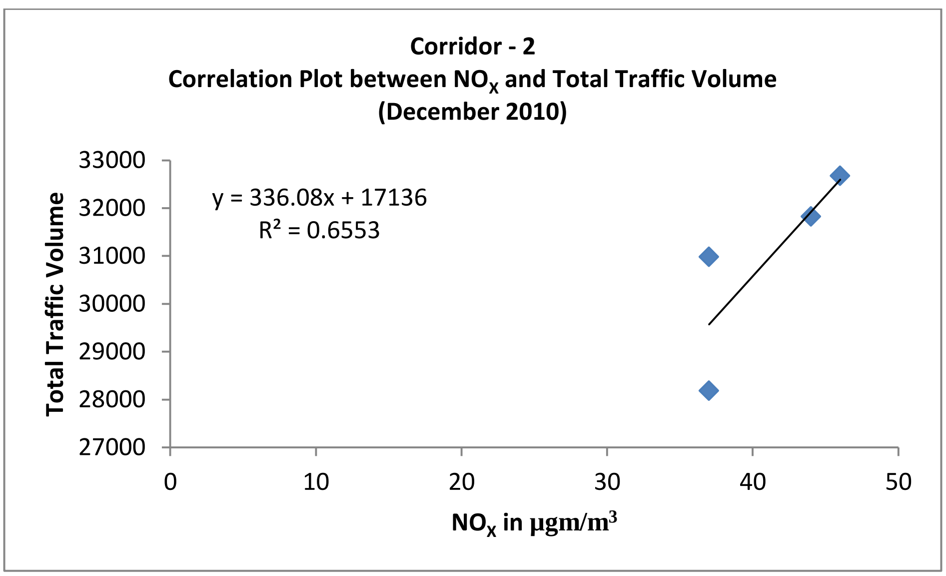


Figure 4.59: Correlation Plot between NO_X and Total Traffic Volume, Corridor – 2 (December 2010)

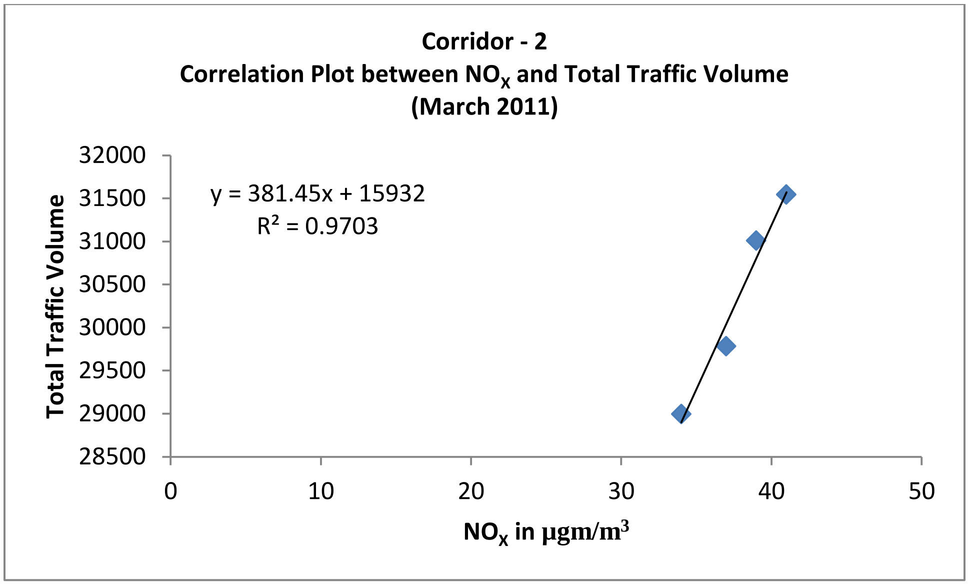


Figure 4.60: Correlation Plot between NO_X and Total Traffic Volume, Corridor – 2 (March 2010)

NO_X Analysis for Corridor 3

NO_X variation at Corridor 3, a major commercial hub, indicates that the peak hour traffic at this location was also highest during 1000 hrs to 1400 hrs in all three seasons i.e. August, December and March, and at the same time NO_X levels were also found to be maximum during the same time of the day, in the total data set. This again shows a good relationship between traffic and air pollutant parameters. Regression analysis of NO_X also indicates a very good co-relation with the total number of vehicles with observed R^2 values of 0.95, 0.94 and 0.92 for August, December and March observations respectively.

NO_X levels in Corridor 3, were also found to be high during December(Post Monsoon/Winter) where the concentration ranged from 23 - 37 µgm/m^3, followed by March, where the values observed were, 22 - 33 µgm/m^3 and least concentration was observed during August (Monsoon period) with the values, 19 – 25 µgm/m^3 .

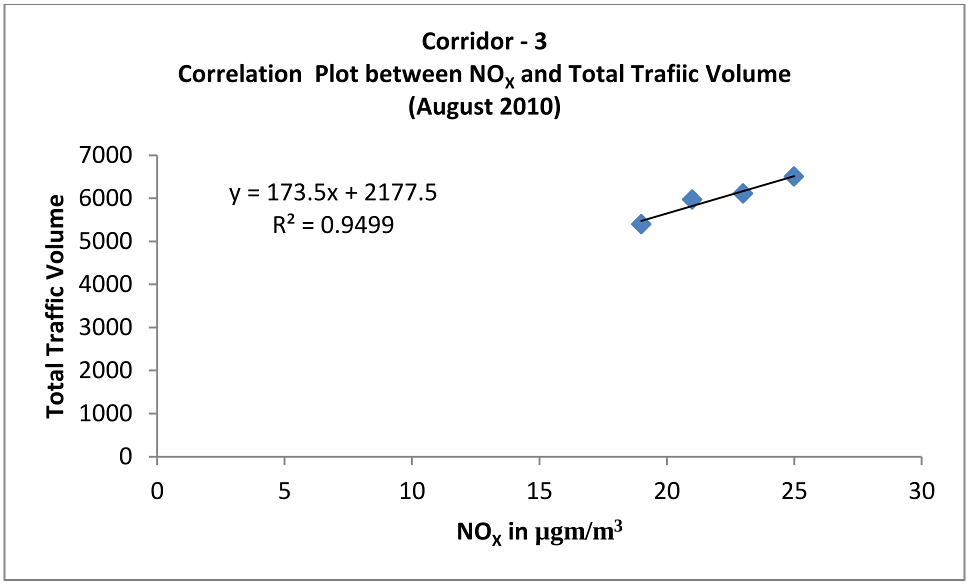


Figure 4.61: Correlation Plot between NO_X and Total Traffic Volume, Corridor – 3 (August 2010)

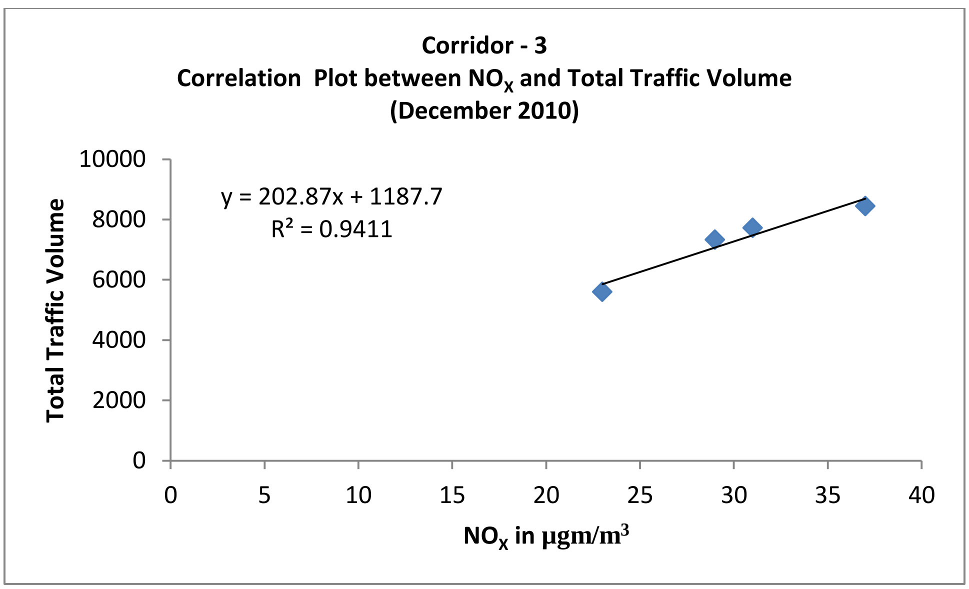


Figure 4.62: Correlation Plot between NO_X and Total Traffic Volume, Corridor – 3 (December 2010)

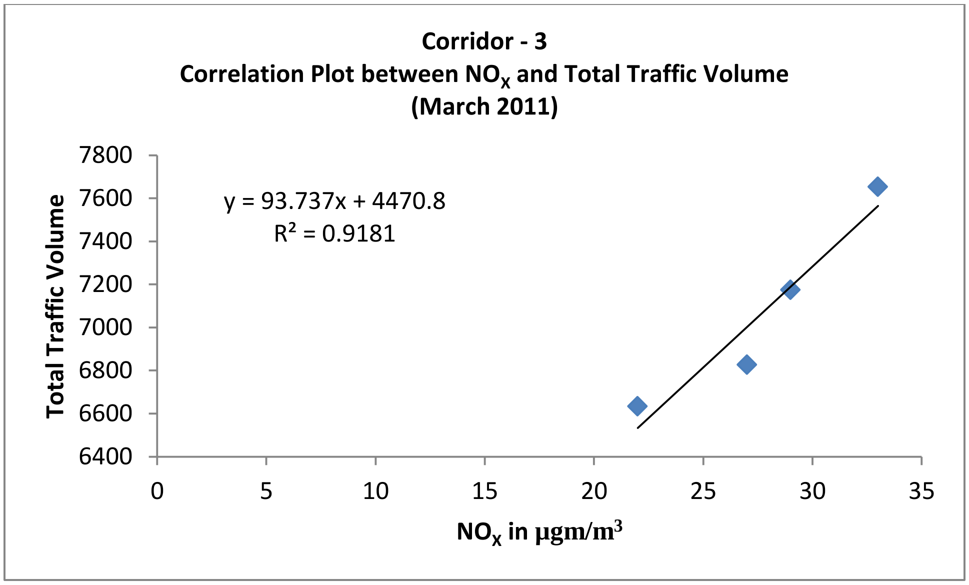


Figure 4.63: Correlation Plot between NO_X and Total Traffic Volume, Corridor – 3 (March 2011)

NO_X Analysis for Corridor 4

NO_X variation at Corridor 4, a semi-urban area with commercial and residential mix, indicates that the peak hour traffic at this location was highest during 1000 hrs to 1400 hrs followed by 1400 hrs to 1800 hrs in all three seasons i.e. August, December and March, and at the same time NO_X levels were also found to be maximum during the same time of the day, in the total data set. This again shows a good relationship between traffic and air pollutant parameters. Regression analysis of NO_X also indicates a very good co-relation with the total number of vehicles with observed R^2 values of 0.63, 0.74 and 0.79 for August, December and March observations respectively.

NO_X levels in Corridor 4, were also found to be high during December(Post Monsoon/Winter) where the concentration ranged from 20-24 µgm/m^3, followed by March, where the values observed were, 20 - 23 µgm/m^3 and least concentration was observed during August (Monsoon period) with the values, 20 – 22 µgm/m^3.

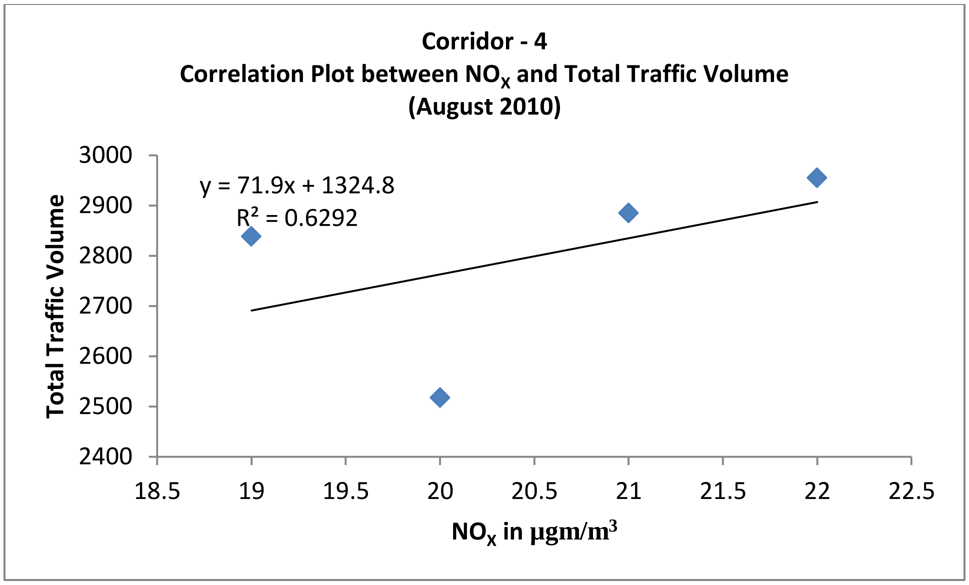


Figure 4.64: Correlation Plot between NO_X and Total Traffic Volume, Corridor – 4 (August 2010)

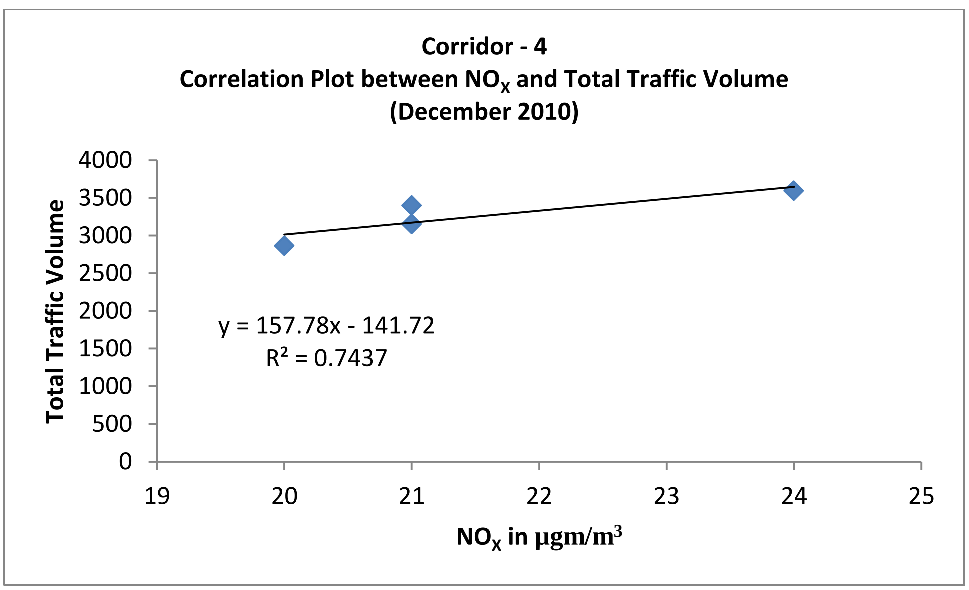


Figure 4.65: Correlation Plot between NO_X and Total Traffic Volume, Corridor – 1 (December 2010)

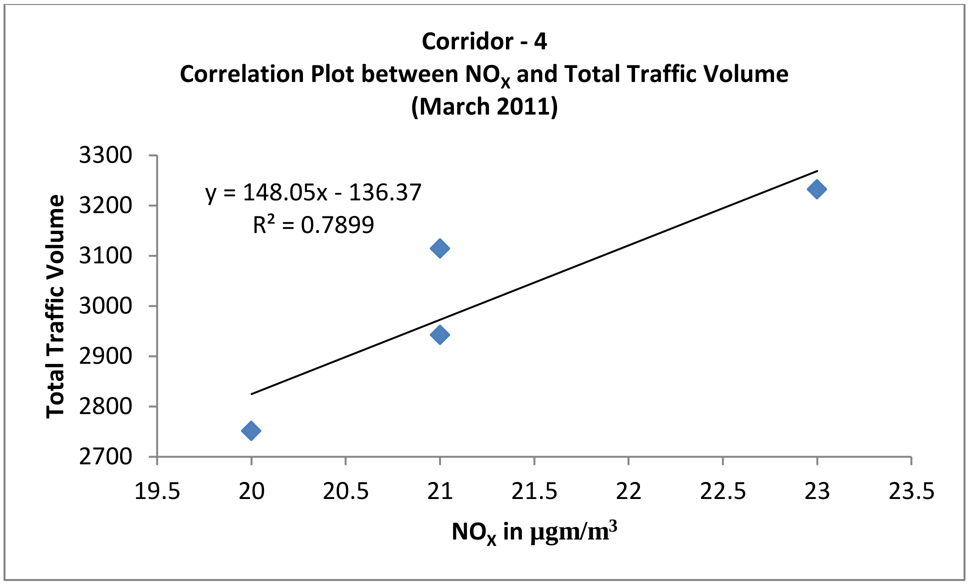


Figure 4.66: Correlation Plot between NO_X and Total Traffic Volume, Corridor – 1 (March 2011)

NO_X Analysis for Corridor 5

NO_X variation at Corridor 5, a residential area, indicates that the peak hour traffic at this location was highest during 1000 hrs to 1400 hrs in all three seasons i.e. August, December and March, and at the same time NO_X levels were also found to be maximum during the same time of the day, in the total data set. This again shows a good relationship between traffic and air pollutant parameters. Regression analysis of NO_X also indicates a very good co-relation with the total number of vehicles with observed R^2 values of 0.59, 0.83 and 0.84 for August, December and March observations respectively.

NO_X levels in Corridor 5, were also found to be high during December(Post Monsoon/Winter) where the concentration ranged from 17- 20 $\mu gm/m^3$, followed by March, where the values observed were, 17 - 19 $\mu gm/m^3$ and least concentration was observed during August (Monsoon period) with the values, 17 – 18 $\mu gm/m^3$, for the reasons mentioned above.

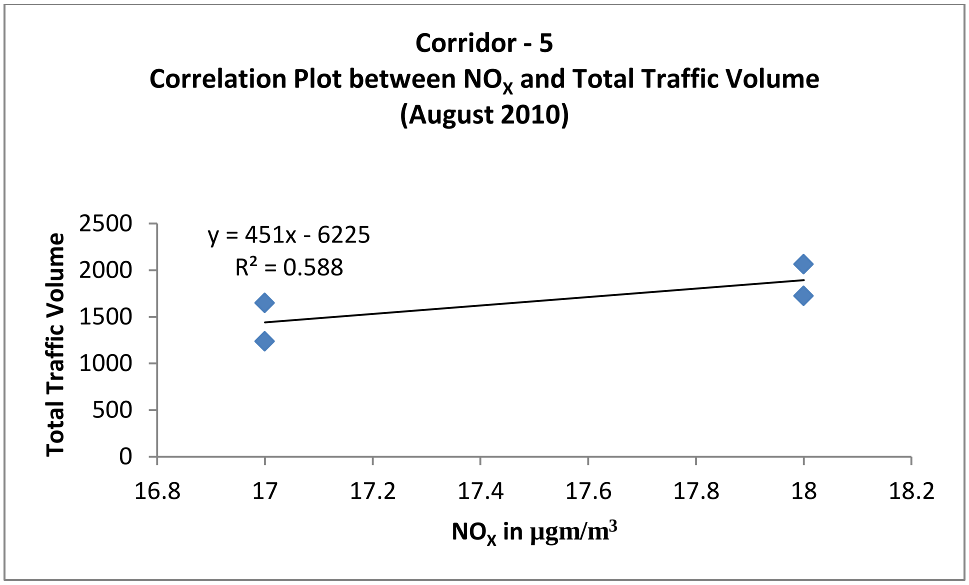


Figure 4.67: Correlation Plot between NO_X and Total Traffic Volume, Corridor – 5 (August 2010)

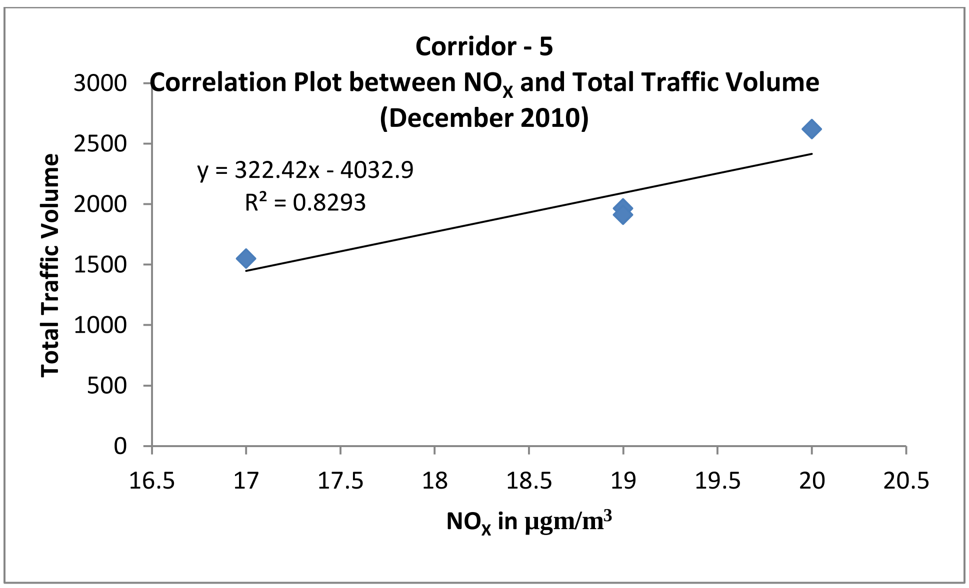


Figure 4.68: Correlation Plot between NO_X and Total Traffic Volume, Corridor – 5 (December 2010)

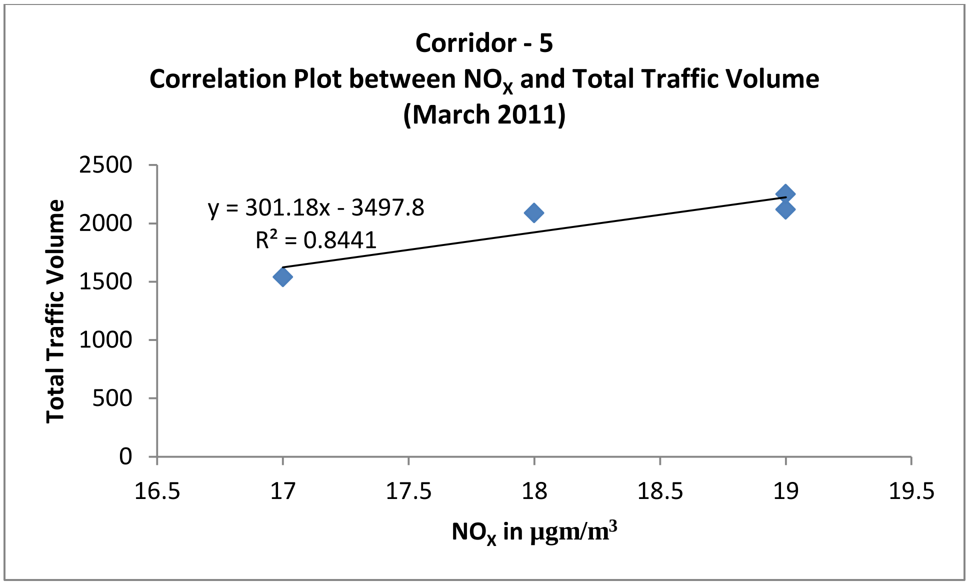


Figure 4.69: Correlation Plot between NO_X and Total Traffic Volume, Corridor – 5 (March 2011)

4.2.2 RELATION BETWEEN VARIOUS AIR POLLUTANTS AND METEOROLOGICAL ATTRIBUTES

To study the relationship between meteorological parameters and air pollutant concentration the data collected for PM, SO_X, NO_X and CO was statistically compared with meteorological variables such as relative humidity, temperature and wind speed. The data highlighted a variation in total concentration of PM, SO_X, NO_X and CO during different parts of the year, i.e. air pollutant levels were found to be high during December (Post Monsoon/Winter) and least during August (Monsoon). The relationship between the air pollutants and meteorological parameters for road corridor 1 was studied for December month since concentration levels were maximum. The Concentration of various pollutants at road corridor 1 and humidity, temperature & wind speed for December month are given in **Table 4.16.**

Table 4.16: Concentration of Various Pollutants, Temperature, Humidity & Wind Speed at Road Corridor 1 in December, 2010

Time	Meteorological Parameters			Air Pollutant Concentration			
	Temperature	Relative Humidity	Wind Speed	PM_{10}	SO_X	NO_X	CO
hours	^0C	%	m/s	µgm/m^3	µgm/m^3	µgm/m^3	mgm/m^3
06:00 to 10:00	11	85	2.3	280	22	47	3.6
10:00 to 14:00	16	60	2.8	262	21	42	3.2
14:00 to 18:00	18	41	3.2	248	20	40	3.1
18:00 to 22:00	14	45	2.1	304	24	52	4.2

Further, regression analysis has been undertaken between these air pollutants and meteorological parameters. Linear regression models developed in the study have been scrutinized using R^2 values. The details of regression analysis and scatter plot between these air pollutants and meteorological parameters are given from **Figure 4.70** to **Figure 4.81**.

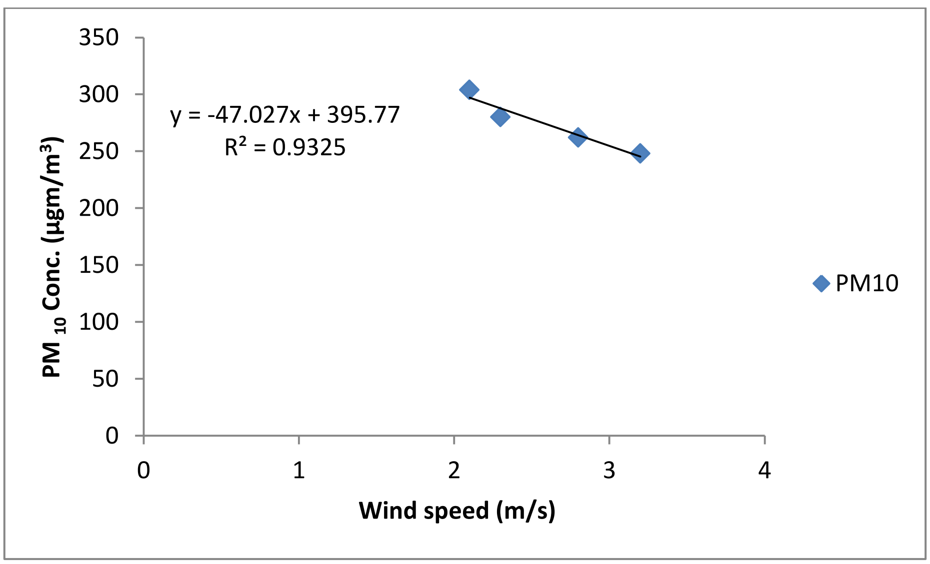


Figure 4.70: Correlation Plot between PM_{10} and Wind Speed

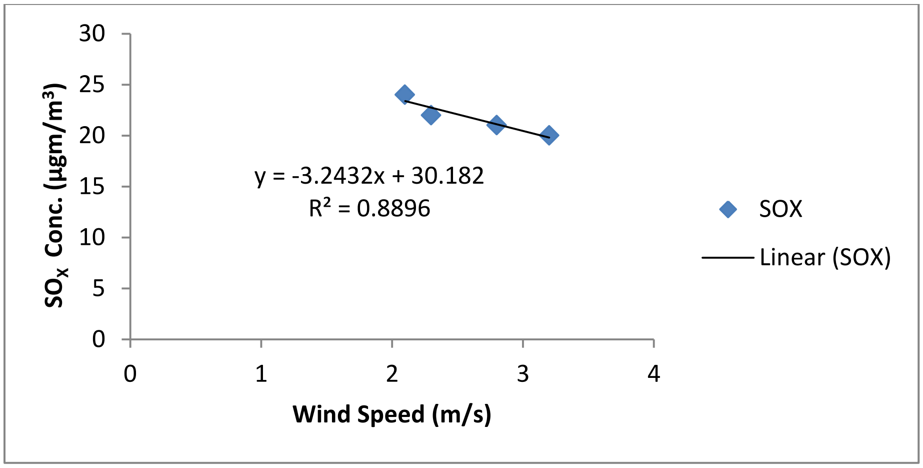


Figure 4.71: Correlation Plot between SOx and Wind Speed

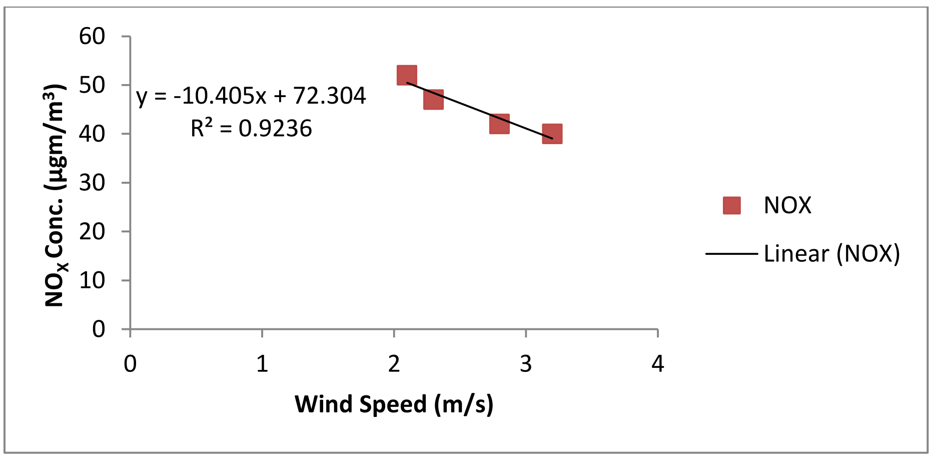


Figure 4.72: Correlation Plot between NOx and Wind Speed

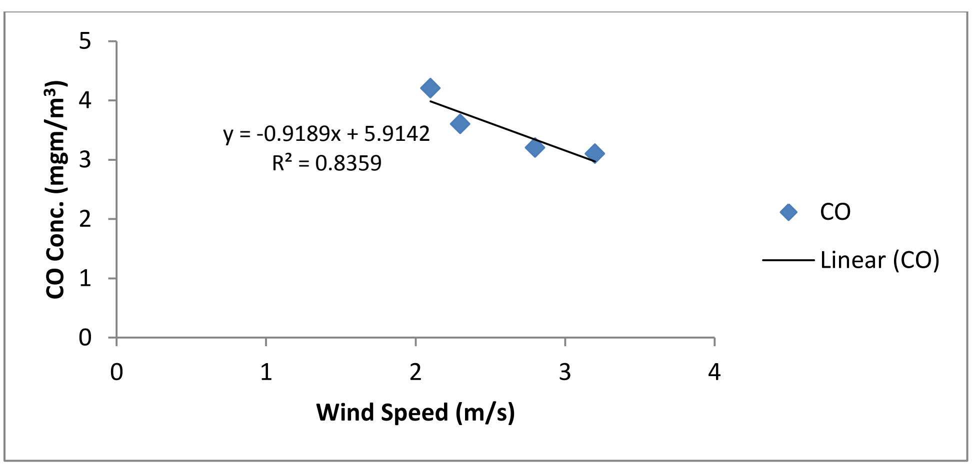


Figure 4.73: Correlation Plot between CO and Wind Speed

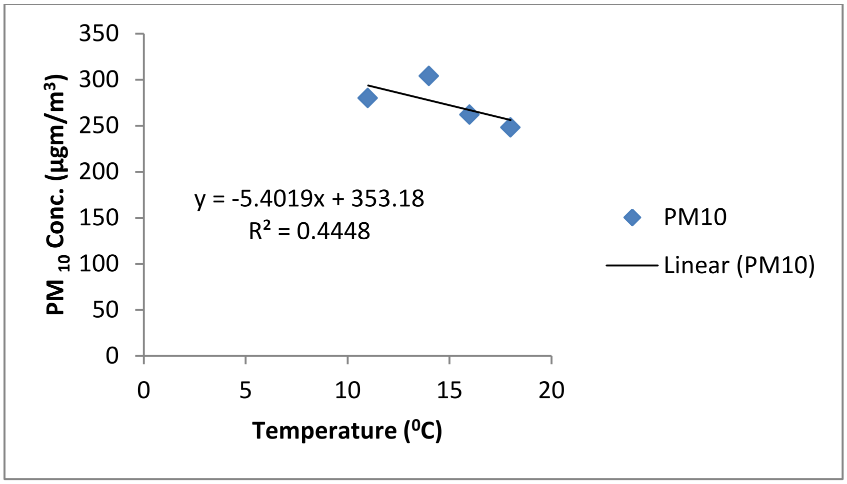


Figure 4.74: Correlation Plot between PM_{10} and Temperature

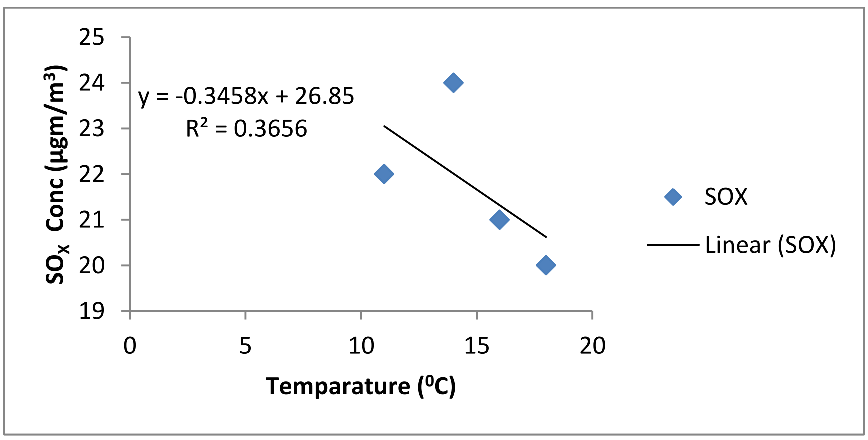


Figure 4.75: Correlation Plot between SOx and Temperature

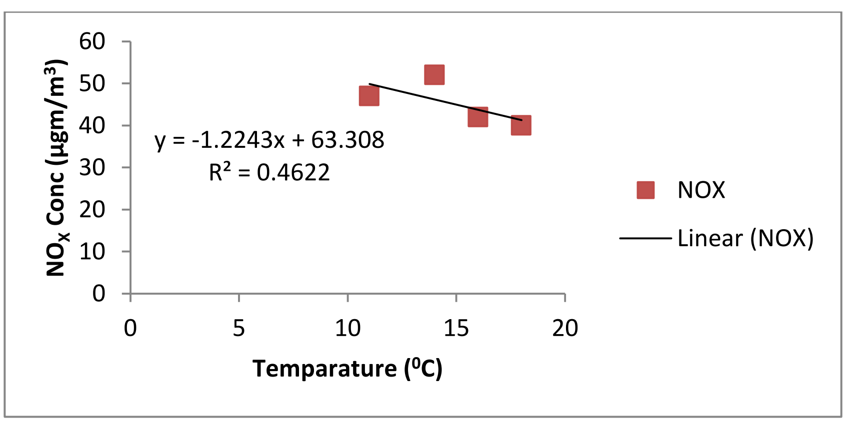


Figure 4.76: Correlation Plot between NOx and Temperature

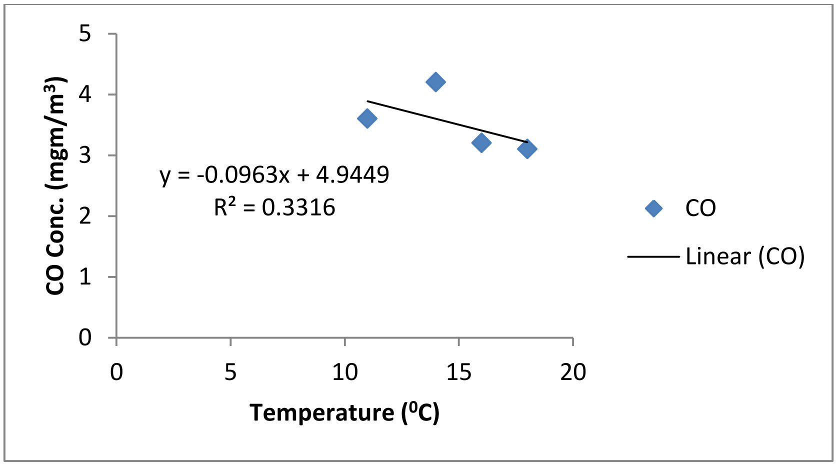


Figure 4.77: Correlation Plot between CO and Temperature

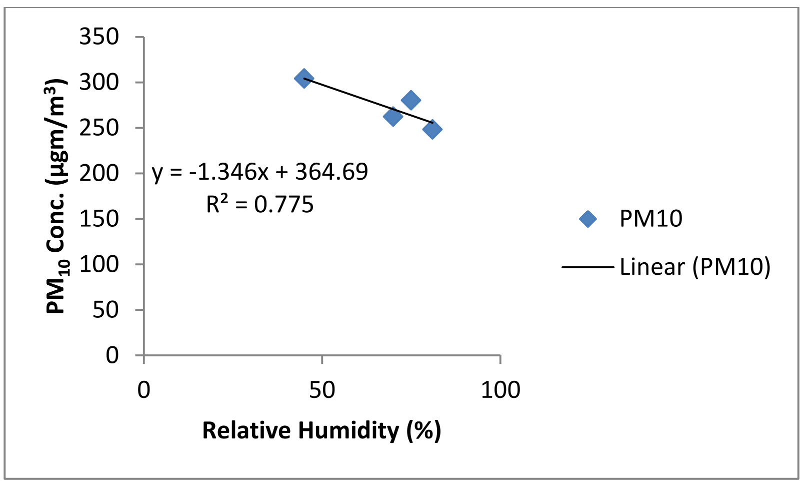


Figure 4.78: Correlation Plot between PM_{10} and Relative Humidity

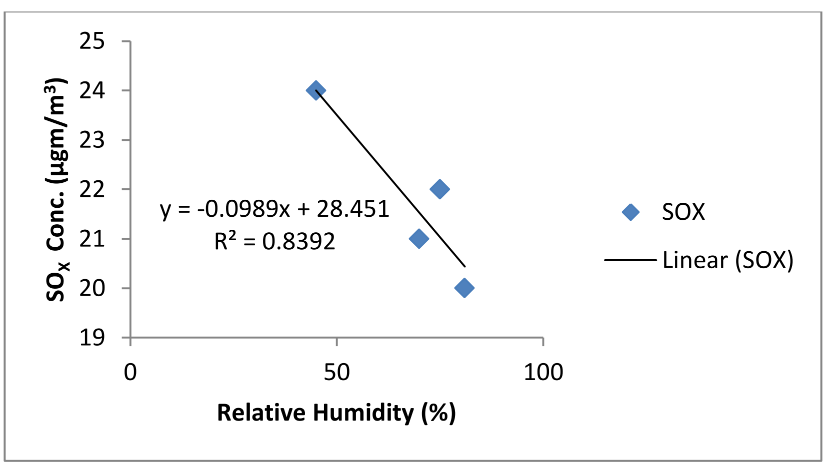


Figure 4.79: Correlation Plot between SOx and Relative Humidity

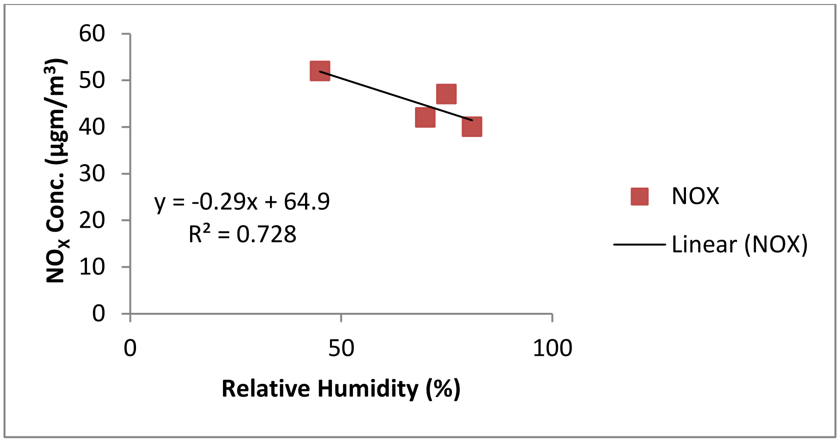


Figure 4.80: Correlation Plot between NOx and Relative Humidity

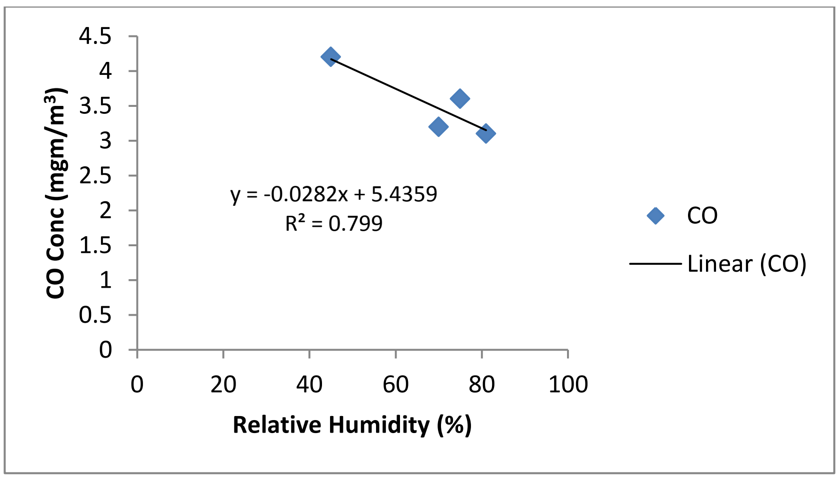


Figure 4.81: Correlation Plot between CO and Relative Humidity

The correlation analysis established a moderately high relationship between air pollutant concentration and wind speed, a moderate relationship between relative humidity and a weak relationship is seen between air pollutant and temperature. Thus, we can deduce that there is a relationship between meteorological factors and pollutant concentrations and are presented below in **Table 4.17**.

Table 4.17: Relationship between Meteorological Factors and Pollutant Concentrations

Dependent Variables	Independent Variables	Linear Relation	Coefficient of determination R^2 (%)	Level of relation
PM_{10}	Wind Speed	Negative	93	Strong
	Temperature	Negative	44	Weak
	Relative Humidity	Negative	77	Moderate
SO_X	Wind Speed	Negative	89	Strong
	Temperature	Negative	36	Weak
	Relative Humidity	Negative	78	Moderate
NO_X	Wind Speed	Negative	92	Strong
	Temperature	Negative	46	Weak
	Relative Humidity	Negative	73	Moderate
CO	Wind Speed	Negative	83	Strong
	Temperature	Negative	33	Weak
	Relative Humidity	Negative	75	Moderate

4.3 Objective III: To Predict Air Concentrations of Carbon Monoxide (CO) Using CALINE 4 Model For Future 5 Years

4.3.1 MODEL SETUP AND RUN

In order to predict air concentrations of Carbon monoxide CALINE4 model was used to predict the concentration of CO emitted from vehicle exhaust under standard meteorological conditions. The model was run for 24-hour period during winter season. Hourly weighted emission factors were calculated using the hourly traffic data recorded on study corridors. As the road corridor 1 (near IFFCO Chowk on NH-8) recorded the significantly higher traffic volumes in comparison to other road corridors, the modeling was performed only for the corridor 1. The CO being major indicator pollutant for vehicular activities was chosen for the present study and hence the modeling was performed for CO only. For the present project, the model was used to predict 1-hour CO concentration for standard meteorological conditions.

The CALINE 4 model was run using two different weighted emission factor (WEF) calculated based on emission factors specified by CPCB and ARAI for Indian vehicles.

The WEF (input parameter for CALINE 4) is a function of vehicle emission factor (as a function of vehicle category, type, fuel type, age profile, vintage etc.) and vehicle activity (traffic volume). The methodology used for calculation of WEF is given below:

WEF= [∑ (i) ∑ (ky) N (j.ky), EF (i,j,ky)]/ Total No. of Vehicles ………. (Eqn. 4.1)

Where,

WEF = Weighted emission factor (g/kg)

N (j.ky) = No. of vehicles of a particular type j and age ky in year y (average daily traffic

EF (i,j,ky) = Emission factor for component I for the vehicle type j and age ky in year y (g/kg)

I = Pollutant component (viz., CO)

J = Type of vehicle [i.e. 2W, 3W, cars, bus, truck etc.]

Ky = Age if vehicle in year y

The 18 receptor points (9 points on each side of the road corridor) were selected at pre-identified receptor location with a specified distance from the edge of the mixing zone width (road width + 3 m on each side of the corridor) i.e. 1 m, 5m, 10m, 20m, 30m, 50m, 75m, 100m and 150m from the edge of the road on both the side.

Under standard meteorological condition, the CALINE4 model predicts the pollutant concentration in the prevailing wind direction; hence hourly concentration values at predetermined receptor locations were obtained. CO predictions have been done for year 2010 and for next five years thereafter i.e. for year 2015.

4.3.2 INPUT VARIABLES

The input parameters used in CALINE 4 model are given below in **Table 4.18.**

Table 4.18: Input Parameters Used in CALINE 4 Model

S.No.	Parameters	Values/ Units	Source
1	Traffic Data (24 hour)	24 hourly	Manual Count
2	Weighted Emission Factors (WEF)	g/miles	Calculated
3	Terrain Type	Urban	Physically observed
4	Mixing Zone width (Carriage width + 3 m on both sides)		Physically measured
a	Road Alignment	Straight	Google Map
b	Road Type	At-Grade	Assumed
5	Meteorological Data		
a	Wind Speed	m/s	IMD
b	Wind Direction	Degree	IMD
c	Mixing Height	m	Atlas, IMD
d	Stability Class	A,B,C,D,E or F	Pasquill (P-G) Stability Class
6	Monitored CO Conc.	$\mu g/m^3$	Recorded

4.3.3 TRAFFIC DATA

The details of hourly traffic data at corridor I (near IFFCO Chowk on NH-8) recorded in December 2010 (winter season) is given in **Table 4.19**.

Table 4.19: 24 Hour Traffic Data at Road Corridor 1

Time (hours)	Two Wheelers	Three Wheelers	Car / Van / Jeep / Sumo	Mini Bus / Bus	Trucks	Tractors	Total
06 :00 to 07:00	1357	231	2376	159	3153	32	7308
07:00 to 08:00	2288	485	4985	382	2648	74	10862
08:00 to 09:00	3278	1075	14763	584	1443	89	21232
09:00 to 10:00	6238	1286	12876	635	927	98	22060
10:00 to 11:00	3254	975	9890	597	886	132	15734
11:00 to 12:00	2476	794	8579	503	654	114	13120
12:00 to 13:00	2086	664	10189	325	465	109	13838
13:00 to 14:00	2679	604	9456	467	512	86	13804
14:00 to 15:00	2773	611	8873	334	589	77	13257

Time (hours)	Two Wheelers	Three Wheelers	Car / Van / Jeep / Sumo	Mini Bus / Bus	Trucks	Tractors	Total
15:00 to 16:00	2234	564	7842	338	663	84	11725
16:00 to 17:00	1702	458	6974	432	785	96	10447
17:00 to 18:00	3765	743	10353	398	1021	108	16388
18:00 to 19:00	4689	1087	12543	487	1549	123	20478
19:00 to 20:00	5682	975	11408	633	4371	93	23162
20:00 to 21:00	3378	604	7546	622	6654	69	18873
21:00 to 22:00	1917	387	6784	543	8545	39	18215
22:00 to 23:00	823	159	4332	211	9826	16	15367
23:00 to 00:00	227	82	2327	57	10982	3	13678
00:00 to 01:00	143	48	1287	23	12667	0	14168
01:00 to 02:00	87	12	976	17	11435	0	12527
02:00 to 03:00	42	9	481	14	9328	0	9874
03:00 to 04:00	28	17	523	9	6267	0	6844
04:00 to 05:00	313	43	838	32	4518	7	5751
05:00 to 06:00	721	126	1298	57	3772	19	5993
Total	**52180**	**12039**	**157499**	**7859**	**103660**	**1468**	**33470 5**

Based on the average results of the fuel station survey the same results has been extended to the traffic survey, assuming that the vehicles plying on the road are being represented by vehicles coming to the fuel stations for filling up of the fuel. The vintage of the vehicles plying on the road as well as the percentage of petrol, diesel and CNG vehicles plying on the corridor are given below in **Table 4.20**.

Table 4.20: Composition of Traffic / Age of Vehicle (%)

Age of Vehicle	2W (2 Stroke) 30%	2W (4 Stroke) 70%	3W (Petrol) 90%	3W (CNG) 10%	Passenger Cars (Petrol) 55%	Passenger Cars (Diesel) 45%	LCV	HCV / BUS
1991-1995	5	0	5	-	5	5	5	5
1996-2000	15	10	15	-	20	20	15	15
2001-2005	50	30	40	100	35	35	40	40
2006-2010	30	60	40		40	40	40	40

* Tractors are assumed in the category of LCV

* As buses and mini buses are counted as same; hence, it is assumed that mini buses account for 10% share

4.3.4 ROAD GEOMETRY

In the CALINE-4 model the length of a road section is divided into various links. The division of a road sections into links has to be done in such way, so that the link can be fairly considered as straight stretch of road having homogenous geometry with uniform width, height and traffic volume. The coordinates of end points of links specify the location of the links in the model. The maximum length of a single link can be up to 10 km. The maximum numbers of link in each road section are 20. The details of Links are provided in **Table 4.21**.

Table 4.21: Details of Link

Link No.	X1 (UTM - Zone 43, m)	Y1 (UTM - Zone 43, m)	X2 (UTM - Zone 43, m)	Y2 (UTM - Zone 43, m)	Length (m)	Width (m)	Link Height (above ground level)
Link_1	703310.29	3152779.97	702741.02	3152079.48	902.64	20	0
Link_2	702741.02	3152079.48	702217.72	3151581.15	722.61	20	0
Link_3	702217.72	3151581.15	701808.66	3151190.24	565.81	20	0

4.3.5 SURFACE ROUGHNESS LENGTH

The surface roughness length is the height at which the mean horizontal wind speed approaches zero and is related to the roughness characteristics of the terrain. It is not equal to the physical dimensions of the obstacles to the wind flow, but is generally proportional to them. This parameter is important as it is a measure of the amount of local air turbulence that affects the spread of the plume. Surface roughness length equal to 200 cm, relevant for centers of large town or cities is used for Corridor-1.

4.3.6 WEIGHTED EMISSION FACTOR

One of the important requirements for CALINE-4 model is the input for emission factor for vehicles. These emission factors have been expressed for various pollutants and vehicle types, year of manufacturing and type of fuel used (petrol or diesel). The improvement in engine technology, resulting in reduced emission factors are reflected in these standard emission factors. Since, there is only one input requirement for total no. of vehicles in the CALINE 4 model, whereas, there are different categories of vehicles (viz. 2/3 wheelers, cars, LCVs and HCVs) with different manufacturing year and fuel type, it is essential that a single value representing the equivalent emission factors for all the vehicles is calculated.

In the present study, the following emission factors specified by the Automotive Research Association of India (ARAI), 2007 **(Ref. Table 4.22)** and Central Pollution Control Board (CPCB), 2000 **(Ref. Table 4.23)** have been used for calculation of weighted emission factors.

Table 4.22: ARAI Emission Factor (gm/km) for Different Category of Vehicles

Year	2 Wheelers		3 Wheelers (CNG)*	Passenger Cars		LCVs	HCVs
	2-Stroke	4-Stroke		Petrol	Diesel		
1991-1995	6	3.12	-	4.75	1.2	3.07	13.06
1996-2000	5.1	1.58	-	4.825	0.87	3.0	4.48
2001-2005	3.435	1.65	1.0	1.30	0.72	3.66	12.14
2005-2010	0.16	0.72	1.0	3.01	0.06	3.66	3.92

* For Original Equipment Manufacturer (OEM) Vehicles. For retrofitted vehicles the emission factor is 0.69 gm/km

Table 4.23: CPCB Emission Factor (gm/km) for Different Category of Vehicles

Year	2 Wheelers		3 Wheelers (Petrol)	Passenger Cars		LCVs	HCVs
	2-Stroke	4-Stroke		Petrol	Diesel		
1991-1995	6.5	3	14.00	9.8	7.3	8.7	5.5
1996-2000	4	2.5	8.60	3.9	1.2	6.9	4.5
2001-2005	2.2	2.2	4.30	1.98	0.9	5.1	3.6
2005-2010	1.4	1.4	2.45	1.39	0.58	0.72	3.2

The calculated total emission load and weighted emission factors for year 2010 are given in **Table 4.24**.

Table 4.24: Total Emission Load & Weighted Emission Factors, 2010

Time (hours)	Total Emission Load (gm/km)	Total Vehicle	Weighted Emission Factor
06 :00 to 07:00	25720.75	7308	5.68
07:00 to 08:00	34229.95	10862	5.08
08:00 to 09:00	57386.18	21232	4.36
09:00 to 10:00	59725.95	22060	4.37
10:00 to 11:00	43484.60	15734	4.46
11:00 to 12:00	35935.49	13120	4.42
12:00 to 13:00	36055.12	13838	4.20
13:00 to 14:00	36341.61	13804	4.25
14:00 to 15:00	35023.97	13257	4.26
15:00 to 16:00	31481.12	11725	4.33
16:00 to 17:00	28636.36	10447	4.42
17:00 to 18:00	44054.24	16388	4.34
18:00 to 19:00	56242.35	20478	4.43
19:00 to 20:00	**69319.25**	**23162**	**4.83**
20:00 to 21:00	63249.05	18873	5.41
21:00 to 22:00	64956.08	18215	5.75
22:00 to 23:00	59748.28	15367	6.27
23:00 to 00:00	57961.61	13678	6.83
00:00 to 01:00	62948.61	14168	7.17
01:00 to 02:00	56103.64	12527	7.22
02:00 to 03:00	44985.01	9874	7.35
03:00 to 04:00	30731.39	6844	7.24
04:00 to 05:00	24250.41	5751	6.80
05:00 to 06:00	23465.60	5993	6.32

The total vehicles and corresponding hourly total emission load for year 2010 is shown below in **Figure 4.82**.

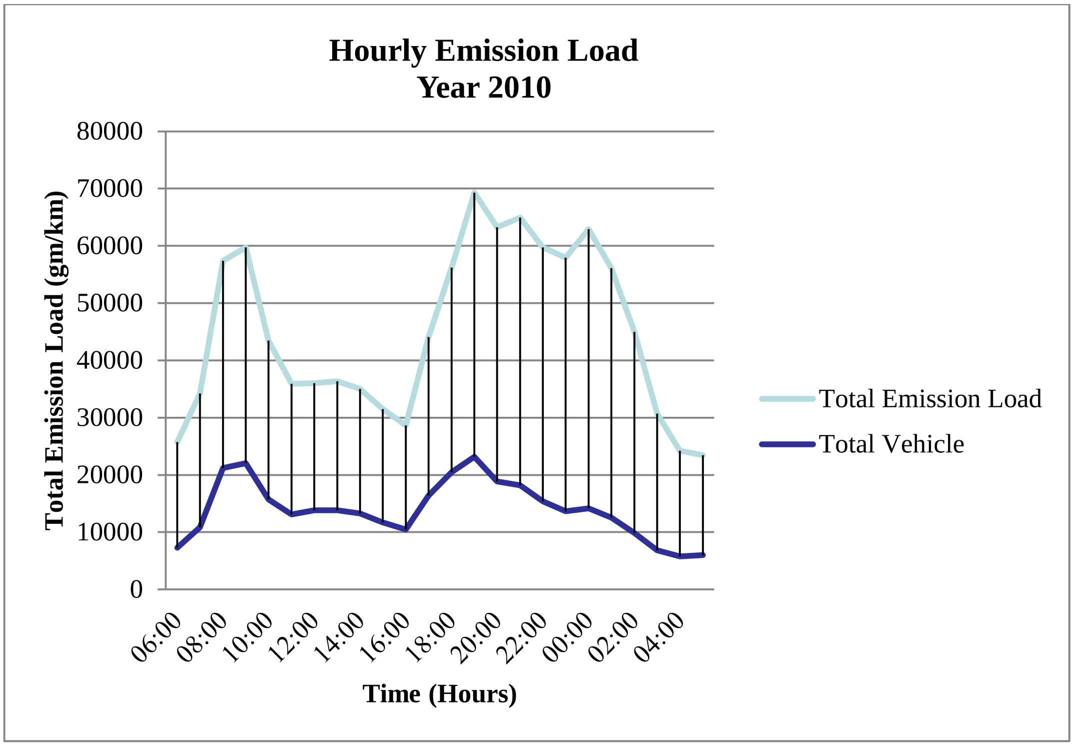


Figure 4.82: Hourly Emission Load

The following results were obtained from CALINE4 model run for year 2010–

a) During the 24-hour period in which the model was run, two distinct peak concentration levels were observed during the morning and evening time; however the evening time peak concentration levels were significantly higher than the morning peak concentration level.

b) Morning Time Peak - The morning time peak was recorded between 9 am to 10 am. The total vehicle recorded vehicles were 22060 and emission load was 59725.95 gm/km

c) Evening Time Peak – The evening time peak was recorded between 7 pm to 8 pm. The total vehicle recorded vehicles were 23162 and emission load was 69319.25 gm/km.

4.3.7 METEOROLOGICAL DATA

The following hourly meteorological data has been obtained from IMD. Since the maximum traffic volume and emission load was observed between 19.00 and 20.00 hours, hence, the meteorological corresponding to that hour has been used for the modelling purpose. The hourly meteorological data is given in **Table 4.25** and summary of site variables & link variables used for the modeling are given in **Table 4.26**.

Table 4.25: Hourly Meteorological Data

Time (hours)	Temperature (^{O}C)	Wind Speed (m/s)	Wind Direction (Degree)	Mixing Height (m)	Stability Class
06 :00 to 07:00	8	1.8	247.5	55	D
07:00 to 08:00	8	1.5	258	60	D
08:00 to 09:00	9.5	2.3	258	75	C
09:00 to 10:00	12	3	247.5	130	C
10:00 to 11:00	15	2.8	270	250	C
11:00 to 12:00	18	3.1	270	440	C
12:00 to 13:00	19.5	3.6	270	630	C
13:00 to 14:00	20.5	4.3	270	725	C
14:00 to 15:00	21	4.6	270	775	C
15:00 to 16:00	21	4.6	270	840	C
16:00 to 17:00	20.5	3.6	270	860	D
17:00 to 18:00	19	2.3	270	800	D
18:00 to 19:00	17.5	2.6	281	725	D
19:00 to 20:00	16	2.2	292	550	D
20:00 to 21:00	15.5	1	292	300	D
21:00 to 22:00	14.5	1	292	150	D
22:00 to 23:00	13.5	1	270	85	D
23:00 to 00:00	12	1	225	55	D
00:00 to 01:00	11	1	225	35	D
01:00 to 02:00	11	2.1	225	25	D
02:00 to 03:00	10.5	2.4	236	15	D
03:00 to 04:00	9.5	2.8	258	10	D
04:00 to 05:00	8.5	2	258	20	D
05:00 to 06:00	8	1.5	247.5	40	D

Source: IMD (Year December 2010)

Table 4.26: Summary of Site Variables & Link Variables Used for Modeling

Site variables		Link Variables	
Wind Speed	2.2 m/s	6 lane carriageway width	21 m
Wind Angle	292 Degree	Median Width	5 m
Stability Class	4 (D)	Mixing Zone Width	32 m
Mixing Height	550 m	Emission Factor	4.8
Surface Roughness	200cm		
Temperature	$16^{0}C$		
Altitude	235 m		

4.3.8 RECEPTORS – LINK RECEPTORS

Link receptors were set up on the representative road sections. Link receptors are used for prediction of concentration pollutant at different horizontal distances from project road section. The 18 receptor points (9 points on each side of the road corridor) was selected at pre-identified receptor location with a specified distance from the edge of the mixing zone width (road width + 3 m on each side of the corridor) i.e. 1 m, 5m, 10m, 20m, 30m, 50m, 75m, 100m and 150m from the edge of the road on both the side. The predicted CO Concentrations in year 2010 at all 18 receptor points is given below in **Table 4.27**.

Table 4.27: Predicted CO Concentrations, Year 2010

LHS (m)									MIXING ZONE	RHS								
-150	**-100**	**-75**	**-50**	**-30**	**-20**	**-10**	**-5**	**-1**		**1**	**5**	**10**	**20**	**30**	**50**	**75**	**100**	**150**
0.34	0.57	0.69	0.80	1.15	1.49	1.83	2.18	2.41		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

The maximum predicted concentration of CO was calculated as 3.41 mg/m^3 on Left side of the road at 1 m distance from the mixing zone. The pollutant concentration decreases drastically to 1/3rd within 50m distance from the mixing zone. After 50m distance, the pollutant concentration decreases gradually to baseline concentration levels. The graphical representation of predicted CO Concentration is shown below in **Figure 4.83**.

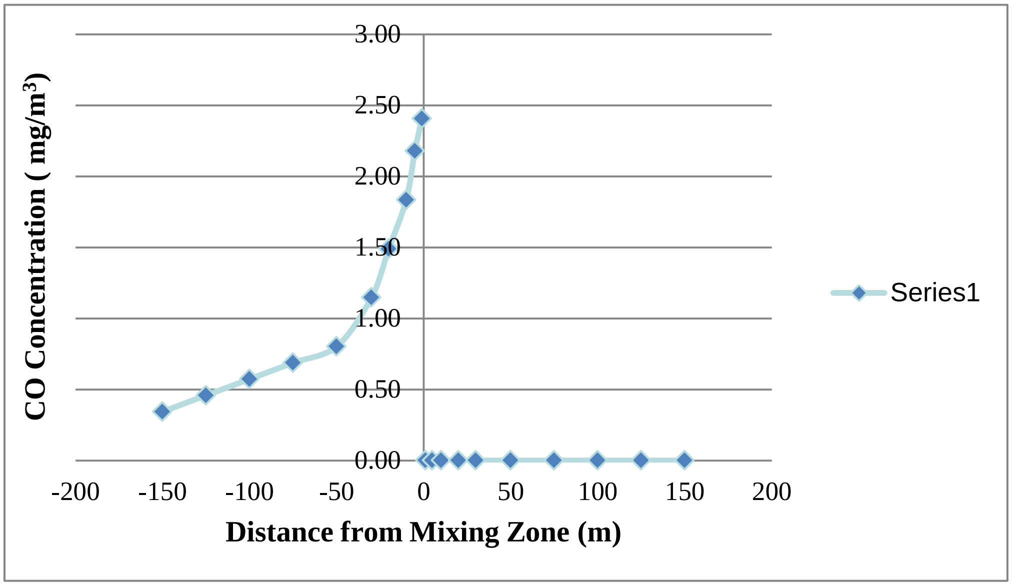


Figure 4.83: Predicted CO Concentration, 2010

The traffic projections five years down the line (i.e. for year 2015) has been done based on annual growth projections in NCR in near past. The projected traffic volume has been calculated with an annual rise of 8% for first 3 years and 7% for 4th and 5th year. The projected traffic composition for year 2015 is given below in **Table 4.28**.

Table 4.28: Projected Traffic Volume, Year 2015

Time (hours)	Two Wheelers	Three Wheelers	Car/Van/ Jeep/Sumo	Mini Bus/Bus	Trucks	Tractors	Total
06 :00 to 07:00	1954	333	3421	229	4540	46	10524
07:00 to 08:00	3295	698	7178	550	3813	107	15641
08:00 to 09:00	4720	1548	21259	841	2078	128	30574
09:00 to 10:00	8983	1852	18541	914	1335	141	31766
10:00 to 11:00	4686	1404	14242	860	1276	190	22657
11:00 to 12:00	3565	1143	12354	724	942	164	18893
12:00 to 13:00	3004	956	14672	468	670	157	19927
13:00 to 14:00	3858	870	13617	672	737	124	19878
14:00 to 15:00	3993	880	12777	481	848	111	19090
15:00 to 16:00	3217	812	11292	487	955	121	16884
16:00 to 17:00	2451	660	10043	622	1130	138	15044
17:00 to 18:00	5422	1070	14908	573	1470	156	23599
18:00 to 19:00	6752	1565	18062	701	2231	177	29488
19:00 to 20:00	8182	1404	16428	912	6294	134	33353
20:00 to 21:00	4864	870	10866	896	9582	99	27177

Time (hours)	Two Wheelers	Three Wheelers	Car/Van/ Jeep/Sumo	Mini Bus/Bus	Trucks	Tractors	Total
21:00 to 22:00	2760	557	9769	782	12305	56	26230
22:00 to 23:00	1185	229	6238	304	14149	23	22128
23:00 to 00:00	327	118	3351	82	15814	4	19696
00 :00 to 01:00	206	69	1853	33	18240	0	20402
01 :00 to 02:00	125	17	1405	24	16466	0	18039
02 :00 to 03:00	60	13	693	20	13432	0	14219
03 :00 to 04:00	40	24	753	13	9024	0	9855
04 :00 to 05:00	451	62	1207	46	6506	10	8281
05 :00 to 06:00	1038	181	1869	82	5432	27	8630
Total	**75139**	**17336**	**226799**	**11317**	**149270**	**2114**	**481975**

In order to predict CO concentration for year 2015, all the meteorological parameters, site variables and link variables were kept constant. Only projected traffic volume for year 2015 was changed and CALINE model was run. The calculated total emission load and weighted emission factors for year 2015 as given below in **Table 4.29**.

Table 4.29: Total Emission Load & Weighted Emission Factors, 2015

Time (hours)	Total Emission Load (gm/km)	Total Vehicle	Weighted Emission Factor
06 :00 to 07:00	37037.88	10524	5.68
07:00 to 08:00	49291.13	15641	5.08
08:00 to 09:00	82636.10	30574	4.36
09:00 to 10:00	86005.36	31766	4.37
10:00 to 11:00	62617.83	22657	4.46
11:00 to 12:00	51747.11	18893	4.42
12:00 to 13:00	51919.38	19927	4.20
13:00 to 14:00	52331.91	19878	4.25
14:00 to 15:00	50434.51	19090	4.26
15:00 to 16:00	45332.81	16884	4.33
16:00 to 17:00	41236.36	15044	4.42
17:00 to 18:00	63438.11	23599	4.34
18:00 to 19:00	80988.98	29488	4.43
19:00 to 20:00	99819.72	33353	4.83
20:00 to 21:00	91078.64	27177	5.41
21:00 to 22:00	93536.75	26230	5.75
22:00 to 23:00	86037.52	22128	6.27
23:00 to 00:00	83464.71	19696	6.83
00:00 to 01:00	90646.00	20402	7.17
01:00 to 02:00	80789.24	18039	7.22
02:00 to 03:00	64778.41	14219	7.35
03:00 to 04:00	44253.20	9855	7.24
04:00 to 05:00	34920.59	8281	6.80
05:00 to 06:00	33790.46	8630	6.32

The morning time peak was recorded between 9 am to 10 am. The total vehicle recorded vehicles were 31766 and emission load was 86005.36gm/km. The predicted CO concentration when compared with NAAQS (Ref. **Appendix 4.1**) was found to be exceeding the limits. The maximum hourly total traffic volume and total traffic load was calculated as 33353 and 99819.72 gm/km respectively.

Same 18 receptor points (9 points on each side of the road corridor) were selected at a specified distance from the edge of the mixing zone width (road width + 3 m on each side of the corridor) i.e. 1 m, 5m, 10m, 20m, 30m, 50m, 75m, 100m and 150m from the edge of the road on both the side. The predicted CO Concentrations at all 18 receptor points in year 2015 is given below in **Table 4.30**.

Table 4.30: Predicted CO Concentrations, Year 2015

LHS (m)									MIXING ZONE	RHS								
-150	**-100**	**-75**	**-50**	**-30**	**-20**	**-10**	**-5**	**-1**		**1**	**5**	**10**	**20**	**30**	**50**	**75**	**100**	**150**
0.57	0.80	0.92	1.26	1.60	2.06	2.64	3.59	4.44		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

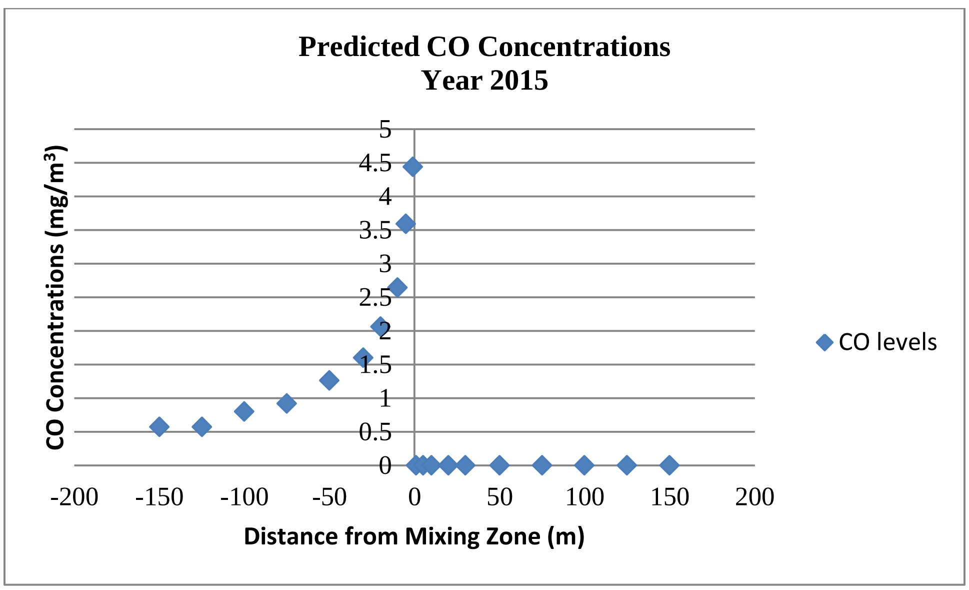


Figure 4.84: Predicted CO Concentration, 2015

4.4 Objective IV: To Carryout Sensitivity Analysis on Predicted Concentrations With Different Combination of Meteorological and Traffic Parameters.

In the CALINE 4 Model various inputs variables (viz., Traffic Volume, Emission Factor, Road Geometry, Wind Speed, Wind Direction, Background Concentration) were used to predict the air pollution concentrations at pre-identified receptor locations along Corridor - I.

Since virtually all input parameters act independently within the model, interaction between two or more variables were presumed to be insignificant. Hence, for sensitivity analysis effect of each input variable was seen by changing one input variable at a time keeping other variable constant.

The sensitivity analysis of the CALINE 4 model was performed to identify the most influential input variable among the various input variables. Sensitivity analysis of CALINE 4 model was done for following input variables:

i. Wind Angle
ii. Wind Speed
iii. Roadway Width
iv. Median Width

The Sensitivity analysis of CALINE 4 model was done for corridor I. Two receptor points on either side (LHS & RHS) of road corridor at a distance of 1 m from the mixing zone were chosen. The site variables/link variables that have been used in sensitivity analysis are given below in **Table 4.31**.

Table 4.31: Site Variables/Link Variables Used in Sensitivity Analysis

Site variables		Link Variables	
Stability Class	4 (D)	Emission Factor	4.8
Mixing Height	550 m		
Surface Roughness	200cm		
Temperature	16^{0}C		
Altitude	235 m		

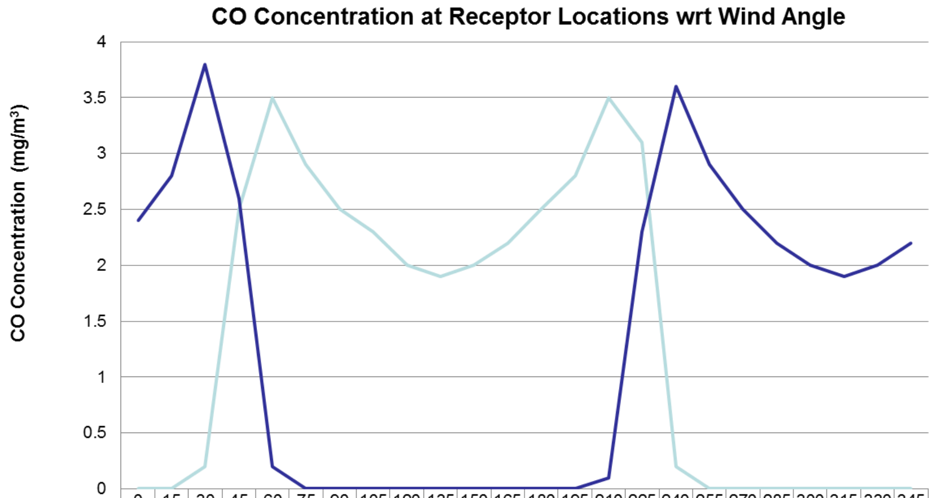
Each input variable has been dealt separately and details are as under:

4.4.1 WIND ANGLE

The wind angle was varied from 0^0 to 360^0 at an interval of 15^0 (viz. 0^0, 15^0, 30^0, 45^0, 60^0, 75^0, 90^0, 105^0, 120^0, 135^0, 150^0, 165^0, 180^0, 195^0, 210^0, 225^0, 240^0, 255^0, 270^0, 285^0, 300^0, 315^0, 330^0, $345^0$and 360^0). CO concentrations obtained at both the receptor points with change in wind angle are shown in **Table 4.32** and **Figure 4.85**.

Table 4.32: CO Concentration at Receptor Points w.r.t. Wind Angles

Wind Angle (Degree)	CO Concentrations (mg/m^3) at Receptors Points (1 m distance from Mixing Zone)	
	LHS	RHS
0	0.0	2.4
15	0.0	2.8
30	0.2	3.8
45	2.5	2.6
60	3.5	0.2
75	2.9	0.0
90	2.5	0.0
105	2.3	0.0
120	2.0	0.0
135	1.9	0.0
150	2.0	0.0
165	2.2	0.0
180	2.5	0.0
195	2.8	0.0
210	3.5	0.1
225	3.1	2.3
240	0.2	3.6
255	0.0	2.9
270	0.0	2.5
285	0.0	2.2
300	0.0	2.0
315	0.0	1.9
330	0.0	2.0
345	0.0	2.2
360 or 0	0.0	2.4



	0	15	30	45	60	75	90	105	120	135	150	165	180	195	210	225	240	255	270	285	300	315	330	345
Receptor LHS at 1m	0	0	0.2	2.5	3.5	2.9	2.5	2.3	2	1.9	2	2.2	2.5	2.8	3.5	3.1	0.2	0	0	0	0	0	0	0
Receptor RHS at 1m	2.4	2.8	3.8	2.6	0.2	0	0	0	0	0	0	0	0	0	0.1	2.3	3.6	2.9	2.5	2.2	2	1.9	2	2.2

Figure 4.85: CO Concentrations at Receptor Locations w.r.t. Wind Angle

CALINE 4 model was found to be very sensitive w.r.t. wind angle. The positioning of the receptor with regards to wind angle plays an important role. When the wind angle was 0^0 it was observed that CO Concentration at receptor on LHS was zero while at the same time CO Concentration at receptor on RHS had a concentration of 2.4 mg/m^3. When the wind angle was changed to 15^0 even then concentration at receptor on LHS remained zero while the CO Concentration on RHS increased to 2.8 mg/m^3. From both the above cases it can be concluded that receptor on RHS was in down wind direction and hence was having positive values for CO Concentrations and the receptor on LHS was on upward wind direction hence concentration was zero.

At wind angle of 45^0 it was observed that CO Concentrations on both LHS & RHS receptors had a positive value of 2.5 mg/m^3 and 2.6 mg/m^3 respectively. This means that wind angle was almost parallel to road corridor and hence had almost similar effect on both receptors. Further it was observed that when the wind angle was increased to 60^0 the CO Concentration on LHS receptor further increased and attained a maximum value of 3.5 gm/m^3, while CO Concentration on RHS receptor slide to 0.2 mg/m^3.This shows that receptor on LHS was coming under down wind direction while the receptor on RHS was coming in upward wind direction.

From the above data it can be concluded that wind angle with respect to receptor is playing an important role. It is observed that when the CO Concentration is maximum on LHS receptor correspondingly the values of the CO Concentration at RHS are minimum and vice versa.

4.4.2 WIND SPEED

In the present study sensitivity analysis was carried out for wind speed, where wind speed was varied from 0.5 m/s to 5.0 m/s. The wind speed was increased by 0.5m/s at each interval. The wind speed for which sensitivity analysis was done are viz. 0.5 m/s, 1.0 m/s, 1.5 m/s, 2.0 m/s, 2.5 m/s, 2.5 m/s, 3.0 m/s, 3.5 m/s, 4.0 m/s, 4.5 m/s and 5.0 m/s. CO concentrations obtained at both the receptor points with change in wind speed are shown in **Table 4.33** and **Figure 4.86**.

Table 4.33: CO Concentration at Receptor Points w.r.t. Wind Speed

Wind Speed (m/s)	**CO Concentrations (mg/m^3) at Receptor Points (@1 m distance from Mixing Zone)**	
	LHS	**RHS**
0.5	10.6	9.7
1.0	7.3	6.6
1.5	5.5	5.1
2.0	4.5	4.1
2.5	3.7	3.5
3.0	3.2	3.0
3.5	2.8	2.6
4.0	2.5	2.4
4.5	2.2	2.1
5.0	2.0	1.9

CALINE 4 model was found to be very sensitive w.r.t. wind speed. The worst case scenario was considered while carrying out the sensitivity analysis. When the wind speed was low 0.5m/s it was observed that CO Concentration at both the receptor points was very high. CO Concentration was 10.6 mg/m^3 at receptor on LHS of the road corridor and CO concentration was 9.7 mg/m^3 at receptor on RHS of the road corridor. When the wind speed was increased to 1.0 m/s it was observed that there was drastic reduction in CO Concentration level at both the receptor points. CO Concentration level at both the receptor points reduced by over 3 mg/m^3 and was observed at 7.3 mg/m^3 and 6.6 mg/m^3 on LHS & RHS of the road corridor.

The reducing trends in CO Concentration were recorded with the increase in wind speed. It was observed that when the wind speed was 5.0 m/s the CO Concentration at both the receptor points has reduced at as low as 2.0 mg/m^3 and 1.9 mg/m^3 on LHS & RHS of the road corridor respectively.

From the above results it can be deduced that as the wind speed is increasing the CO Concentration levels are also reducing. The rate of reduction in CO Concentration levels was higher when wind speed was increased from 0.5 m/s to 1.5 m/s. The CO Concentration levels reduced to fifty percent from 10 mg/m^3 to 5.0mg/m^3. There after the reduction in CO Concentration level was gradual with increase in wind speed.

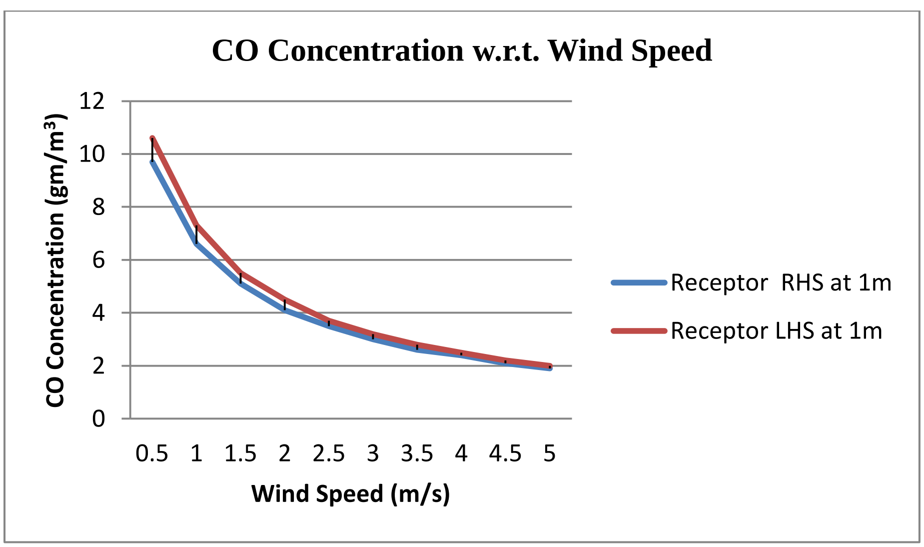


Figure 4.86: CO Concentration w.r.t. Wind Speed

4.4.3 ROADWAY WIDTH

The present road corridor is 6 lane divided carriageway and has a road width of 21 m (10.5 m on LHS and 10.5 m on RHS). For sensitivity analysis, highway width was varied to 8 lane (28m), 10 lane (35m) and 12 lane (42 m) carriageway width configurations. The present road corridor has a median width of 5 m. Predicted CO concentrations obtained have been shown in **Table 4.34** and **Figure 4.87**. CALINE 4 model was run under standard conditions and it was observed that CO Concentration at receptor point on LHS of road corridor observed a value of 2.1 mg/m^3, while the receptor point on RHS of road corridor observed a value of 0.0 mg/m^3. This shows that under the standard run conditions the maximum influence was on LHS of the road corridor.

Table 4.34: CO Concentration at Receptor Points w.r.t. Highway Width

Road Width (m)	Road Lane	CO Concentrations (mg/m^3) at Receptor Points @1 m distance from Mixing Zone)	
		LHS	RHS
21	6	2.1	0
28	8	2.0	0
35	10	2.0	0
42	12	1.9	0

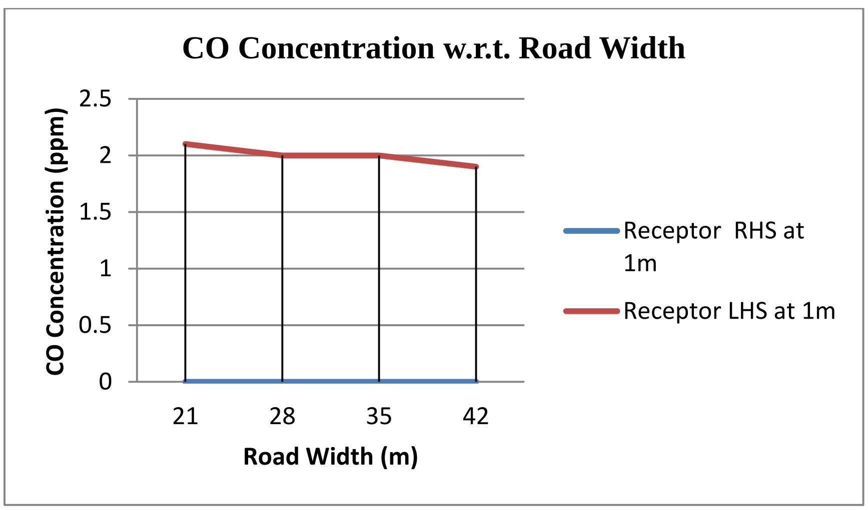


Figure 4.87: CO Concentration w.r.t. Road Width

When the road width was increased to 28m there was a negligible effect on the CO Concentration where the values of CO Concentration dropped to 2.0 mg/m^3 on LHS of the road corridor and value at receptor point on RHS remained 0.0 mg/m^3.

Further when the road width was increased to 35m and 42m, it was observed that there was negligible effect on CO Concentration. The corresponding values of CO Concentration at receptor point on LHS were 2.0 mg/m^3 and 1.9 mg/m^3 respectively while the values of CO Concentration at receptor point on RHS remained 0.0 mg/m^3 at both road width.

4.4.4 MEDIAN WIDTH

Because of the link capabilities of CALINE 4, it is no longer necessary to incorporate median as part of the mixing zone. A divided roadway may be modeled as either two separate links or a single link with the median incorporated in the highway width specification (this assumes identical link specifications for both direction of flow). For cases where there is a significant median involved, the two link computation gives slightly higher predicted concentrations over the single link model. This holds true for virtually all wind angles, but tends to be slightly more pronounced for crosswind conditions (Benson, 1979). For the present study since the median width is 5 m hence, single link has been considered.

For sensitivity analysis, median width was varied from 1m to 5m at an interval of 1m (viz. 1m, 2m, 3m, 4m and 5m). Predicted CO concentrations obtained have been shown in **Table 4.35** and **Figure 4.88**.

Table 4.35: CO Concentration at Receptor Points w.r.t. Median Width

Median width (m)	CO Concentrations (mg/m^3) at Receptor Points @1 m distance from Mixing Zone)	
	LHS	RHS
1	2.1	0
2	2.1	0
3	2.1	0
4	2.1	0
5	2.1	0

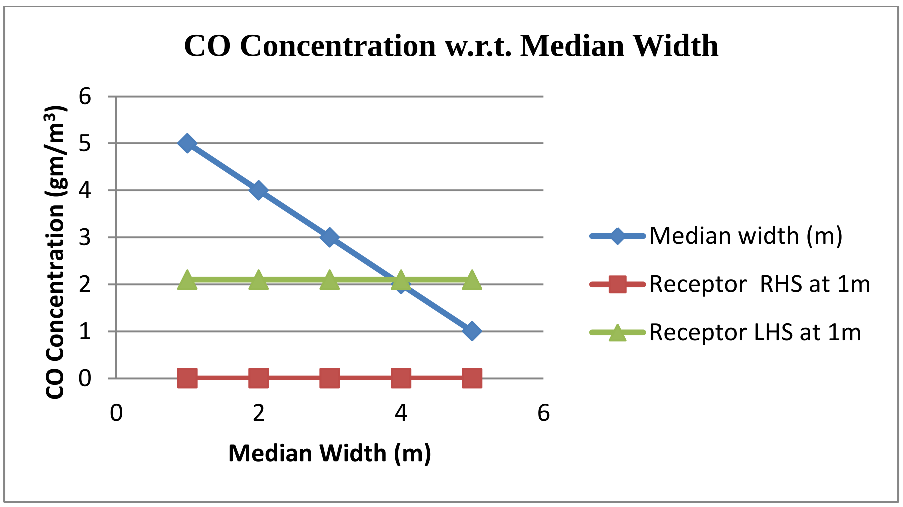


Figure 4.88: CO Concentration w.r.t. Median Width

CALINE 4 model was less sensitive to median width. It was see that with increase in median width, there was no change in CO Concentration levels at both the receptor points. The CO Concentration at receptor on LHS of the road showed a value of 2.1mg/m^3, while the receptor on RHS of the road showed a value of 0.0mg/m^3. Hence, it can be deduced that median width up to 5 m has no effect on CO Concentration.

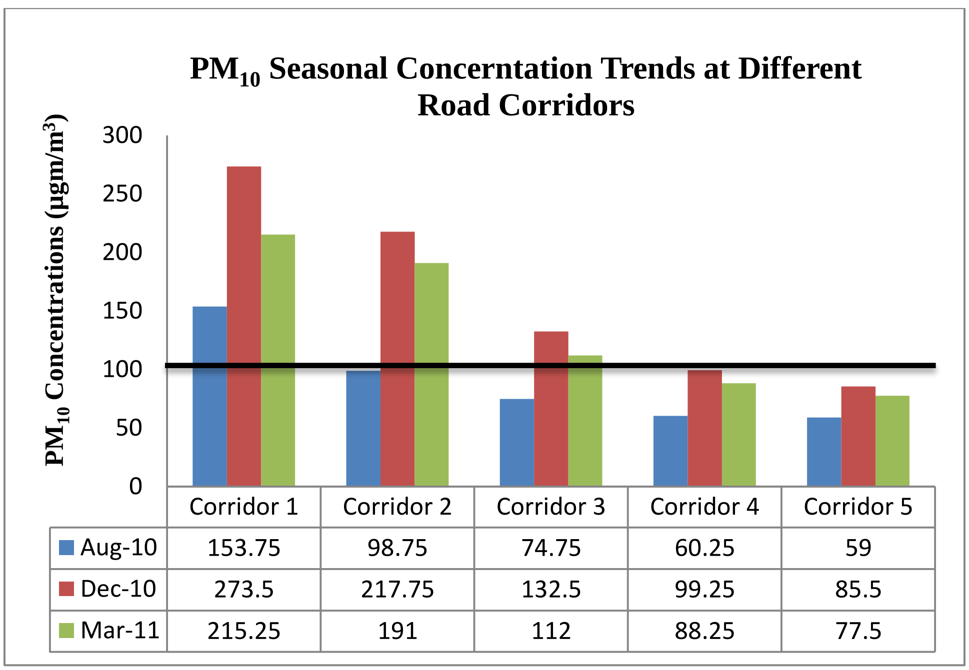
4.4.5 SUMMARY OF RESULTS

The sensitivity analysis using CALINE 4 model was done for various inputs variables (viz., Wind Angle, Wind Speed, Roadway Width and Median Width).

The results of sensitivity analysis revealed that Wind Angle, Wind Speed and Road width are significant input variables while Median Width was less significant input variable.

4.5 Objective V: To Suggest Remedial Measures by Preparing Environmental Management Plan

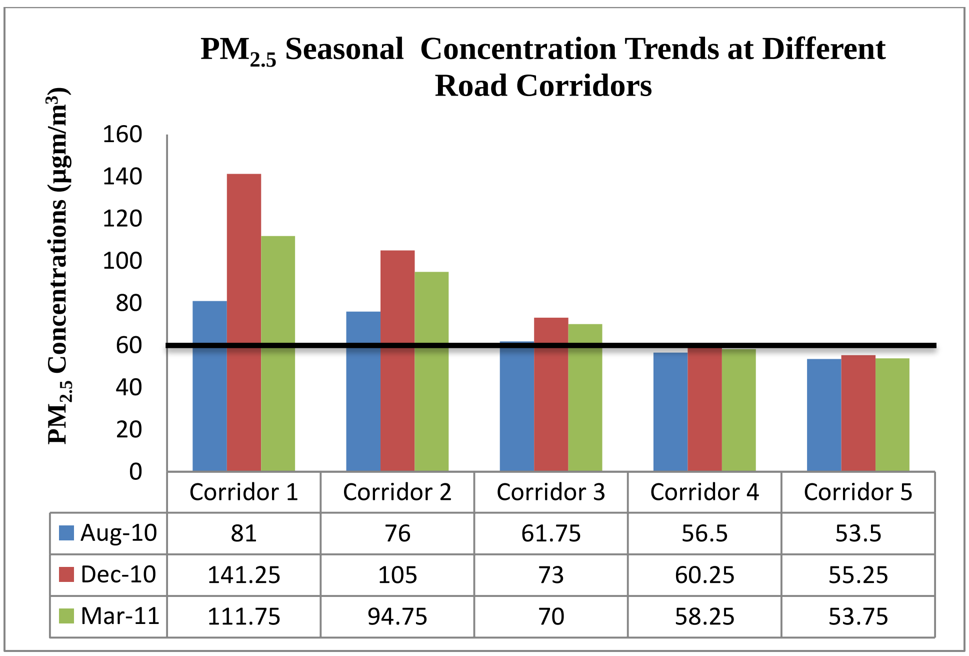
The monitored PM_{10} data during 3 seasons at all the 5 road corridors is shown below in **Figure 4.89**. At corridor 1 the average PM_{10} concentration is ranging from is from ~ 154 – 274 µgm/m^3. At corridor 2 the average PM_{10} concentration is ranging from is from ~ 99 – 218 µgm/m^3. At corridor 3 the average PM_{10} concentration is ranging from is from ~ 75 – 133 µgm/m^3. At corridor 4 the average PM_{10} concentration is ranging from is from ~ 60 – 99 µgm/m^3. While at corridor 5 the average PM_{10} concentration is ranging from is from ~ 59 – 86 µgm/m^3.When the monitored results were compared with National Ambient Air Quality Standard for PM_{10} (i.e.100 µgm/m^3) it was found that the monitored results were exceeding the standard limits at corridor 1, corridor 2 and corridor 3.



	Corridor 1	Corridor 2	Corridor 3	Corridor 4	Corridor 5
Aug-10	153.75	98.75	74.75	60.25	59
Dec-10	273.5	217.75	132.5	99.25	85.5
Mar-11	215.25	191	112	88.25	77.5

Figure 4.89: PM_{10} Seasonal Concentration Trends

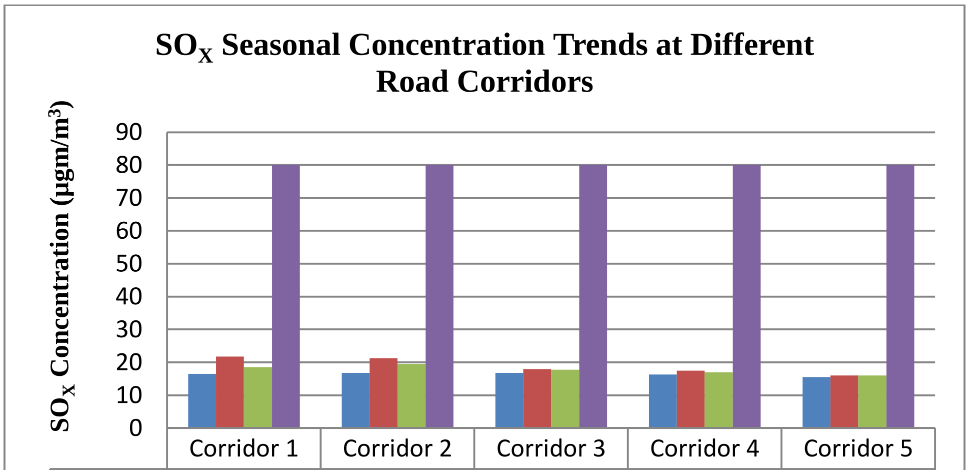
The monitored $PM_{2.5}$ data during 3 seasons at all the 5 road corridors is shown below in **Figure 4.90**. At corridor 1 the average $PM_{2.5}$ concentration is ranging from is from ~ 81 – 141 µgm/m^3. At corridor 2 the average $PM_{2.5}$ concentration is ranging from is from ~ 76 – 105 µgm/m^3. At corridor 3 the average $PM_{2.5}$ concentration is ranging from is from ~ 62 – 73 µgm/m^3. At corridor 4 the average $PM_{2.5}$ concentration is ranging from is from ~ 57 – 60 µgm/m^3. While at corridor 5 the average $PM_{2.5}$ concentration is ranging from is from ~ 54 – 55 µgm/m^3.When the monitored results were compared with National Ambient Air Quality Standard for $PM_{2.5}$ (i.e.60 µgm/m^3) it was found that the monitored results were exceeding the standard limits at corridor 1, corridor 2, corridor 3 and corridor 4.



	Corridor 1	Corridor 2	Corridor 3	Corridor 4	Corridor 5
Aug-10	81	76	61.75	56.5	53.5
Dec-10	141.25	105	73	60.25	55.25
Mar-11	111.75	94.75	70	58.25	53.75

Figure 4.90: $PM_{2.5}$ Seasonal Concentration Trends

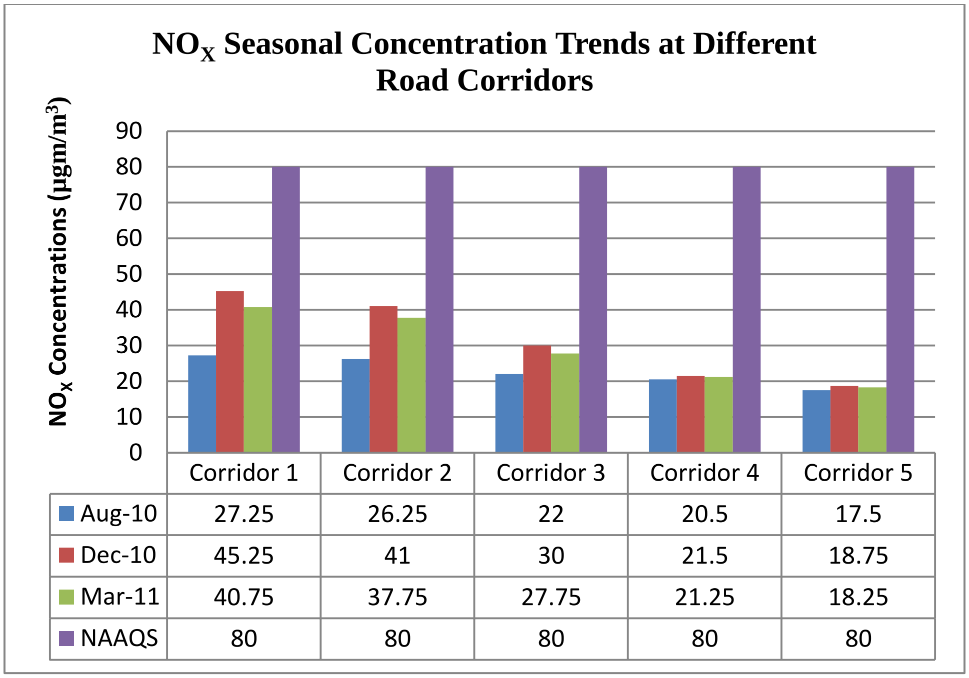
The monitored SO_X data during 3 seasons at all the 5 road corridors is shown below in **Figure 4.91**. At corridor 1 the average SO_X concentration is ranging from is from ~ 17 – 22 µgm/m^3. At corridor 2 the average SO_X concentration is ranging from is from ~ 17 – 21 µgm/m^3. At corridor 3 the average SO_X concentration is ranging from is from ~ 17 – 18 µgm/m^3. At corridor 4 the average SO_X concentration is ranging from is from ~ 16 – 18 µgm/m^3. While at corridor 5 the average SO_X concentration is ranging from is from ~ 15 – 16 µgm/m^3.When the monitored results were compared with National Ambient Air Quality Standard for SO_X (i.e.80 µgm/m^3) it was found that the monitored results were far below the standards at all 5 road corridors.



	Corridor 1	Corridor 2	Corridor 3	Corridor 4	Corridor 5
Aug-10	16.5	16.75	16.75	16.25	15.5
Dec-10	21.75	21.25	18	17.5	16
Mar-11	18.5	19.5	17.75	17	16
NAAQS	80	80	80	80	80

Figure 4.91: SO_X Seasonal Concentration Trends

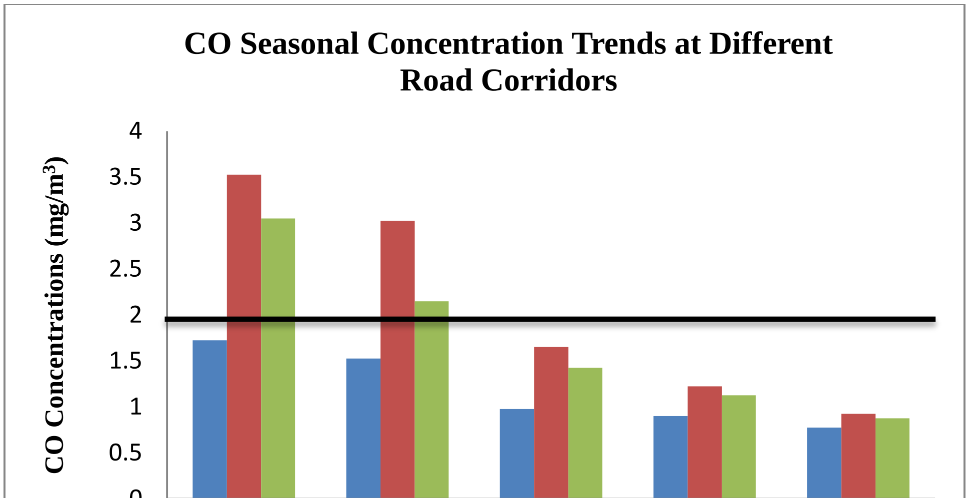
The monitored NO_X data during 3 seasons at all the 5 road corridors is shown below in **Figure 4.92**. At corridor 1 the average NO_X concentration is ranging from is from ~ 27 – 45 µgm/m^3. At corridor 2 the average NO_X concentration is ranging from is from ~ 26 – 41 µgm/m^3. At corridor 3 the average NO_X concentration is ranging from is from ~ 22 – 30 µgm/m^3. At corridor 4 the average NO_X concentration is ranging from is from ~ 20 – 22 µgm/m^3. While at corridor 5 the average NO_X concentration is ranging from is from ~ 17 – 19 µgm/m^3.When the monitored results were compared with National Ambient Air Quality Standard for NO_X (i.e.80 µgm/m^3) it was found that the monitored results were far below the standards at all 5 road corridors.



	Corridor 1	Corridor 2	Corridor 3	Corridor 4	Corridor 5
Aug-10	27.25	26.25	22	20.5	17.5
Dec-10	45.25	41	30	21.5	18.75
Mar-11	40.75	37.75	27.75	21.25	18.25
NAAQS	80	80	80	80	80

Figure 4.92: NO_X Seasonal Concentration Trends

The monitored CO data during 3 seasons at all the 5 road corridors is shown below in Figure 4.93. At corridor 1 the average CO concentration is ranging from is from ~ 1.7 – 3.5 mg/m^3. At corridor 2 the average CO concentration is ranging from is from ~ 1.5 – 3.0 mg/m^3. At corridor 3 the average CO concentration is ranging from is from ~ 0.9 – 1.6 mg/m^3. At corridor 4 the average CO concentration is ranging from is from ~ 0.9 – 1.2 mg/m^3. While at corridor 5 the average CO concentration is ranging from is from ~ 0.8 – 0.9 mg/m^3.When the monitored results were compared with National Ambient Air Quality Standard for CO (i.e. 2 mg/m^3) it was found that the monitored results were exceeding the standard limits at corridor 1 and corridor 2.



	Corridor 1	Corridor 2	Corridor 3	Corridor 4	Corridor 5
Aug-10	1.725	1.525	0.975	0.9	0.775
Dec-10	3.525	3.025	1.65	1.225	0.925
Mar-11	3.05	2.15	1.425	1.125	0.875

Figure 4.93: CO Seasonal Concentration Trends

In order to prepare an Environmental Management Plan it was necessary to identify the probable cumulative impacts due to different air pollutants on all the road corridors. To study the cumulative effect of concentration of individual pollutants in ambient air a single value was required and was expressed through Air Quality Index. The probable risks in terms of Air Quality Index (AQI) for all 5 road corridors were calculated using excel based AQI Calculator for Delhi (SIM air working paper No. 34).

An air quality index (AQI) is defined as a numerical rating that reflects the composite influence on overall quality of a number of air quality parameters which will be helpful not only for public awareness but also for urban planning. The AQI focuses on health effects we may experience after breathing polluted air. The AQI varies from 0 to 500 and its health indicators are mentioned in **Table 4.36**.

Table 4.36: AQI Values and Corresponding Air Quality Conditions

S. No.	AQI value (when the AQI value is in this range)	Level of health concern (air quality conditions)
1	0 - 50	Good
2	51 - 100	Moderate
3	101 - 150	Unhealthy for sensitive group
4	151 – 200	Unhealthy
5	201 - 300	Very Unhealthy
6	301 - 500	Hazardous

The higher the AQI value, the greater the level of air pollution and the greater are the health concerns. An AQI value of 100 generally corresponds to the national air quality standard, which is the level set to protect public health in India. AQI values below 100 are generally considered satisfactory. When AQI values are above 100, air quality is considered to be unhealthy for certain sensitive groups of people, then for everyone for higher AQI values. The average AQI over different road corridors in Gurgaon during 2010 - 2011 is shown below in **Table 4.37**.

Table 4.37: Air Quality Index in Gurgaon (2010 - 2011)

Road Corridor	August 2010	December 2010	March 2011
1	133	177	154
2	115	153	143
3	102	122	116
4	93	106	102
5	90	98	95

At road corridor 1, AQI values varied from 133 to 177, while at road corridor 2 AQI values varied from 115 to 177 and at road corridor 3 AQI values varied from 102 to 122. AQI values at road corridor 4 varied from 93 to 106, while AQI value at road corridor 5 varied from 90 to 98.

High AQI values were estimated at road corridor 1, corridor 2, and corridor 3 where values were over 100 during all the three seasons. Low AQI values were estimated at road corridor 4 and corridor 5, where the values were around 100 or less. The AQI range and corresponding air quality conditions for all 5 road corridor s are shown below in **Table 4.38**.

Table 4.38: AQI Range and Air Quality Conditions at All 5 Road Corridors

Road Corridor	AQI value range	Level of health concern (air quality conditions)
1	133 – 177	Unhealthy
2	115 - 150	Unhealthy for sensitive group
	151 – 153	Unhealthy
3	102 - 122	Unhealthy for sensitive group
4	93 - 100	Moderate
	101 - 106	Unhealthy for sensitive group
5	90 - 98	Moderate

The above data reveals that air quality at road corridor 1 & 2 is unhealthy, while air quality at road corridor 3 is unhealthy for sensitive group. Road corridor 4 & 5 has moderate air quality levels.

The highest AQI values were observed in the winter season and this can be attributed to the meteorological conditions, during this season which has less general circulation and more stagnant air masses. Lowest AQI values were noted in the monsoon season. In this season due to precipitation and high wind velocity changes in the general wind direction also a major reason for low AQI. The precipitation helps in wet deposition of pollutants. The changes in wind velocity and reversal of its direction carry the pollutants away from sources as well as increase the possibilities of dilution of concentration of pollutants also.

Since the air pollution levels are exceeding the National Ambient Air Quality Standards at road corridor 1, 2 and 3 and also the corresponding AQI levels at road corridors 1, 2 and 3 are showing unhealthy air pollution levels hence an Environmental Management Plan with site specific remedial measures has been suggested for these road corridors. In addition to this a general remedial measures are also suggested which can be implemented on all the 5 road corridors and on other urban roads of Gurgaon.

4.5.1 SPECIFIC REMEDIAL MEASURES

4.5.1.1 Establishment of Air Quality Monitoring Plan

Since the air quality levels with regards to PM_{10}, $PM_{2.5}$ & CO at road corridor 1, 2 and 3 is exceeding the National Ambient Air Quality Standards, hence it is suggested that a regular monitoring of air quality should be undertaken by district administration at these road corridors. As a part of Environmental Management Plan an Air Quality Monitoring Plan is suggested and is given below in **Table 3.39**.

Table 3.39: Air Quality Monitoring Plan

	Road Corridor 1	**Road Corridor 2**	**Road Corridor 3**
Parameter to be Monitored	$PM_{10,}$ $PM_{2.5}$, CO	$PM_{10,}$ $PM_{2.5}$, CO	$PM_{10,}$ $PM_{2.5}$, CO
Applicable Standards	NAAQS, 2009	NAAQS, 2009	NAAQS, 2009
Frequency of Monitoring	Twice a year. Once during Summers Once during Winters	Twice a year. Once during Summers Once during Winters	Twice a year. Once during Summers Once during Winters
Duration	24 hours Sampling	24 hours Sampling	24 hours Sampling
Implementation Agency	District Administration / Haryana State Pollution Control Board through NABL approved monitoring agencies.		
Supervision Agency	Haryana State Pollution Control Board, Gurgaon		

4.5.1.2 Restriction of Heavy Vehicles Movement in Urban Areas

Road corridor 1 and road corridor 2 are important National Highways while road corridor 3 is also an important State Highway, hence there is large movement of heavy vehicles on all three roads. It is seen especially during night time that movement of heavy vehicles increases many fold on these roads as a result the air pollution levels are also higher on these corridors. It is suggested that an alternate corridors should be identified/built for safe movement of these heavy vehicles. It is suggested that entry of Heavy vehicles within urban limits of Gurgaon town should be strictly prohibited.

4.5.1.3 Introduction of air quality index

At present there is no system to tackle air pollution quality in the town. It is proposed that government should prepare a uniform air quality index as part of measures to address the menace of air pollution not only for Gurgaon town but also for other major towns across the country.

A uniform national air quality index should be prepared that would be easily understandable by a common man as against the present regime of measuring air quality, which gives values that are difficult for a common person to grasp.

The air quality index prepared should help the authorities in ranking of road corridors within the city on the basis of air pollution. The index will serve as a blueprint for the government in chalking out measures to curb air pollution on such road corridors and also enable to draft their own policies.

4.5.2 GENERAL REMEDIAL MEASURES

Urban air quality, land use pattern and transportation systems are interlinked thus planning of air quality management, transportation and landuse should be coordinated to develop a set of integrated strategies to reduce emissions from motor vehicles. While vehicle related measures such as the use of clean fuels and fuel efficient, clean vehicles can reduce emissions from vehicles, there is also a need to discourage car use through measures related to land-use and traffic management.

In the development of strategies to deal with urban air quality issues, local traffic management can be used to reduce vehicle emissions. Traffic management measures include computerized traffic light control, network and junction design, parking controls, reducing the supply of space allocated to car parks, speed limits, restricted access for non-essential traffic, bus priority lanes, pedestrian areas and cycling facilities. These measures not only reduce energy use but also provide an environment, which is more people-friendly. Some of the measures, which can be implemented, are discussed below:

4.5.2.1 Public Transport

In cities across the world, the major emphasis has been on controlling vehicular pollution, has been shift from private modes of transport to public modes of transport. The promotion of rail, buses, walking and cycling can reduce the use of the motor vehicle in the city. The cost and quality of public transport are important factors then may influence its use. The maintenance of the bus fleet is important so they do not add to existing air quality problems.

Mass Transport system in Gurgaon is inadequate. Intra-urban mass transport system is almost negligible. The result is that personalized mode of transport is used heavily which is creating congested conditions on roads. The share of mass transport needs to be increased substantially by way of augmenting mass transport infrastructure, not only for intra-urban but also with Delhi and other urban areas.

At present only Delhi – Gurgaon Metro line is operational for last 3 years which runs along Mehrauli - Gurgaon road. This line needs to be extended in second phase to cover new developing areas along Sohna Road. Airport Metro line should also be extended along NH-8 till Manesar. This will result in lesser use of personalized mode of transport and will eventually reduce air pollution. Rapid Rail Transit System (RRTS) has recently started which is expected to ease traffic congestion problems along DLF cyber city (a major corporate hub).There is an immediate requirement to plan for new corridors for Light Rail Transit and Bus Rapid Transit. Also there is a need to integrate Metro and RRTS system.

Bus will play an important role in the mass transport system in Gurgaon. Therefore, various facilities for bus transport such as bus terminals, properly designed bus stops, exclusive busways / bus lanes etc. are need of the hour. The bus system needs to be properly integrated with other transport system.

4.5.2.2 Traffic Management

Smoothing traffic flow and reducing speed, banning or restricting traffic, or particular types of vehicle, from some roads; making use of public transport more attractive; and working with business and the public to raise the awareness of the implications of transport choices.

4.5.2.3 Traffic Segregation

Segregation of motorized and non-motorized vehicles and differentiation of routes have been beneficial in reduction of congestion. The segregation of vehicles moving at different speeds would help improve traffic flow, increase the average speed of traffic and reduce emissions resulting from sub-optimal speeds. Cities like Delhi has witnessed steady decline in non-motorized trips (17% in 1981 to 7% in 1994). This has been primarily attributed to the greater risk of accidents as the non-motorized mode share a common Right of Way with other motorized modes of transport.

Apart from improving safety by segregation vehicular type the National Urban Transport Policy recommends creating facilities like shade giving landscaping, provision of drinking water and resting stations along bicycle corridors to mitigate, to a large extent, adverse weather conditions. Innovatively designed road crossing should be considered for developing the cycle tracks.

4.5.2.4 Traffic Control System

Where signals control junctions, a traffic control system, which responds automatically to changing conditions, can give better traffic flow than uncoordinated signals. However, before improving the traffic flow, road authorities should consider what to do with the road capacity they will release and should consider re-distributing it in favour of buses, cyclists and pedestrians. The intersection between NH-8 and Mehrauli – Gurgaon road is a very congested junction because of very high traffic volume. This junction should be made signal free by providing clover leafs and underpasses so that traffic can move uninterrupted.

4.5.2.5 Pedestrian/ Vehicle Restricted areas

Restricting access to town centers can improve the local environment. Pedestrian areas can maintain or improve local economic activity. However, people must be able to reach the area by other means. These could include: good public transport; facilities for cyclists and pedestrians; peripheral car parking; access for people with limited mobility; and access for taxis, where appropriate.

4.5.2.6 Congestion Charging

The scheme has been used in control of traffic in London and Singapore. Singapore's vehicle control is done through electronic road pricing (ERP). Since 1998, an electronic cordon has been placed around the most congested portion of the city, a 720 hectare 'restricted zone' (RZ). All vehicles (excluding emergency vehicles) entering the RZ between 7.30 am and 7 pm on weekdays pay a fee. This was used as a model for London's congestion charge. A similar model based on Indian conditions can also be developed.

4.5.2.7 Land use Planning

An integrated land use and transportation plan can govern the pattern and modal choice of travel by the residents within the city, and thus can reduce reliance on the car. Through appropriate planning, new growth within the urban region can be directed towards designated areas that have high residential and employment density and a good choice of transit service.

Land use planning can be used to promote compact communities of mixed uses that would increase accessibility of various amenities to its residents, and thus would reduce the need for single-occupant vehicle trips for daily activities.

Also, it is very important to enforce designated land use as per master plan as traffic infrastructure is developed in accordance with the land use. In modern city like Gurgaon, enforcement of land use planning has been poor resulting in mixing of different land uses, especially commercial with residential land use, resulting in stress on infrastructure. Traffic congestion arising due to such situations is a major reason for deteriorating air quality along transport corridors.

In Gurgaon, Sectors 28 and 28 A along the Mehrauli Gurgaon Road has been designated under residential land use. However, it is observed that land along this road have been used for commercial development, resulting in high traffic volumes and congestions. Strict enforcement of land use thus would be essential for controlling vehicular pollution. It is thus recommended to maintain status quo and freeze further commercial development in Sectors 28, and 28A. Commercial development should only be allowed in sectors so designated.

There is a need to integrate land-use and transport planning within local air quality management strategies in order to improve air quality and change travel behavior. The provision of infrastructure in the past has shown it exacerbates rather than solves the problem. New roads can generate more new traffic.

4.5.2.8 Cleaner Vehicles

a) New Vehicles

Significant advancement in vehicle technology has been made during the past three decades to make vehicles more energy efficient and cleaner burning. Today's vehicles emit considerably less air pollutants than those of past years. For example, on a gram per kilometer travel basis, today's motor vehicles can generate 90 to 98% less carbon monoxide, hydrocarbons and nitrogen oxides than those manufactured in the 1960s. Vehicles are also designed to be more fuel efficient, i.e. less fuel is burned to travel a unit distance and thus generate less air pollution.

In Gurgaon, Euro III equivalent emission norms for all new private vehicles, city public service vehicles and city commercial vehicles has been implemented from April 2005. Further to this, as per the Government of India Policy, Euro IV equivalent emission standard for all new four wheeled vehicles has been implemented from April 2010. For 2/3 wheelers, Bharat Stage-II norms were applicable from April 2005 and Euro-III norms come in force from April 2010.

b) Vehicle Emission Inspection and Maintenance

Motor vehicles are manufactured to meet certain emission standards during their use over the vehicle warranty period. Proper maintenance of vehicles is necessary to ensure emission levels remain below those standards. However, as a vehicle is used, its emission characteristics gradually deteriorate, even when it is properly maintained. In a typical urban vehicle fleet, older vehicles generate disproportionately more air pollutants than the newer vehicles. A poorly maintained older vehicle can emit one hundred times more pollutants than a properly cared for modern vehicle. Therefore, implementation of an appropriate vehicle emission inspection and maintenance program is an effective measure to ensure efficient operation of vehicles.

c) Old Vehicle Scrapping

In order to reduce the number of old polluting vehicles in the urban fleet, a vehicle-scrapping program could be introduced specifically for the 3-wheelers, taxis and public vehicles. Under such a program, the owners of old vehicles could be given an incentive, either as money or public transit pass, in exchange for giving up the vehicle for scrapping by the agency responsible.

The reusable parts from a scrapped vehicle should be recycled, and the rest should be disposed of as waste.

d) Cleaner Fuel

Petrol and diesel oil have long been the primary transportation fuels, and they will continue to be so throughout India. In recent years, considerable improvement in petroleum refining techniques has been made to produce fuels much cleaner than before. Unleaded and reformulated gasoline of less volatile types with reduced sulphur and toxic constituents are commercially available; and so is low-sulphur diesel fuel. Clean fuels are necessary to operate the new low-emission vehicles properly. The National Urban Transport policy also lays stress on use of clean fuels in urban transport.

Successful conversion of public transport to CNG has significantly reduced air pollution problems in Delhi. Presently Gurgaon has only 4 CNG stations which are not able to fulfill the need of city. There is a huge demand of CNG in Gurgaon city which needs to properly assess and more CNG stations should be setup. Electric operated vehicles can be considered for operation in limited area. Appropriate techniques for conversion of older vehicles to run on alternative fuels are also available.

4.5.2.9 Avenue Plantation

The road side plantation acts as a carbon sink. The road side plantation along M.G. Road and Sohna road is almost absent. Also at various locations along NH 8 the tree planation cover is missing. Concerned authorities should plan to plant more trees along these roads so that maximum pollutants can either be filtered or absorbed near the source.

CHAPTER -5

CONCLUSION AND FINDINGS

5.1 CONCLUSION AND FINDINGS

The baseline traffic and transport scenario was established to understand the impact on ambient air quality at selected 5 road corridors within Gurgaon city. The corridor 1 is 6-lane road and has a capacity of handling about 1.2 lakhs passenger car units (PCU) per day, while at present the corridor is handling over 2.5 lakhs PCUs. Similarly corridor 2 is 4-lane road and has a capacity of handling about 0.4 lakhs PCUs, while at present the corridor is handling over 1.0 lakhs PCUs. Simultaneously it was also observed that pollutants PM_{10}, $PM_{2.5}$ and CO concentrations when compared with National Ambient Air Quality Standards of CPCB were also found to be above permissible limits both in corridor 1 & corridor 2. The percentage proportion of buses is very less (less than 3%) in all the 5 road corridors which shows inadequate public transport facility in the city. On the other hand, the percentage proportion of car/jeeps and 2 wheelers is very high (over 70%) which, shows more use of personalized vehicle in absence of adequate public transport system. According to the results of seasonal variation in ambient air quality, high concentration of air pollutant was recorded in the winter seasons due to low temperature and low wind speed. This may be due to the stable atmospheric conditions leading to accumulation of pollutants in the area.

To establish the relation between air pollutants and total vehicles a correlation and regression analysis was undertaken between various air pollutants and total vehicles for all 5 road corridors. Linear regression models developed in the study have been scrutinized using R^2 values. The R^2 values were found supporting the hypothesis that there is a significant relationship between total traffic volume and level of air pollutants. The R^2 values reported moderately high to very high values ranging from 0.6 to 0.99 for various pollutants.

To establish the relationship between meteorological parameters and air pollutant concentration the data collected for PM, SO_X, NO_X and CO was statistically compared with meteorological variables such as relative humidity, temperature and wind speed. The correlation analysis established a moderately high relationship between air pollutant concentration and wind speed, a moderate relationship between relative humidity and a weak relationship is seen between air pollutant and temperature.

The concentration of CO was predicted for corridor 1 where two distinct peak concentration levels were observed during the morning and evening time. The morning time peak was recorded between 9 am to 10 am. The evening time peak was recorded between 7 pm to 8 pm. The maximum predicted concentration of CO for year 2015 at 1 m distance from the mixing zone was 4.44 mg/m^3 on Left side of the road. The predicted CO concentration when compared with NAAQS was found to be exceeding the limits.

The pollutant concentration decreases drastically to 1/3rd within 50m distance from the mixing zone. After 50m distance, the pollutant concentration decreases gradually to baseline concentration levels.

The sensitivity analysis on predicted concentrations of CO was carried out with different combination of meteorological parameters (wind speed & wind angle) and traffic parameters (road width & median width). The results of sensitivity analysis revealed that Wind Angle, Wind Speed and Road width are significant input variables while Median Width was less significant input variable.

The increasing air pollution from motorized vehicles is the leading cause of deterioration of air quality in Gurgaon. Concentration of PM_{10}, $PM_{2.5}$ & CO at road corridors 1, 2 and 3 are exceeding the National Ambient Air Quality Standards. Also calculated AQI levels at these three road corridors show an unhealthy air quality. Hence an Environmental Management Plan with site specific remedial measures has been suggested for these road corridors. In addition to this a general remedial measures are also suggested which can be implemented on all the 5 road corridors and on other urban roads of Gurgaon.

5.2 SIGNIFICANT FINDINGS OF THE STUDY

The ambient air quality with respect to pollutants - PM_{10}, $PM_{2.5}$ and CO at three road corridors (corridor 1, corridor 2 and corridor 3) is exceeding the National Ambient Air Quality Standards. More over the calculated AQI levels and their corresponding health impacts at road corridor 1 and road corridor 2 shows unhealthy air quality levels and need immediate remediation measures.

5.3 NOVELTY OF RESEARCH

Expansion of urban land use and increase in vehicular traffic population are aggravating the environmental problems in urban areas. The present research work focuses to establish baseline traffic and transport scenario to understand its impact on Ambient Air Quality with seasonal variation within the urban limits of Gurgaon (a satellite town in NCR) which has witnessed a tremendous growth in traffic population in last few years.

Through this study an effort has been made to establish relationship between total vehicles and air pollutants at selected road corridors with different land use pattern. The CO Concentration for next 5 years was predicted using CALINE 4 and sensitivity analysis was performed on predicted concentrations with different combination of meteorological and traffic parameters.

This research will help in understanding the air pollution trends in Satellite towns and has established a baseline data for air quality and traffic volume trends on different road corridors in Gurgaon town and will help in future research studies.

5.4 SCOPE FOR FUTURE WORK

Any research brings new series of research in order to establish facts and reach (new) conclusions. Consequent upon fine-tuning of methodology and need of the new horizon of problems, further investigations may be needed. A preview of further research which may be needed in this area is presented hereunder:

(i) Traffic volume count could also be monitored for inactive hours for the day so as to obtain a real traffic count.

(ii) The traffic volume count should also be conducted at some major Junctions so as to give real time traffic counts about the traffic congestions.

(iii) There is always scope of realistic emission factor for in-use vehicles pertaining to Indian traffic condition (i.e. city specific driving cycle).

(iv) For Sensitivity analysis traffic parameters such as Roadway Height or distance of receptor to roadway can also be considered.

(v) Sensitivity analysis of CALINE 4 for CO concentrations can also be done for worse case condition.

REFERENCES

- Ahmad Kafeel (2013). Physical Simulation of Automobile Exhausts Dispersion at an Urban Intersection – Part II: Traffic Induced Effects. International Journal of Engineering Research and Applications, Vol. 3, Issue 1, January-February 2013, pp.887-890.

- Akyurtlu, A. and Akyurtlu, J. (2012). An Investigation on the Dispersion of Pollutants from Major Roadways Hampton University, Chemical Engineering Department. Proceedings of 1st National Conference on Intermodal Transportation (NCIT): Problems, Practices, and Policies', Organized by Eastern Seaboard Intermodal Transportation Applications Centre (ESITAC) Hampton University, Hampton, Virginia, October 11–12, 2012.

- Anjaneyulu M.V.L.R., Harikrishna M., and Chenchuobulu, S. (2006). Modeling Ambient Carbon Monoxide Pollutant Due to Road Traffic, World Academy of Science, Engineering and Technology, 17, 103-106.

- ARAI (2007). Emission Factor Development for Indian Vehicles. Project Report No. AEF/2006-07/IOCL/Emission Factor Project. Automotive Research Association of India, Pune (available on www.cpcb.nic.in).

- Bansal S. (1996), "Ambient air quality of Bhopal city with reference to nitrogen dioxide". Pollution Research, 15(2); 117-119.

- Benson, P.E. (1984) 'CALINE4: A dispersion model for predicting air pollutant concentrations near roadways'. FHWA-CA-TL-84-15, California Department of Transportation, Sacramento, CA (USA).

- Benson, P. E., Nokes, W. A., Cramer, R. L. (1986). Evolution of the CALINE 4 Line Source Dispersion Model for Complex Terrain Application, Transportation Research Record N1058, 7-13.

- CERC. Robins, A. (2000), Discussion of the Building Modules in ADMS 3 and PRIME, Cambridge Environmental Research Consultant Report.

- Chandrasekaran GE, Ravichandran C, Shetty Neetha. (1997), “Ambient air quality at selected sites in Banglore city”. Indian Journal of Environmental Protection, 17(3); 184-188.

- Cline, W.R. (1991). Scientific basis for the greenhouse effect. Econ. J. 101:904-919.

- CPCB, (2010). Status of the Vehicular Pollution Control Programme in India. Central Pollution Control Board, Ministry of Environment and Forest, New Delhi, Govt. of India.

- CPCB, (2006). “National Air Quality Status 2004. National Ambient Air Quality Monitoring Series NAAQMS/27/2006-2007”.Central Pollution Control Board, Ministry of Environment and Forests, Government of India, New Delhi.

- CPCB, (2003). “Alternative Transport Fuels- An Overview”. Parivesh newsletter, Central Pollution Control Board, Ministry of Environment and Forests, Government of India, New Delhi, April 2003.

- CPCB, (1999). Transportation Fuel Quality for year 2005” Central Pollution Control Board, Ministry of Environment and Forests, Government of India, New Delhi.

- CPCB, (2000a). Transportation Fuel Quality for year 2005. PROBES/78/2000-01, Central Pollution Control Board, Ministry of Environment and Forest, New Delhi, Govt. of India.

- CPCB, (2000b). Air Quality Status and Trends in India. National Ambient Quality Monitoring Series, NAAQMS/14/1999-2000, Central Pollution Control Board, Ministry of Environment and Forest, New Delhi, Govt. of India.

- CRRI (2002). “Urban Road Traffic and Air Pollution (URTRAP) Study”. Technical Report, carried out on the behalf of ‘Mashelkar Committee’. Central Road Research Institute, New Delhi.

- CRRI, (2005). Measurement of Vehicular Pollution at Selected Intersection in Delhi. Central Road Research Institute Report.

- CSE (1996). Slow murder- The Deadly Story of Vehicular Pollution in India. State of the Environment Service, Center for Science and Environment, New Delhi.

- Das DB, Bhargava A, Gupta AB, Gupta K. (1997), Sulphur dioxide, nitrogen dioxide and carbon monoxide concentrations during evening peak traffic hours in Jaipur city. Indian Journal of Environmental Protection, 17(11); 833-840.

- Dayal HV, Nandini SN. (2000), Vehicular emissions and ambient air quality in Bangalore city. Pollution Research, 19(2); 205–209.

- Doreena Dominick, Mohd Talib Latif, Hafizan Juahir, Ahmad Zaharin Aris and Sharifuddin M. Zain (2012), “An assessment of influence of meteorological factors on PM_{10} and NO_2 at selected stations in Malaysia”. Sustain. Environ. Res., 22(5); 305-315.

- Dubey Bhawna, Asim Kumar Pal and Gurdeep Singh (2013). Assessment of Vehicular Pollution in Dhanbad City Using CALINE 4 Model. International Journal of Geology, Earth and Environmental Sciences, 2013 Vol. 3 (1) January-April pp.156-164.

- Elsom, D. M. (1994). The Development of Air Quality Management System in the United Kingdom. In: Baldasano, J. M., Brebbia, C. A., Power, H. and Zannetti, P. (Eds). Air Pollution Control and Monitoring, II, 22-29.

- Eskridge, R. E. and Rao, S. T. (1983). Measurement and prediction of Traffic Induced Turbulence and Velocity Fields Near Roadways. Journal of Applied Meteorology, 22, 1431-1440.

- Eskridge, R. E. and Rao, S. T. (1986). Turbulent diffusion behind vehicles: experimentally determined turbulence mixing parameters. Atmospheric Environment, 20 (5), 851-860.

- Eskridge, R. E. and Thampson, R. S. (1982). Experimental and Theoretical Study in the Wake of a Block Shaped Vehicle in Shear Free Boundary Flow, Atmospheric Environment, 16 (12), 2821- 2836.

- Gadgil AS, Jadhav RS. (2004). Street-level concentrations of suspended particulate matter (SPM), nitrogen dioxide (NO_2) and sulphur dioxide (SO_2) in Pune city. Journal of Environmental Sciences and Engineering, 46(2); 143-150.

- Ganguly, R., Broderick, B. M. and O'Donoghue, R. (2009). Assessment of a General Finite Line Source Model and CALINE 4 for Vehicular Pollution Prediction in Ireland, Environ Model Assess, 14, 113–125.

- Gilbert M. M. (1997). Introduction to Environmental Engineering and Science, Second Edition, Prentice Hall, USA.

- Godish, T. (1985). Air Quality. Lewis Publishers, Inc. Chelsea, USA.

- Goyal SK, Gupta HK, Lohitesh MD, Chalapti Rao CV. (2002). "Effect of seasonal variations on dispersion of air pollutants – a case study". Proceedings National Conference Pollution Prevention Control India: IAEM, 2-3 March Nagpur, 65-69.

- Goyal, S.K. et al. (2006). Understanding urban vehicular pollution problem vis-à-vis ambient air quality – Case study of a Megacity (Delhi, India), Environmental Monitoring and Assessment, 119: 557-569.

- Goyal, P. and Rama Krishna, T.V.B.P.S. (1999). A Line Source Model for Delhi, Transportation Research Part D 4, 241-249.

- Gramotnev, Galina, Brown, Richard J., Ristovski, Zoran, Hitchins, Jane, & Morawska, Lidia (2003). Determination of Average Emission Factors for Vehicles on a Busy Road, Atmospheric Environment, 37(4), 465-474.

- Guttikunda S.(2009) Air Quality Management in Delhi, India: Then, Now, and Next.

- Hanna, S. R. (1982). Review of Atmospheric Diffusion Models for Regulatory Applications, Technical Note No. 177, World Meteorological Organization, Geneva, Switzerland.

- Hayes, S. R. and Moore, G. E. (1985). Air quality model performance: A comparative analysis of 15 model evaluation studies. Systems Applications, Inc., 101 Lucas Valley Road, San Rafael, California 94903, U.S.A.

- IRC (1989). "Environmental Impact Assessment of Highways Projects" (IRC: 104-1989) Indian Roads Congress, New Delhi.

- Jain, Parida M., Rastogi, A., Mittal, N. (2006) 'Performance Evaluation of Air Pollution Models for Delhi City', Journal of Institution of Engineers, Vol. 87(9), pp. 16-26.

- Jayshree J. (2000), "Automobile pollution in Thiruvananthapuram city". Pollution Research, 19(3); 395–397.

- Joshi G., Mishra A. (1998[a]), "The ambient air quality at Indore, Madhya Pradesh". Pollution Research, 17(1) 21-24.

- Joshi G. (1998[b]). "Ambient air quality at roadside of an urban area with special reference to respirable dust and total suspended particulate matter". Pollution Research, 17(1); 798.

- Joshi G., Jain C. (2000). "Suspended particulates in the ambient air at the road sides of Indore city". Pollution Research, 19(3); 365–367.

- Jungers, B. D. et al. (2006). A Survey Of Air Quality Dispersion Models For Project-Level Conformity Analysis, UC Davis-Caltrans Air Quality Project, Air Quality and Conformity Coordination, Division of Transportation Planning, Sacramento, CA.

- Kala, J., Sharma, G., Kumar, S. and Pipralia, S. (2014). Study of Ambient Air Quality Status on Urban Roads using Air Quality Index -A Case of Jaipur City (Rajasthan, India), International Journal of Theoretical & Applied Sciences 6(1): 138-147.

- Kamath and Lokeshappa (2014). Air Quality Indexing For Selected Areas in Bangalore City, Karnataka State, India, International Journal of Innovative Research in Science, Engineering and Technology, Vol. 3, Issue 8, August 2014, 15625-15630.

- Kandlikar, M and Ramachandran, G. (2000) The causes and consequences of particulate air pollution in urban India, The Annual review of Energy and the Environment, 25:629-684.

- Kaushik, S.P., Tyagi, A., Tyagi, P.K. and Tyagi, H. (2013). Air Pollution and its impact on human health in Panipat City of Haryana, India. International Journal of Advanced Research (2013), Volume 1, Issue 8, 450-457.

- Kenty, K. L. et al. (2007). Application of CALINE4 to roadside NO/NO_2 transformation, Elsevier, Atmospheric Environment, 4270-4280.

- Kulandi Samy I, Jeba Rajasekhar RV, Muthu Subramanian P. (2000). “Suspended particulate matter concentration in the ambient air of Madurai city – kerbside urban air quality model prediction”. Indian Journal of Environmental Sciences, 5(1); 57-61.

- Kumar, A., Garg, A. and Pandel, U. (2011). A Study of Ambient Air Quality Status in Jaipur City (Rajasthan, India), Using Air Quality Index, Nature and Science, 2011; 9(6).

- Kyrkilis, G., Chaloulakou, A . and Kassomenos, P.A. (2007). Development of an aggregate Air Quality Index for an urban Mediterranean agglomeration: Relation to potential health effects, Environment International, Vol.33, pp. 670-676.

- Lau, K.M. and Kim, M.K. (2006). Asian Summer Monsoon Anomalies Induced by Aerosol Direct Forcing: The Role of Tibetan Plateau. Clim. Dyn. 26: 855–864.

- Levitina, J., Harkonenb, J., Kukkonenb, J. and Nikmob, J. (2005). Evaluation of the CALINE4 and CAR-FMI models against measurements near a major road, Atmospheric Environment, 39, 4439–4452.

- Lin, J. and Ge, Y (2006). Impacts of traffic heterogeneity on roadside air pollution concentration, Transportation Research Part D 11, 166–170.

- Li, W.F., Bai, Z.P., Liu, A.X., Chen, J. and Chen, L. (2009). Characteristics of Major PM 2.5 Components during Winter in Tianjin, China. Aerosol Air Qual. Res.9: 105–119.

- Li, Z. (2004). In Observations, Theory, and Modelling of the Atmospheric Variability, Zhu, X. (Eds.), Aerosol and Climate: A Perspective from East Asia. World Scientific Pub. Co., p. 501–525.

- Lone PM, Khan AA, Shah SA. (2005). "Study of dust pollution caused by traffic in Aligarh city". Journal of Environmental Sciences and Engineering, 47(1); 33-36.

- Longhurst, J. W. S., Elsom, D. M. and Power, H. (2000). Air Quality Management, WIT Press, Southampton, Boston (USA).

- Lua, K.M., Ramanathan, K., Wu, G.X., Li, Z., Tsay, S,C., Hsu, C., Sikka, R., Holben, B., Lu, D., Tartari, G., Chin, M., Koudelova, P., Chen, H., Ma, Y., Huang, J., Taniguchi, K. and Zhang, R. (2008). The Joint Aerosol Monsoon Experiment-A New Challenge for Monsoon Climate Research. Bull. Am. Meteorol. Soc. 89: 369–383.

- Luhar, A. K. and Patil, R.S. (1989). A General Finite Line Source Model for vehicular pollution prediction, Atmospheric Environment, 23 (3), 555-562.

- Mage, D., Ozolins, G., Peterson, P., Webster, A., Orthofer, R., Vandeweerd, V. and Gwynne, M. (1996). Urban Air Pollution in Mega Cities of the World. Atmos. Environ. 30: 681–696.

- Mahendra SP, Krishnamurthy. (2003). Vehicular air pollution at some intersections in Bangalore city: a case study. Nature Environment Pollution Technology, 2(2); 187-191.

- Majumdar, B. K., Dutta, A., Chakrabarty, S. and Ray, S. (2009) 'Assessment of Vehicular Pollution in Kolkata, India using CALINE4 Model'. Environment Monitoring Assessment, Vol. 70, pp. 33-43.

- Majumdar, B. K., Dutta, A., Chakrabarty S. and Ray, S. (2008). Correction Factors of CALINE 4: A Study of Automobile Pollution in Kolkata, Indian Journal of Air Pollution Control, 8 (1), 1-7.

- Manab, D.; Subodh, M.; Ujjal, M. (2006) Distribution of $PM_{2.5}$ and $PM_{10-2.5}$ in PM_{10} fraction in Ambient Air due to Vehicular Pollution in Kolkata Megacity. Environmental Monitoring & Assessment. Vol. 122 Issue 1-3, p111-123

- Marmur, A. and Mamane, Y. (2003). Comparison and evaluation of several mobile-source and line-source models in Israel, Transportation Research part D, 8, 249-265.

- Meenakshi, P. and Saseetharan, M.K. (2004). Urban Air Pollution Forecasting with Respect to SPM using Time Series Neural Networks Modelling Approach – A Case Study in Coimbatore City. J. Environ. Sci. Eng. 46: 92–101.

- Menon, S., Hansen, J., Nazarenko, L. and Luo, Y. (2002). Climate Effects of Black Carbon Aerosols in China and India. Science 297: 2250–2253.

- Ministry of Road Transport and Highways, Govt. of India, Road Transport Year Book 2010-11.

- MoEF (1988). "Environmental Guidelines for Rail/Road/Highway Project" Ministry of Environment and Forests, Government of India.
- MoEF (2001). "Environment Impact Assessment – A Manual". Ministry of Environment and Forests, Government of India.
- MoEF (2006). "Environment Impact Assessment Notification". Ministry of Environment and Forests, Government of India.
- Mohanty SK. (1999). "Ambient air quality status in Koraput". Indian Journal of Environmental Protection, 19(3); 193-199.
- Mondal R, Sen GK, Chatterjee M, Sen BK, Sen S. (2000). "Ground level concentration of nitrogen oxides (NOx) at some traffic intersection points in Calcutta". Atmospheric Environment, 34(4); 629-633.
- Nagendra, S. M. S. and Khare, M. (2002). Line Source Emission Modelling, Atmospheric Environment, 36, 2083–2098.
- Neimeier D, Eisinger D, Kear T & Jungers B D, (2006). A survey of air quality dispersion models for project-level conformity analysis, UC Davis- Caltrans Air Quality Project, Air Quality and Conformity Coordination, Division of Transportation Planning Sacramento, CA.
- Nirjer R.S, Jain S.S, Parida M, Sharma N, Robert V R & Mittal N. (2002). Development of transport related air pollutants modeling for an urban area. J Indian Roads Congress, 63 (2), 289-326.
- Panda B.K. and Panda C.R. (2012). Estimation of ambient air quality status in Kalinga Nagar industrial complex in the district of Jajpur of Odisha. International Journal of Environmental Sciences Volume 3, No 2, 767-775.
- Pandey V, Kumar A, Pal A, Singh N, Yunus M. (1999). Status of ambient air quality in Lucknow city. Indian Journal of Environmental Protection, 19(3); 181-184.

- Panwar TS, Bhujange Ras DD, Sreakesh S. (1997). Ambient air quality status of various cities in India. Indian Journal of Environmental Protection, 17(11); 841-845.

- Pasquill, F. and Smith, F. B. (1983). Atmospheric Diffusion, 3rd Edition, New York, USA: John Wiley & Sons Inc.

- Ramachandran, S. (2007). Aerosol optical depth and fine mode fraction variations deducted from MODIS over four urban areas in India. J. Geophys. Res. 112; doi:10.1029/2007JD008500.

- Ramanathan, V., Chung, C., Kim, D., Bettge, T., Buja, L., Kiehl, J.T., Washington, W.M., Fu, Q., Sikka, D.R. and Wild, M. (2005). Atmospheric Brown Clouds; Impact on South Asian Climate and Hydrologic Cycle. Proc. Nat. Acad. Sci. U.S.A. 102: 5326–5333.

- Ramamurthy N, Thirumaran M. (2001). The carbon monoxide levels in automobile exhaust – a case study in Chidambaram town. Indian Journal of Environmental Health, 43(4); 144-147.

- Ramanathan, V., Crutzen, P.J., Kiehl, J.T. and Rosenfeld, D. (2001). Atmosphere – Aerosols, Climate, and the Hydrological Cycle. Science 294: 2119–2124.

- Rao, K. S. (2002). Roadway-2: A Model for Pollutant Dispersion near Highways, Water, Air, and Soil Pollution: Focus, 2, 261–277.

- Rao, C.V.C., Chelani, A.B., Phadke, K.M., and Hasan, M.Z. (2002) Formation of an air quality index in India, International Journal of Environmental Studies, Vol.59, pp. 331–342.

- Robet, V. R. (2002). A Study on Transport Related Air Pollution, M. Tech. Dissertation, IIT – Roorkee.

- Rosenfeld, D. (2000). Suppression of Rain and Snow by Urban and Industrial Air Pollution. Science 287: 1793–1796.

- Sachdeva, Y. (2010) "Transportation Planning Issues for Gurgaon Urban Area" Urban Transport Journal, Vol. 9 (1), Pg. 20 – 29.

- Saini RS, Dadhwal PJS, Jaswal S. (1994). "Deteriorating air quality in Chandigarh: a study on levels of suspended particulate matter in the city". Indian Journal of Environmental Protection, 14 (9); 700-702.

- Sarath, G.; Ramani, K.; Prasad, D.; Gertler, A. (2013). Receptor model -based source apportionment of particulate pollution in Hyderabad , India Environmental Monitoring & Assessment. Jul2013, Vol. 185 Issue 7, p5585-5593.

- Sarath K. Guttikunda and Puja Jawahar (2012). Application of SIM-air modeling tools to assess air quality in Indian cities. Atmospheric Environment 62 (2012) 551 – 561.

- Sarin, S. M. Singh, A. Sharma, N. Sharma, K. and Shanmugum, P. (2001). Evaluation of emission characteristics and compliance of emission standards for in-use petrol driven vehicles in Delhi, Indian J Environ Health, 43(1), 1-20.

- Sathe Yogesh, Ayare Atul and Kulkarni Girish (2013). Urban Air Quality Modelling and Simulation: A Case Study of Kolhapur (M.S.), India, ACEE Int. J. on Civil and Environmental Engineering, Vol. 2, No. 1, Aug 2013.

- Satsangi G.P, Kulshrestha A., Taneja A. and Rao P S P (2011). Measurement of PM_{10} and $PM_{2.5}$ aerosols in Agra, a semiarid region of India. Indian Journal of Radio & Space Physis, Vol. 40, August 2011, 203-210.

- Savile, S.B. (1993).Automotive options and air quality management in developing countries. Indust. Envt. 16 (1-2):20-32.

- Senthilnathan T, Srivatsan PS, Rao Anusha S, Bhaskaran A, Rajan RD. (2002). "Analysis of ambient air pollutants in Chennai during the year". Proceedings National Conference Pollution Prevention Control India: IAEM, 2-3 March Nagpur, 71-74.

- Senthilnathan T. (2008). Measurements of Urban Ambient Air Quality of Chennai City. Indian Journal of Air Pollution Control. Vol. No. I March, 35-47.

- Senthilnathan T. (2008). Utilization of Satellite Communication Networks for Urban Ambient Air Forecasting. Journal of Environmental Research and Development Vol. 2 No. 4, April-June, 2008.

- Senthilnathan, T. (2007) Analysis of concentration of Air pollutants and Air Quality Index levels in the ambient air in Chennai city, Journal of Institution of Engineers, Vol.87, pp.3-7.

- Sharma, N, Gulia, S, Dhyani, R, & Singh A. (2013). Performance evaluation of CALINE 4 dispersion model for an urban highway corridor in Delhi. Journal of Scientific & Industrial Research, 72, 521-530.

- Sharma, N., Gangopadhyay, R. and Dhyani, R. (2010). Methodology for Estimation of CO_2 Reduction from Mass Rapid Transit System (MRTS) Project, Journal of Scientific & Industrial Research, 69, 586-593.

- Sharma DK, Satvat PS, Krishna CBM. (2009). Effect of CNG Implementation on Ambient Air Quality: the case of Kanpur City. Proceedings of International Conference on Energy and Environment. Enviro Energy. ISSN 2070-3740, 19-21 March, 103-106.

- Sharma, N., Gangopadhyay, S. and Singh, A. (2008). Environmental Impacts of Road Transport – An Indian Scenario, Indian Highways, January, 2008, 17-29.

- Sharma, N., Chaudhry K.K. and Chalapati Rao C.V. (2004). "Vehicular Pollution Modeling in India". Journal of the Institution of Engineers (India), 85; 46-63.

- Sharma, M., Pandey, R., Maheshwari, M., Sengupta, B., Shukla, B.P., Gupta, N.K., and Johri S. (2003a). Interpretation of air quality data using an air quality index for the city of Kanpur, India, Journal of Environmental Engineering and Science, Vol.2, pp.453-462.

- Sharma, M., Pandey, R., Maheshwari, M., Sengupta, B., Shukla, B.P., and Mishra, A. (2003b). Air quality index and its interpretation for the city of Delhi, Clean Air, International Journal on Energy for a Clean Environment, Vol.4, pp.83–98.

- Sharma, P. and Khare, M. (2001). Modelling of vehicular exhausts-a review, Transportation Research Part D 6(2001), 179-198.

- Sharma, P. and Khare, M. (1999). Application of intervention analysis for assessing the effectiveness of CO pollution control legislation in India, Transportation Research Part D 4(1999), 427-432.

- Shen Z.X., Cao, J.J., Tong, Z., Liu, S.X., Reddy, L.S.S., Han, Y.M., Zhang, T. and Zhou, J. (2009). Chemical Characteristics of Submicron Particles in Winter in Xi'an. Aerosol Air Qual. Res. 9: 80–93.

- Shukla Ankita, Mishra Rajeev Kumar, Parida M. (2010). Estimation of Composite Air Quality Index for Lucknow. Institute of Town Planners, India Journal October - December 2010, 7 - 4, 45 – 56.

- Shukla A.K., Jain S.S., Parida M, Sharma S.P. (2006). Assessment of Traffic Impact on Ambient Air Quality in Lucknow City. Indian Highways Vol.34 No.5, May, 19 – 31.

- Singh, B.K., Singh, R.P., Singh, A.K. and Prashad, S.C. (2006). Deterministic Models for Line Source Emission: A Review, Journal IAEM, 33 (3), 163-167.

- Singh Richa & Sharma Chhemendra (2012). Assessment of emission from transport sector in Delhi. Journal of Scientific and Industrial Research, Vol. 71, February 2012, 155-160.

- Sivacoumar, R. and Thanasekaran, K. (1998). Line source model for vehicular pollution prediction near roadways and model evaluation through statistical analysis, Environmental Pollution, 104, 389-395.

- Small, K.A.; and Kazimi, C. (1995). On the costs of air pollution from motor vehicles. J. Transp. Econ. Policy 29: 7-32.

- Sonawane, N.V., Patil, R.S. And V. Sethi (2012) Health Benefit Modelling and Optimization of Vehicular Pollution Control Strategies. Atmospheric Environment. Volume 60, Page 193 – 201.

- Srinivas DSRK. (1999). Spatial patterns of air pollution in Delhi. Indian Journal of Environmental Protection, 19(3); 172-180.

- Shrivastava R. K., Saxena Neeta and Gautam Geeta (2013). Air Pollution Due to Road Transportation in India: A Review on Assessment and Reduction Strategies. Journal of Environmental Research and Development Vol. 8 No. 1, July-September 2013, 69 -77.

- Srivastava, R.K. and Sarkar, R. (2006). Air Quality Index: A Brief Review. Indian J. Environ. Prot. 26: 344–347.

- Stern, A.C. (1976). Air Pollution. Vol. 1, 3rd edn. Academic Press, New York, USA.

- Stieb, D.M., Doiron, M.S., Blagden, P. and Burnett, R.T. (2005) Estimating the public health burden attributable to air pollution: an illustration using the development of an alternative air quality index, Journal of Toxicology and Environmental Health, Part A, Vol.68, No.13, pp.1275–1288.

- Sunil (2008). Vehicular Pollution Modelling Along a Highway Corridor Under Mixed Traffic Condition. M.Tech. dissertation, Guru Jambheshwar University of Science and Technology.

- Takemura, T., Kaufman, Y.J., Remer, L.A., Nakajima, T. (2007). Two competing pathways of aerosol effects on cloud and precipitation formation, Geophys. Res. Lett. 34: L04802. doi: 10.1029/2006GL028349.

- Tsang, H., Kwok, R. and Miguel, A.H. (2008). Pedestrian Exposure to Ultrafine Particles in Hong Kong under Heavy Traffic Conditions. Aerosol Air Qual. Res. 8: 19–27.

- Turmer, D. B. (1970). Workbook of Atmospheric Dispersion Estimates. AP-26, Office of Air Programs, US Environmental Protection Agency, Research Triangle Park, NC.

- UNEP/WHO (1992). Air Pollution in Mega Cities of The World. United Nations Environment Programme and World Health Organization, Blackwell Publications, Oxford (UK).

- USEPA (2000). Meteorological Monitoring Guidance for Regulatory Modeling Applications, EPA-454/R-99-005, United State Environmental Protection Agency.

- USEPA (2004). Summary Descriptions of Alternative Air Quality Models, United State Environmental Protection Agency.

- USEPA (2008). Emission and Air Quality Modelling Tool for Near-Roadway Application, EPA/600/R-09/001, United State Environmental Protection Agency.

- Wahab, S. A. A. (2004). An Application and Evaluation of the CAL3QHC Model for Predicting Carbon Monoxide Concentrations from Motor Vehicles Near a Roadway Intersection in Muscat, Oman, Environmental Management, 34 (3), 372–382.

- Yang M. (1998), Climate Change and GHGs from urban transport. ADB technical paper, document 10B.

- Yura, E. A., Kear, T. and Niemeier, D. (2007). Using CALINE dispersion to assess vehicular PM 2.5 emissions, Atmospheric Environment, 41, 8747–8757.

- Zhang, R.J. Shen, Z.X. Zou, H. Wang, W. Han, Y. and Zhou, J. (2008). Study of Elemental Mass Size Distributions of Aerosol in Lijiang, a Background Site in Southwest China. Aerosol Air Qual. Res. 8: 339–347.

- Ziauddin A, Zainab B, Siddiqui NA. (2009). "Vehicular Air Pollution with regards to Carbon Monoxide emission – a case study". Environmental Pollution Control Journal, 12(5), 67-70.

Appendix 2.1

VEHICULAR POLLUTION CONTROL PROGRAMME IN INDIA

A2.1 INTRODUCTION

Air pollution is one of the serious environmental concerns of the urban Asian cities including India where majority of the population is exposed to poor air quality. The health related problems such as respiratory diseases, risk of developing cancers and other serious ailments etc. due to poor air quality are known and well documented. Besides the health affects, air pollution also contributes to tremendous economic losses, especially in the sense of financial resources that are required for giving medical assistance to the affected people. The poor are often the most affected segment of the population as they do not have adequate measures to protect themselves from air pollution.

Most of the Indian Cities are also experiencing rapid urbanization and the majority of the country's population is expected to be living in cities within a span of next two decades. Since poor ambient air quality is largely an urban problem this will directly affect millions of the dwellers in the cities.

The rapid urbanization in India has also resulted in a tremendous increase the number of motor vehicles. The vehicle fleets have even doubled in some cities in the last one decade. This increased mobility, however, come with a high price. As the number of vehicles continues to grow and the consequent congestion increases, vehicles are now becoming the main source of air pollution in urban India. Although, the air quality can be improved through a combination of technical and non-technical measures, legislative reforms, institutional approaches and market-based instruments, there are certain unique challenges which the country has to face in tackling the problem of urban air pollution. These include, the transport features which are different from the developed countries particularly in terms of the types of vehicles commonly used, the manner in which the road network is operated and sharing of the limited space by pedestrians and non-motorized modes with modern vehicles in Indian cities. Vehicles in India are often much older and usually comprise technologies considered as out-dated in the developed world. The institutions responsible for managing urban air quality are also not as well developed as those in the developed countries. The country has however taken a number of measures for the improvement of the air quality in cities. These include, right from the improvement in the fuel quality, formulation of necessary legislation and enforcement of vehicle emission standards, improved traffic planning and management etc. The non-technical measures taken include, awareness raising regarding the possible economic and health impacts of air pollution and available measures for improving air quality, increasing use of cleaner fuels and purchase of vehicles with advance emission control devices, increasing institutional framework and capacity building for the monitoring of vehicle emissions.

The following section presents a review of the problems associated with vehicular emissions, health and environmental effects of vehicular pollutants, vehicular pollution and climate change, vehicular pollution problems in india, control measures taken and details of legislative and implementing agencies.

A2.2 PROBLEMS ASSOCIATED WITH VEHICULAR EMISSIONS

The major problems associated with vehicular emission are mainly related to health and climate change.

A2.2.1 MAJOR VEHICLE/FUEL POLLUTANTS

Organization like TERI, UNEP/ WHO, World Bank, BARC/CESE/IIT, etc. have carried out studies in the past to estimate the contribution of various sources towards the ambient air quality. Automotive vehicles emit several pollutants depending upon the type of quality of the fuel consumed by them. The release of pollutants from vehicles also include fugitive emissions of the fuel, the source and level of these emissions depending upon the vehicle type, its maintenance etc. The major pollutants released as vehicle/fuel emissions are, carbon monoxide, nitrogen oxides, photochemical oxidants, air toxics namely benzene, aldehydes, 1-3 butadiene, lead, particulate matter, hydrocarbon, oxides of sulphur and polycyclic aromatic hydrocarbons. While the predominant pollutants in petrol/gasoline driven vehicles are hydrocarbons and carbon monoxide, the predominant pollutants from the diesel based vehicles are Oxides of nitrogen and particulates. The summary of the results of the above studies for Delhi & Mumbai are given pollutant wise in **Table A2.1** below:

Table A2.1: Summary of The Results of Various Studies

S.No.	Parameter	Delhi			Mumbai		
		Transport	Industrial	Domestic & other Sources	Transport	Industrial	Domestic & other Sources
1.	CO	76% to 90%	37% to 13%	10% to 16.3%	92%	8%	Nil
2.	NOx	66% to 74%	13% to 29%	1% to 2%	60%	40%	Nil
3.	SO_2	5% to 12%	84% to 95%	Nil to 4%	2% to 4%	82% to 98%	Nil to 16%
4.	PM	3% to 22%	74% to 16%	2% to 4%	Nil to 16%	34% to 96%	53% to 56%

Source: Auto Fuel Policy Report

A2.3 HEALTH AND ENVIRONMENTAL EFFECTS OF VEHICULAR POLLUTANTS

The vehicular emissions have damaging effects on both human health and ecology. There is a wide range of adverse health/environmental effects of the pollutants released from vehicles. The effects may be direct as well as in-direct covering right from reduced visibility to cancers and death in some cases of acute exposure of pollutants specially carbon monoxide. These pollutants are believed to directly affect the respiratory and cardiovascular systems. In particular, high levels of Sulphur dioxide and Suspended Particulate Matter are associated with increased mortality, morbidity and impaired pulmonary function. The pollutant wise health effects are summarized in **Table A2.2.**

Table A2.2: Health effects associated with Air Pollutants

Pollutant	Effect on Human Health
Carbon Monoxide	Affects the cardio vascular system, exacerbating cardiovascular disease symptoms, particularly angina; may also particularly affect foetuses, sick, anaemic and young children, affects nervous system impairing physical coordination, vision and judgments, creating nausea and headaches, reducing productivity and increasing personal discomfort.
Nitrogen Oxides	Increased susceptibility to infections, pulmonary diseases, impairment of lung function and eye, nose and throat irritations.
Sulphur Dioxide	Affect lung function adversely.
Particulate Matter and Respirable Particulate Matter (SPM and RPM)	Fine particulate matter may be toxic in itself or may carry toxic (including carcinogenic) trace substance, and can alter the immune system. Fine particulates penetrate deep into the respiratory system irritating lung tissue and causing long-term disorders.
Lead	Impairs liver and kidney, causes brain damage in children resulting in lower I.Q., hyperactivity and reduced ability to concentrate.
Benzene	Both toxic and carcinogenic. Excessive incidence of leukaemia (blood cancer) in high exposure areas.
Hydrocarbons	Potential to cause cancer

A2.4 VEHICULAR POLLUTION AND CLIMATE CHANGE

Global Warming and Climate Change

The world average temperature has risen by about 1^{o}F over the past century. It is widely accepted that the global warming is related to anthropogenic Green House Gases (GHGs). GHGs include, the common gases namely, carbon dioxide and water vapor, and rarer gases such as nitrous oxide, methane and chlorofluorocarbons (CFCs) whose properties relate to the transmission or reflection of different types of solar radiations. The increase in such gases in the atmosphere is a result of the burning of fossil fuels, emission of pollutants into the atmosphere by power plants and vehicle engines, etc. Of all human activities, driving motor vehicles produces the most intensive CO_2 emissions and other toxic gases per capita. A single tank of gasoline releases 140 ~180 kilograms of CO_2. Over 25% of transportation-related GHG emissions originate from urban passenger travel (Yang M. 1998). Unsustainable trends in urban transportation have already manifested in frequent congestions, periodic gridlock and evidence linking respiratory illnesses and deaths to poor air quality.

Global Emissions of GHG's from Transport Sector

Transport sector contributes around 14% towards the global emissions of greenhouse gases. Carbon dioxide represents the largest proportion of basket of greenhouse gas emissions. During, the past three decades, carbon dioxide emissions from transport have increased faster than those from all other sectors and are projected to increase more rapidly in future. The Road transport alone emits around 16% of the global CO_2 emissions (Source: OICA). From 1990 to 2004, carbon dioxide emissions from the world's transport sector have increased by 36.5%.For the same period, road transport emissions have increased by 29% in industrialized countries and 61% in the other countries (IEA, 2006).

A2.5 VEHICULAR POLLUTION PROBLEMS IN INDIA

Motor vehicles have been closely identified with increasing air pollution levels in urban centres of the world (Mage et al, 1996; Mayer 1999). Besides substantial CO_2 emissions, significant quantities of CO, HC, NO_x, SPM and other air toxins are emitted from these motor vehicles in the atmosphere, causing serious environmental and health impacts. Like many other parts of the world, air pollution from motor vehicles is one of the most serious and rapidly growing problems in urban centres of India (UNEP/WHO, 1992). The problem of air pollution has assumed serious proportions in some of the major metropolitan cities of India and vehicular emissions have been identified as one of the major contributors in the deteriorating air quality in these urban centres The problem has further been compounded by the concentration of large number of vehicles and comparatively high motor vehicles to population ratios in these cities. Reasons for increasing vehicular pollution problems in urban India are as below:

- High vehicle density in Indian urban centres.
- Older vehicles predominant in vehicle vintage

- Predominance of private vehicles especially cars and two wheelers, owing to unsatisfactory public transport system, thereby causing higher idling emissions and traffic congestion.
- Absence of adequate land use planning in development of urban areas, thereby causing more vehicle travel and fuel consumption
- Inadequate inspection & maintenance facilities.
- Adulteration of fuel & fuel products
- Improper traffic management system & road conditions
- High levels of pollution at traffic intersections
- Absence of effective mass rapid transport system & intra-city railway networks
- High population exodus to the urban centres.
- Increasing number Skyrocketing buildings in the urban areas causes stagnation of the vehicular emissions to the ground level and unable its proper dispersion.

A2.6 VEHICULAR POLLUTION CONTROL MEASURES TAKEN IN INDIA

For containing vehicular pollution, the Government has taken important initiatives in recent years. The Union Government and the Provincial Governments in India have been emphasizing the need for planning and developing strategies to implement mitigation measures to maintain the urban air quality and make the cities cleaner and greener for achieving better air quality and good health for its citizens. Over the past decade or so, the government has bought in statutes aimed at regulating and monitoring industrial and vehicular pollution across the country.

A2.6.1 HISTORY OF THE EVENTS

The sequence of events covering the various measures /initiatives /action taken for vehicular pollution prevention and control in the past 25 years are as follows (CPCB, 2010):

i. During January 15, 1985 an expert committee was constituted by the Secretary, Department of Environment (Now MoEF) under the chairmanship of director ARAI with Member Secretary from CPCB. The terms of reference of the committee were:
   a) To finalize vehicular emission standards at the manufacturing stage and also at the road side
   b) To finalize the frequency and method of testing of vehicles at the manufacturing stage

c) To approve laboratories in India to carry out chassis dynamometer test on vehicles

The committee recommended mass emission norms and in-use emission norms for different categories of vehicles along with testing method (The recommendations of the committee were notified later under Environment (Protection) Act 1986 during1990.

ii. During February 5, 1990, under Section 25 of Environment (Protection) Act 1986, Environment (Protection) Second Amendment Rule 1990 was notified where mass emission norms and in-use emission norms were prescribed for the first time in the country.

iii. The Hon'ble Supreme Court of India constituted a committee on Vehicular pollution control under the chairmanship of Retd. Justice Shri. K.N. Sakia with CPCB and MoEF as members. The terms of reference of the committee were to make an assessment of the technologies available for vehicular pollution control in world and in India to look at the low cost alternatives for operating vehicles at reduced pollution levels in the metropolitan cities of India and to examine the feasibility of measures to reduce pollution from motor vehicles both on short term and long term basis and make appropriate recommendations in this regard. The recommendation of the Sakia committee submitted to Hon'ble Supreme court in 1991 are as follows:

- For phasing out leaded petrol and phasing in unleaded or lead free petrol in Delhi by 01.04.1992 and with that end in view allowing fiscal and other incentives to lead free petrol users;
- For prescribing of strict medium and long term standards for different vehicular pollutants and strict enforcement of the same;
- To expand and strengthen the air pollution monitoring system and its working in Delhi to encourage public awareness and reaction to vehicular pollution;
- To encourage and finance advanced research and development in the field of vehicular pollution control through indigenous efforts, inter-regional and international exchange of data, co-operation and coordination;
- Of making it compulsory for all petrol vehicle on the road to retrofit a suitable catalytic converter or a suitable emission control device so as to control CO and HC with effect from 1.4.1992 and also a suitable emission control device on diesel vehicles so as to control particulate gases and smoke;

- Of issuing a directive by the Hon'ble Supreme court to the appropriate Ministry of the Central Government to stop forthwith the criminal waste of flaring up of natural gas in the different oil fields of the country, and to store and make the gas available for use as vehicular fuel;
- Of issuing of a directive by the Hon'ble Supreme Court to the appropriate departments of the central government to spread a national gas grid with network of pipelines reaching the metropolitan cities and supply compressed natural gas through such network for use as vehicular fuel at economic prices;
- Of issuing of a direction by the Hon'ble Supreme Court to Delhi transport Cooperation to convert at least 1/5th of its bus fleet every year to CNG and to purchase henceforth only new buses that use CNG as fuel and if licenses are issued to private buses those should be issued only for buses running on CNG or on batteries in Delhi;
- For Delhi Transport Corporation itself operating a fleet of electric trolley buses in Delhi area or inviting private enterprises including NRIs to operate such a system;
- Of improving the circular railway and treating it as a unit and increasing frequency of trains and issuing tickets on board like trams and buses;
- Of issuing of a directive for taking immediate steps for a metro for Delhi so as to function by 2000.
- These propositions led to the start of introduction of CNG in Delhi and phasing out of lead in gasoline.

iv. In 1992, MoEF brought out two documents namely, National Conservation Strategy & Policy Statement on Environment and Development and Policy Statement for Abatement of Pollution which identified that ambient air quality trends with respect to SPM in metro cities were higher than the prescribed limits especially during summer time. The levels of nitrogen di-oxide are increasing in urban centres with growth in vehicular emissions. For prevention and control of vehicular pollution and for development of environmentally compatible transport system, the following steps to be taken:

- Improvement in mass transport system to reduce increasing consumption of fuel, traffic congestion and pollution;

- Improved transport system based on bio-energy and other non-polluting energy sources
- Rail transport and pipelines transport instead of road transport, where ever possible, by appropriate freight pricing so as to reduce congestion, fuel consumption and environmental hazards;
- Improvement in traffic flow through proper maintenance of roads, updated traffic regulation and strict enforcement of prescribed standards;
- Enforcement of smoke emission standards for containing vehicular exhaust, at the manufacturer and user level;
- Phasing out of use of lead in motor spirit; and
- Regulation from environmental safety in transportation of hazardous substances

v. On May 16, 1991, CPCB constituted a committee to evolve mass emission standards for motor vehicles for year 1995 and 2000 under the chairmanship of Prof. H.B. Mathur. The terms of reference of the committee were:
    - To suggest the emission standards for 2, 3 & 4 wheelers to be implemented from year 1995 and 2000 with respect to carbon monoxide, hydrocarbons and oxides of nitrogen.
    - To identify the nature of changes required in engine design and types of devices to be installed to meet the suggested standards.

vi. During 1992 the committee recommended emission norms for vehicles applicable from 1995 and 2005 with technological options for meeting these norms. It also recommended redrafting the Indian standards to specify the fuel parameters affecting the emissions and make commercial fuel available. The lead free petrol has to be made available in limited quantity by 1995 and all commercially available petrol will have to be lead free by the year 2000. The recommendations of the committee were also deliberated at MoEF where 1995 norms were reviewed & postponed to 1996 and submitted to Ministry of Road Transport & Highways (MoRT&H) for notification.

vii. During the year 1992 a policy for providing clean fuels for power plants and motor vehicles were prepared by CPCB during its Board meeting and recommended to MoEF for Ministry of

Petroleum and Natural Gas (MoPNG) to take necessary action. During May 1994 a draft specification for motor gasoline and diesel was proposed by CPCB and submitted to MoEF.

viii. A meeting on fuel and fuel quality of automobiles was held on 17.6.1994 under the chairmanship of the Hon'ble Shri. Kamal Nath, Minister of Environment and Forests.

- From April 1, 1995 unleaded petrol (i.e. petrol with lead content less than 0.013 g/l) will be supplied in metropolitan cities, along with leaded petrol as at present.
- All new vehicles (4 wheelers) sold in metros after 1st April 1995, will have to be equipped with catalytic converters.
- Diesel supplied in metro cities will have only 0.5% sulphur content as compared to 1% at present, from 1st April, 1996.
- All 2 stroke engine 2 – wheelers and 3 wheelers will have to meet notified norms of emission by 1st April, 1996, if not, production of 2 stroke engines not meeting the norms will have to cease.
- Norms for year 2000 were discussed and it was decided to finalize these within six months, after some more discussions. Thus there will be adequate time for technical changes in design, etc.
- Fiscal mechanism was discussed-price differentials for different types of fuels.
- Also administrative mechanism such as staggering peak etc., were also discussed.
- Fuel standards comments from IIP, Dehradun within 15 days.

ix. Low leaded fuel (0.15 g/l) was made available by MoPNG for metro from January 1994.

x. During October 21, 1994 Hon'ble Supreme Court passed following order:

- Petrol with 0.15 g/l TEL to made available by December 1996 to entire country.
- Lead free petrol to be made available at selected outlets in 4 metro cities by April 1995.
- New vehicles (Petrol driven) should be equipped with catalytic converter by April 1995.

xi. On January 20, 1995 MoEF has constituted a committee to finalize fuel quality specification for motor gasoline and diesel. The recommendations of the committee with respect to emission related fuel quality specification were later notified under EPA.

xii. Bureau of Indian Standards incorporated the emission related specifications and prescribed fuel quality specifications. Based on MoEF recommendations and Supreme Court order, unleaded Petrol was made available in four metro cities during June 1995 and passenger cars are made to fit catalytic converter.

xiii. During April 20, 1996 the fuel quality specifications were notified under EPA Act and directives were issued by CPCB to various refineries under Section 5 of EPA for compliance of the specifications. In the same year revised ambient air quality standard were notified.

xiv. During May 1997 a policy paper on control of automobile exhaust pollution was prepared by CPCB which recommended:

- Introduction of Inspection and maintenance programme for in-use vehicles
- Phasing out of 15 years old vehicles
- Improving Public Transport system by introducing high capacity bus system on dedicated pathways
- Introduction of fleet of alternate fuel vehicles

xv. During August 1997 mass emission norms for vehicles (equivalent to Euro-I norms) with effect from 1.4.2000 were notified under Motor vehicle Act.

xvi. During August 1997 MoEF brought a white paper on pollution in Delhi. To implement the recommendations of white paper, MoEF constituted “Environmental Pollution Control Authority” on January 1998 on the directions of the Supreme Court. The important directions issued by the Hon’ble court on 26.7.1998 are as follows:

- Augmentation of public transport to 10,000 buses by 1.4.2001
- Elimination of leaded petrol from NCT Delhi by 1.9.1998
- Supply of only pre-mix petrol by 31.12.1998 for two stroke engines of two wheelers and autos

- Replacement of all pre-1990 autos and taxis with new clean vehicles on clean fuels by 31.3.2000
- No 8-year-old buses to ply except on CNG or other clean fuels by 1.4.2000
- Entire city fleet (DTC & Private) to be converted to single fuel mode on CNG by 31.3.2001
- New ISBTs to be built at entry point in North and south west to avoid pollution due to entry of Interstate buses by 31.3.2000
- GAIL to expedite and expand from 9 to 80 CNG supply outlets by 31.3.2000
- Two independent fuel testing laboratories to be established by 1.6.1999
- Proper inspection and maintenance facilities to be set up for commercial vehicles with immediate effect
- Comprehensive inspection & maintenance programme to be started by transport department and private sector by 31.3.2000
- CPCB/DPCC to setup a few more monitoring stations and strengthen the air quality monitoring stations for monitoring critical pollutants by 1.4.2000. The Hon'ble Court also directed that the time frame as fixed by Environment Pollution (Prevention & Control) Authority should be strictly adhered to by all the authorities
- Some of these orders have led to phasing out of diesel commercial vehicles especially buses and petrol three wheelers will be replaced with CNG vehicles in Delhi

xvii. During September 1998 lead in petrol was phased out in Delhi while during February 2000 lead in petrol was phased out from petrol all over the country.

xviii. During November 1998, EPCA brought up the issue of phasing out of diesel private vehicles in Delhi. CPCB recommended to EPCA that these vehicles should meet Euro-II norms otherwise they should not be allowed to ply. During the hearing in Supreme Court, the court ordered that Euro-I norms has to be made applicable for private non-commercial vehicles registered after June 1999 in Delhi. This led to introduction of Euro-II norms for other categories of vehicles and in other cities of the country.

xix. CPCB constituted a working group to formulate the transport fuel specifications for the year 2005 under the chairmanship of Dr. P.K. Mukhopadhyay, Ex-Director IOC (R&D). The terms of reference of the working group were as follows:

- To recommend the fuel specifications of automotive commercial fuels (gasoline and diesel) for the year 2005
- To recommend the reference fuel quality specifications at the testing stage
- To recommend technology to be adopted to meet the fuel quality specifications recommended for the year 2005
- To draw-up a strategy for monitoring the fuel quality at petrol pump stations to check adulteration

xx. As per decision taken by the committee of secretaries Ministry of Petroleum and Natural Gas constituted an-inter ministerial task force on auto fuel specifications and vehicular emission standards on August 14, 2000 under the chairmanship of the chairman CPCB. The committee in its report submitted to MoPNG on 31.3.2001 recommended the road map for introduction of Bharat stage –II norms in entire country along with fuel quality specifications.

xxi. In a meeting taken by the prime Minister on 30 August 2001 it was decided to constitute a committee of the experts of national repute under the chairmanship of Dr. R. A. Mashelkar which was formed on September 13, 2001. The expert committee on Auto fuel policy has proposed an auto fuel policy for India and also for selected major cities and a road map for its implementation. It has also recommended suitable auto fuels with their specification, taking into account the availability and logistic of fuel supplies, the economics of processing auto fuels and possibilities multiple fuel use in different categories of vehicles.

xxii. The Hon'ble Supreme Court of India, in the matter of CWP No. 13029 of 1985, passed the orders on 05.04.2001, regarding formulation and implementation of action plans for control of pollution in cities namely Kanpur, Lucknow, Varanasi, Agra, Jharia, Patna, Jodhpur, and Pune & Faridabad.

xxiii. During May 2002 the Hon'ble court has also asked the union of India to prepare a scheme for compulsory switch over to CNG/LPG as automotive fuels in the cities those are equally or more polluted than Delhi. Later CPCB identified these cities as Ahmedabad, Kanpur, Kolkata and Pune.

xxiv. In the year 2003 the Hon'ble Supreme Court vide its order dated 16.8.2003 directed Union of India and State Government to prepare action plan for lowering the rate of RSPM level for cities of Kanpur, Ahmedabad, Sholapur, Bangalore, Lucknow, Chennai, Hyderabad, Mumbai, Kolkata. Hon'ble Supreme Court also asked respective State Boards to place the proposed action plans before EPCA.

xxv. In the year 2004 new PUC norms have been implemented for in-use vehicles.

xxvi. In the year 2005 Bharat stage-III emission norms have been implemented in 11 megacities for all the new vehicles except 2 & 3 wheelers while Bharat stage-II norms have been implemented all over the country .

xxvii. On April 1, 2010 Bharat stage-IV emission norms have been implemented in 11 megacities for all the new vehicles except 2 & 3 wheelers while Bharat Stage-III norms have been implemented for 2 & 3 wheelers all over the country.

A2.6.2 VEHICULAR EMISSION STANDARDS

The mass emission norms for vehicles at manufacturing stage as well as for in-use vehicles have been notified during 1990-91 but these did not require the manufactures any modification. The emission norms along with fuel specifications laid down in 1996 required the automobile manufacturers to make modifications in engine design particularly with regard to crankcase emissions and evaporative emission control. New standards have been laid time to time. Some of these are mentioned below:

a) **April 1995:** New passenger cars were registered only if fitted with catalytic converters in Delhi, Mumbai, Calcutta and Chennai.
b) **April 1998:** The testing method for passenger cars norms was changed to cold start, which is stricter procedure than the previous one.
c) **June 1999**: Private vehicles had been required to meet EURO-I or EURO-II and only those vehicles, which conformed to these rules, were registered.
d) **Year 2000**: The norms required major modification in the engine design especially with regard to the fuel injection system in passenger cars and fitment of catalytic converters in the two-stroke engines. These standards are akin to Euro-I norms adopted in the European countries in 1992.

e) **April 1, 2000**: Only such private vehicles, which meet EURO-II norms, were registered in NCR.
f) **October 6, 2003**: The National Auto Fuel policy was announced which envisages a phased program for introducing Euro II-IV emission and fuel regulations by 2010.
g) **In the year 2005 Bharat stage-III** emission norms have been implemented in 11 megacities for all the new vehicles except 2 & 3 wheelers while Bharat stage-II norms have been implemented all over the country.
h) **On April 1, 2010 Bharat stage-IV** emission norms have been implemented in 11 megacities for all the new vehicles except 2 & 3 wheelers while Bharat Stage-III norms have been implemented for 2 & 3 wheelers all over the country.

A2.7 LEGISLATIVE AND IMPLEMENTING AGENCIES

The environmental legislation concerning vehicular pollution and the implementation authorities are given below in **Table A2.3**:

Table A2.3: Environmental Legislation Concerning Vehicular Pollution and Implementation Authorities

Legislation / Act	**Authority**	**Responsibility / Notifications**
The Environment (Protection) Act, 1986, amended 1991 *Environmental (Protection) Rules, 1986 (amended in 1999, 2001, 2002, 2002, 2002, 2003, 2004)*	Ministry of Environment & Forests	Notification of standards for emission or discharge of environmental pollutants from the industries, operations or process. The notified standards related to vehicular are as follows: • Specification of Motors Gasoline for emission related parameters • Specification of Diesel for emission related parameters • Specifications of two- stroke engine oil • Standard for emission smoke, vapour etc from motor vehicles • Noise limits for Automobiles at the manufacturing stage
The Central Motor Vehicles Act, 1988	Ministry of Road Transport	Makes rules regulating construction, equipment and maintenance of motor vehicles and trailers

Legislation / Act	**Authority**	**Responsibility / Notifications**
The Central Motor Vehicles Rules, 1989 (Second amendment 2009)	and Highways	as per section 110 of Motor Vehicle Act. The notified emission standards related to vehicular are as follows: • Relating to Emission of smoke and vapour from agricultural tractors driven by diesel engines • Relating to Diesel vehicles with original equipment fitment - Replacement of in-use diesel engine by new LPG engine - Applicable emissions norms • Relating to Diesel driven Agricultural tractor for standards of gaseous pollutants • Relating to idling emissions standards for petrol / CNG/LPG driven vehicles • Mass emission standards Bharat Stage III for four wheeled vehicles in NCR & other cities • Mass emission standards Bharat Stage III for two and three wheelers manufactured on and from 1st April, 2010. • Mass emission standards Bharat Stage IV for M and N category vehicles

Since vehicular pollution has been recognized as the major contributor to air pollution especially in urban centres, government has introduced various policies and legislations from time to time to deal with such kind of a problem. A brief summary of various vehicular emission related legislations in India are given below:

A2.7.1 VEHICULAR EMISSION RELATED LEGISLATIONS IN INDIA

India is the one of the few countries of the world, which has provided for constitutional safe guards for the protection and conservation of the environment. Various laws have been enacted in India having direct or indirect bearing on various aspects related to the transport and environment. Important amongst them are Air (Prevention and Control of Pollution) Act, 1981, the Environment Protection Act, 1986 and the Motor Vehicles Act, 1988 including the Central Motor Vehicle Rules, 1989 (CPCB, 2006). These laws cover a wide range of rules, regulations and/or provisions related to ambient air quality standards, vehicle emission norms for different categories of vehicles: in- use as well as for vehicles at conformity of production (CoP) stage, specification of fuels, guidelines for EIA for highway and road projects.

Apart from the legislative Acts, Constitution also empowers the parliament to enact legislations in conformity with various international agreements. India is already a signatory to international agreements pertaining to controlling the ozone depleting substances in the atmosphere (Montreal Protocol, 1986) and controlling the GHG's emissions (Rio Declaration, 1992; Kyoto Protocol, 1997) and contributing to various global environmental conservation and management programmers under the auspices of United Nations.

In order to arrest the deterioration in air quality, Govt. of India has enacted Air (Prevention & Control of Pollution) Act in 1981. The responsibility has been further emphasized under Environment (Protection) Act, 1986. A brief summary of Air (Prevention and Control of Pollution) Acts enacted in India are given below:

A2.7.2 AIR (PREVENTION AND CONTROL OF POLLUTION) ACT 1981

Government of India enacted the Air (Prevention and Control of Pollution) Act 1981 to arrest the deterioration in the air quality. The act prescribes various functions for the Central Pollution Control Board at the apex level and State Pollution Control Board at the state level. The main functions of the Central Pollution Control Board are as follows:

- To advice the Central Government on any matter concerning the improvement of the quality of the air and the prevention, control and abatement of air pollution.
- To plan and cause to be executed a nation-wide programme for the prevention, control and abatement of air pollution.
- To provide technical assistance and guidance to the State Pollution Control Board.
- To carry out and sponsor investigations and research related to air pollution prevention, control and abatement of air pollution.

- To collect, compile and publish technical and statistical data related to air pollution; and
- To lay down standards for the quality of air and emission quantities.

The main functions of the State Pollution Control Board are as follows:

- To plan a comprehensive programme for prevention, control or abatement of air pollution and to secure the execution thereof;
- To advise the State Government on any matter concerning prevention, control and abatement of air pollution.
- To collect and disseminate information related to air pollution.
- To collaborate with Central Pollution Control Board in programme related to prevention, control and abatement of air pollution; and
- To inspect air pollution control areas, assess quality of air and to take steps for prevention, control and abatement of air pollution in such areas.

A2.7.3 NATIONAL AMBIENT AIR QUALITY STANDARDS (NAAQS)

The ambient air quality objectives/standards are pre-requisite for developing management programme for effective management of ambient air quality and to reduce the damaging effects of air pollution. The objectives of air quality standards are: -

- To indicate the levels of air quality necessary with an adequate margin of safety to protect the public health, vegetation and property.
- To assist in establishing priorities for abatement and control of pollutant level.
- To provide uniform yardstick for assessing air quality at national level.
- To indicate the need and extent of monitoring programme.

The Central Pollution Control Board had adopted first Ambient Air Quality Standards on November 11, 1982 as per section 16 (2) (h) of the Air (Prevention and Control of Pollution) Act, 1981. The air quality standards have been revised by the Central Pollution Control Board on April 11, 1994 and were notified in Gazette of India, Extra-ordinary Part-II Section 3, sub section (ii), dated May 20, 1994. The Government has recently revised the National Ambient Air Quality Standards (NAAQS) and limits for 12 pollutants have been notified. Area classification based on land –use has been done away with so that industrial areas have to conform to the same standards as those for residential areas. The annual average norms for Lead, Nitrogen Dioxide, Arsenic, Nickel, Benzene and Benzoalphapyrene in ambient air are at par with the European Union norms. However, the norms for Particulate Matter having size less than 10 micron (PM_{10}) and Particulate Matter having size less than 2.5 micron ($PM_{2.5}$) are more relaxed than EU norms. Indian norms for Carbon Monoxide, Ozone and Sulphur Dioxide (SO_2) are more stringent than EU norms. Ammonia is additionally included in our NAAQS.

Under the Environment Surveillance Programme, CPCB has undertaken the task of development of monitoring protocols and the infrastructure needed for monitoring and enforcement of the new ambient air quality norms. It undertakes inspection of various industrial units under the 17 categories of highly polluting industries to verify compliance to the prescribed standards. Based on the level of non-compliance observed, directions are issued to the concerned State Pollution Control Boards under section 18(I) (b) of the water (Prevention and Control of Pollution) Act, 1974 and or The Air (Prevention and Control of Pollution) Act, 1981 as the case may be, and directly to the industries under section 5 of The Environment Protection Act, 1986. Such actions have been taken against major defaulters in sectors like Thermal Power, Cement, Fertilizers, etc., by the CPCB.

National Ambient Air Quality Standards are the limits for levels of air pollutants with an adequate margin of safety to protect the public health, vegetation and property. There were 7 parameters, namely, Sulphur Dioxide (SO_2), Oxides of Nitrogen (NOx), Suspended Particulate Matter (SPM), Respirable Particulate Matter (RSPM) Lead Carbon Monoxide (CO) and Ammonia (NH_3) notified under the Air Act, 1981 and the Environment (Protection) Act, 1986. National Ambient Air Quality Standards (NAAQS) were earlier notified in the year 1994 under the Air Act. There is a difference between the World Health Organisations norms-2005 and our revised standards (NAAQS). Whereas we have prescribed 12 parameters, mainly PM_{10}, $PM_{2.5}$, SO_2, NO_2, CO, NH_3, Ozone, Lead, Benzene, Arsenic and Nickel. WHO has suggested five parameters, out of which, only four are to be monitored i.e. PM_{10}/ $PM_{2.5}$, Sulphur Dioxide, Nitrogen Dioxide and Ozone. The CPCB monitors $PM_{2.5}$, Ozone (ground level), Carbon Monoxide, Lead, Hydrocarbons, Ammonia, Benzene, etc., at selected locations in few cities apart from Sulphur Dioxide, Nitrogen Dioxide and PM_{10} at all locations under National Air Monitoring Programme (NAMP).

Initially the Central Pollution Control Board started the National Ambient Air Quality Monitoring (NAAQM) programme in the year 1984 with 7 stations at Agra and Anpara.

Subsequently the programme was renamed as National Air Quality Monitoring Programme. NAAQS have been notified for seven parameters viz. SPM, RSPM, NO_2, SO_2, CO, NH_3 and Pb. Under National Air Quality Monitoring Programme presently ambient air quality is being monitored at 342 monitoring stations covering 128 cities/towns as on 31st March 2009 which was at 328 stations as on 31st March 2008. During 2008-09, 42 stations have been sanctioned additionally. Further:

(i) Parameters SPM, RSPM, SO_2 and NO_2 are being monitored at all the locations.

(ii) Three more parameters i.e. CO, Pb, and NH_3 are being monitored at selected locations in few cities.

(iii) Other parameters i.e. O_3, Benzene, Trace heavy metals and PAHs are being monitored occasionally at selected locations for creating data base. (National Ambient Air Quality Monitoring Series: Naaqms//2009-10).

Appendix – 3.1

CLASSIFIED TRAFFIC VOLUME COUNT FORMAT

1. Station No.:
2. Location/ Area:
3. Traffic Direction:
4. Date of Sampling and Month:

Time (hours)	Two Wheeler	Three Wheeler	Car/Van/Jeep/ Sumo	Mini Bus/Bus	Trucks	Tractor	Others	Remarks
06:00 – 07:00								
07:00 – 08:00								
08:00 – 09:00								
09:00 – 10:00								
10:00 – 11:00								
11:00 – 12:00								
12:00 – 13:00								
13:00 – 14:00								
14:00 – 15:00								
15:00 – 16:00								
16:00 - 17:00								
17:00 – 18:00								
18:00 – 19:00								
19:00 – 20:00								
20:00 - 21:00								
21:00 – 22:00								

Appendix – 3.2

AMBIENT AIR SAMPLING DATA FORMAT

I. Parameter:

1. Station No.:
2. Location/ Area:
3. Distance from the edge of the Road:
4. Height of High Volume Sampler from Road:
5. Date of Sampling and Month:
6. Running Period of Sampler:
   Started Time :
   End Time :

S.No.	Time Period (hours)	Time Duration (hours)	Concentration (μg /m^3)	Remarks
1	06:00 – 07:00	1		
2	07:00 – 08:00	1		
3	08:00 – 09:00	1		
4	09:00 – 10:00	1		
5	10:00 – 11:00	1		
6	11:00 – 12:00	1		
7	12:00 – 13:00	1		
8	13:00 – 14:00	1		
9	14:00 – 15:00	1		
10	15:00 – 16:00	1		
11	16:00 - 17:00	1		
12	17:00 – 18:00	1		
13	18:00 – 19:00	1		
14	19:00 – 20:00	1		
15	20:00 - 21:00	1		
16	21:00 – 22:00	1		

Appendix – 3.3

FUEL STATION SURVEY FORMAT

1. Name of the Station No.:
2. Location/ Area:
3. Data on Vehicle type, fuel used and Vintage

S. No.	Type of Vehicle	Fuel used (Petrol/Diesel/CNG)	Year of Manufacture
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			
16			

Appendix – 3.4

ROAD GEOMETRY SURVEY FORMAT

Road Corridor Number	Laning of the road corridor (2/4/6/8)	Carriageway Width (m)	Median Width (m)

<u>Appendix 3.5</u>

DESCRIPTION OF CALINE 4 MODEL

A brief description about the data used in CALINE 4 model is as below:

A3.1 DATA ENTRY SCREENS

CALINE 4 model contains five data entry screens, listed below, and must be complete in order to run CALINE 4:

I. Job Parameters
II. Link Geometry
III. Link Activity
IV. Run Conditions
V. Receptor Conditions

I. Job Parameters

The job parameters Screen contains general information that identifies the job, define general modeling parameters, and sets the units (feet or meters) that will be used to input data on the Link Geometry and Receptor Positions Screens.

File Name: Display only, not editable. Displays the name of the file where the current job is stored.

Job Title: Operational, Provides a space for the user to enter a brief job description, up to 40 characters in length.

Run Type: Different choices determine averaging times (for CO concentrations) and how the hourly average wind angle(s) will be determined. (Wind angle is the angle between the roadway link and the wind direction. CALINE 4 calculates the angles based on data in the Link Geometry and Run Conditions Screens). Most users should invoke the "worst-case wind angle" run type and apply a persistence factor of 0.6 to 0.7 in order to estimate an 8-hours average CO concentration.

i. **Standard** – Calculates 1-hour average CO concentrations at the receptors. The user must input a wind direction on the Run Conditions Screen.
ii. **Multi-Run** – Calculates 8-hours average CO Concentrations at the receptors. The user must input wind angles for each hour.
iii. **Worst-case wind angle** – Calculates 1-hour average CO concentrations at the receptors. The model selects the wind angles that produce the highest CO

concentrations at each of the receptors. This is the most appropriate choice for most users.

iv. **Multi-Run/Worst-case hybrid –** Calculates 8-hours average CO concentrations at the receptors. The model selects the wind angles that produce the highest CO concentrations at each of the receptors.

Aerodynamic Roughness Coefficient: Also known as the Davenport – Wieringa roughness-length. These choices determine the amount of local air turbulence that affects plume spreading. This subject is usually discussed in elementary meteorology books. CALINE 4 offers the following 4 choices for aerodynamics roughness coefficient:

Rural: Roughness Coefficient = 10 cm

Suburban: Roughness Coefficient = 100 cm

Central Business District: Roughness Coefficient = 400 cm

Other: Use **Table A3.1** as guidance to select an appropriate value.

Model Information: Provides summary information for convenience and quality assurance.

Link/Receptor Geometry Units: Select whether meter or feet will be used to define the geometry of the roadway links and receptor positions. This choice only affects the Altitude input choice, and the data shown on the Link Geometry and Receptor Positions pages. Meteorological inputs always require inputs with metric units. Emission factors are always defined in terms of grams per mile. (Note that CALINE 4 reports data in metric units, with the exception of the Altitude).

Table A3.1: Aerodynamic Roughness Coefficient Defined for various Types of Landscapes

Roughness Coefficient (cm)	Landscape Type
0.002	Sea, paved areas, snow-covered flat plain, tide flat, smooth desert
0.5	Beaches, pack ice, morass, snow-covered fields
3	Grass prairies or farm fields, tundra, airports, heather
10	Cultivated areas with low crops and occasional obstacles (such as bushes)
25	High crops, crops with varied height, scattered obstacles (such as trees or hedgerows), vineyards
50	Mixed far fields and forests clumps, orchards, scattered buildings

Roughness Coefficient (cm)	Landscape Type
100	Regular coverage with large obstacles, open spaces roughly equal to obstacle heights, suburban houses, villages, mature forests
≥ 200	Centers of large towns or cities, irregular forests with scattered clearings

(Source: User's guide for CALINE 4, Coe et al., 1998)

Altitude above sea Level: Define the altitude above mean sea level. This input is used to determine the rate of plume spreading. It does not affect the Link Geometry or Receptor Positions.

Number of Links: The sum total number of links that the user has defined on the Link Geometry page.

Number of Receptors: The sum total number of receptors that the user has defined on the Receptor Position page.

Averaging Interval: Indicates whether the user has opted to calculate 1-hour or 8-hour average CO concentrations at the receptors.

"Run" – Click this button to run the job as specified. First, be sure that the information on all five pages of CALINE 4 is complete: Job Parameters, Link Geometry, Link Activity, Run Conditions and Receptor Conditions.

"Exit" – Click this button to exit the CALINE 4 program. CALINE 4 issues a warning if changes or new user inputs might be lost.

II. Link Geometry Screen

Fill in the matrix to define the roadway network to be modelled. Each row in the matrix defines a single link. Up to 20 links may be entered. Links are defined as straight-line segments. The distance between the centreline of the curved roadway, and the straight-line link should be no greater than 3 meters.

Link Type: The user must select one of the following 5 choices to define the type of roadway that each link represents. (Click a cell in this column to view a drop list and select from the following 5 options).

- **At-Grade** – For at-grade sections, CALINE does not permit the plume to mix below ground level, which is assumed to be at a height of zero. The height of the link above the ground is defined in the Link Height cell.
- **Fill** – For fill sections, CALINE 4 automatically resets the link height to zero, and assumes that air flow follows the surface terrain, undisturbed. This choice is functionally no different than the At-Grade choice with a link height defined as zero. If you wish to model a link that is slightly elevated above ground, the At-Grade choice is more appropriate.
- **Depressed** – For depressed sections, CALINE 4 increases the residence time of an air parcel in the mixing zone. The residence time increases in relation to the depth of the roadway depression. (Mixing zone = width of traffic lanes(s) plus 3 meters on each side). In such a case, CO concentrations adjacent to the mixing zone are higher than those for an equivalent at-grade or fill section. CO concentration drops more rapidly downwind of a depressed link because vertical mixing increases with residence time.
- **Bridge** – For bridge sections, CALINE 4 allows air to flow above and below the link. The plume is permitted to mix downward from the link, until it reaches the distance defined in the Link Height cell.
- **Parking Lot** – Parking lot links should be defined to be coincident with the parking lot access ways. The CALINE 4 algorithms adjust to account for the reduced mechanical and thermal turbulence anticipated from slow moving, cold-start vehicles.

Endpoint Coordinates: Links are defined as straight-line segments. The entire length of each link should be deviate no further than 3 meters from the centreline of the actual roadway. The endpoint coordinates, (x_1,y_1) and (x_2,y_2), define the positions of link endpoints.

- The units of measure (feet or meters) are user-specified on the Job Parameters Page.
- The user must define the link geometry and receptor positions with a consistent Cartesian coordinate system. The position of the coordinate system origin is arbitrary and at the user's discretion. The y-axis should be oriented north-south, with values increasing in the eastward direction. The choice of magnetic north, true north, or some other approximation is at the user's discretion. However, the wind direction must be defined on the Run Conditions page according to the same direction of north.

Link Height: For all link types except bridges, Link Height represents the height of the link above the surrounding terrain. Ground level is defined at 0 meters or feet (z=0). The units of measure (feet or meters) are user-specified on the Job Parameters Page. For at-grade links, the link height may be defined as 0 or a positive value. For fill links, CALINE 4 always treats the link as through its height was zero. For depressed links, the depth of the depression should be indicated as a negative value. For parking lots, the link height should be defined as zero. For bridges, Link Height defines the height of the bridge above the surface beneath it (a positive value), while the link itself is considered to be at z=0

Mixing Zone Width: Mixing zone is defined as the width of the roadway, plus 3 meters on either side. The minimum allowable value is 10 meters, or 32.81 feet.

Canyon/ Bluff Mix: CALINE 4 is based on two somewhat restrictive assumptions:

1) Horizontally homogeneous wind flow, and
2) Steady-state meteorological conditions.

Complex topography can in validate each of these assumptions. Land features such as canyons can channel winds. Hill and valleys are likely to cause frequent shifts in wind direction. For these reasons, use of CALINE 4 in complex terrain should be approached with care. CALINE 4 handles certain bluff and canyon situations by reflecting the plume at the distances specified on one or both sides of the mixing zone (Turner, 1970). CALINE 4 assumes that the topographic barrier and wind direction are parallel to the roadway. CALINE 4 also alters the vertical dispersion curve to account for vehicle-related heat flux distributed over the width of the canyon. This is especially important in the case of a narrow urban street canyon. The Canyon/Bluff Mix feature has not been validated with field measurements. Only very rare circumstances warrant its use. Use extreme caution with this feature. Users of the Canyon Bluff Mix feature should be thoroughly familiar with dispersion modeling, with key reference (Turner, 1970), and with the CALINE 4 source code. All other users should leave the Canyon/ Bluff input values set to zero, which disables the feature.

III. Link Activity Screen

The Link Activity screen defines the level of traffic and auto emission rate observed at each link.

Traffic Volume: The hourly traffic volume anticipated to travel on each link, in units of vehicles per hour. If a multi-run scenario is selected, traffic volume must be defined for 8 hours.

Emission Factor: The weighted average emission rate of the local vehicle fleet, expressed in terms of grams per mile per vehicle. Emission factors should be modelled using the CT-EMFFAC computer model 3. Emission rates vary by time of day. Therefore, if a multi-run scenario is selected, emission factors must be defined for 8 hours.

IV. Run Condition Screen

The Run Conditions screen contains the meteorological parameters needed to run CALINE 4. Users should employ the worst-case meteorological conditions that can be anticipated at the project location. The selection of worst-case conditions should be made in consultation with the local air district.

Wind Speed: Expressed in meters per second. The minimum choice of wind speed available for CALINE 4 is 0.5 m/s. Alternatively, EPA (1992) recommends a value of 1 m/s as the worst-case wind speed. The local air district should be consulted to make a decision that is appropriate for the project location.

Wind Direction – The direction of the wind is blowing from, measured clockwise in degrees from the north (0 = north, 90 = east, 180 = south, 270 = west). Most users should opt for the "Worst Case Wind Angle" choice on the Job Parameters screen. If "Worst-case" is selected, CALINE 4 does not use this input.

Wind Direction Standard Deviation – The statistical standard deviation of the Wind Direction, sometimes termed "sigma theta". **Table A3.2** provides guidance for this choice.

Table A3.2: Lateral Turbulence Criteria for Initial Estimate of Standard Deviation of Wind Angle

Initial estimate of P-G stability category	Standard deviation of wind azimuth angle σ (degrees)
A	$22.5 \leq \sigma$
B	$17.5 \leq \sigma < 22.5$
C	$12.5 \leq \sigma < 17.5$
D	$7.5 \leq \sigma < 12.5$
E	$3.8 \leq \sigma$ 7.5
F	$\sigma < 3.5$

Atmospheric Stability Class: It is a measure of the turbulence of the atmosphere. This concept is discussed further in elementary meteorological textbooks. The hourly stability classes viz., A-F (Pasquill and Gilford; P-G) were obtained by the Turner Scheme (Turner, 1964) (Ref. Table 3.5).

Mixing Height – The altitude to which thermal turbulence occurs due to solar heating of the ground. This concept is discussed further in elementary meteorological textbooks. Reasonable values for the worst-case mixing height rarely have a significant impact on CALINE 4 model results. If an extreme condition could be anticipated at the project location (mixing height x 10 meters), the local air district should be consulted for guidance.

Ambient Temperature – The ambient air temperature significantly affects vehicle CO emissions. A temperature that reflects wintertime conditions should be selected, expressed in degree Celsius.

Ambient Pollutant Concentration - This measure reflects the pre-existing background level of Carbon monoxide, expressed in parts per million. CALINE 4 adds the pre-existing and modeled CO concentrations together to determine the total impact at each receptor.

V. Receptor Position Screen

The Receptor Positions Screen contains the data inputs for all receptor positions, and also displays a diagram of the link geometry and receptor positions.

Receptor should be defined with the same Cartesian coordinates system and units of measure as the link geometry. For each receptor (maximum no. of receptors = 20), space is provided for an 8-character description, the X-coordinate, the Y- coordinate, and the height (Z).

A3.2 CALINE 4 OUTPUT FILE

The CALINE 4 output file is divided into four sections - Header, Site Variables, Link Variables and Receptor Locations and Model Results. The variables named in CALINE 4 output files are defined below:

U = wind speed

Z0 = aerodynamic roughness coefficient

ALT = altitude above sea level

BRG = wind angle

VD = deposition velocity

CLAS = atmospheric stability class

VS = settling velocity

MIXH = atmospheric mixing height

AMB = ambient CO concentration

SIGTH = standard deviation of wind direction

TEMP = ambient temperature

Type = Link type (AG = at-grade, etc., DP = depressed, FL = fill, PK = parking lot)

VPH = vehicles per hour

EF = Emission Factor

H = Link Height

W = Mixing Zone Width

Pred. Conc. = Predicted CO concentration contributed by each link at a receptor position

AVG = Average 8-hour CO concentration predicted at the receptor.

Appendix 4.1

NATIONAL AMBIENT AIR QUALITY STANDARDS

Concentration in Ambient Air				
Pollutant	**Time Weighted Average**	**Industrial, Residential, Rural and Other Area**	**Ecologically Sensitive Area (notified by Central Government)**	**Method of Measurement**
Sulphur Dioxide (SO_2) µg/m^3	Annual*	50	20	Improved West and Geake Method Ultraviolet Fluorescence
	24 hours**	80	80	
Oxides of Nitrogen (NO_x) µg/m^3	Annual*	40	30	Jacob & Hochheiser Modified (Na-Arsenite) Method Chemiluminescence
	24 hours**	80	80	Gas Phase Chemiluminescence
Particulate Matter (Size less than 10 µm) or PM_{10} µg/m^3	Annual*	60	60	Gravimetric TOEM Beta attenuation
	24 hours**	100	100	
Particulate Matter (Size less than 2.5 µm) or $PM_{2.5}$ µg/m^3	Annual*	40	40	Gravimetric TOEM Beta attenuation
	24 hours**	60	60	
Ozone (O_3) µg/m^3	8 hours**	100	100	UV Photometric Chemiluminescence Chemical Method
	1 hour**	180	180	
Lead (Pb)	Annual*	0.5	0.5	ASS/ ICP Method

Concentration in Ambient Air				
Pollutant	**Time Weighted Average**	**Industrial, Residential, Rural and Other Area**	**Ecologically Sensitive Area (notified by Central Government)**	**Method of Measurement**
µg/m^3	24 hours**	1.0	1.0	after sampling on EPM 2000 or equivalent Filter paper ED – XRF using Teflon filter
Carbon Monoxide (CO) mg/m^3	8 hours**	02	02	Non Dispersive Infra Red (NDIR) Spectroscopy
	1 hour**	04	04	
Ammonia (NH_3) µg/m^3	Annual*	100	100	Chemiluminescence Indophenol blue method
	24 hours**	400	400	
Benzene (C_6H_6) µg/m^3	Annual*	05	05	Gas Chromatography based continuous analyzer Adsorption and Desorption followed by GC analysis
Benzo (a) pyrene (BaP) – Particulate phase only, ng/m^3	Annual*	01	01	Solvent extraction followed by HPLC/GC analysis
Arsenic (As) ng/m^3	Annual*	06	06	AAS/ICP method after sampling on EPM 2000 or equivalent filter paper

Concentration in Ambient Air				
Pollutant	**Time Weighted Average**	**Industrial, Residential, Rural and Other Area**	**Ecologically Sensitive Area (notified by Central Government)**	**Method of Measurement**
Nickel (Ni) ng/m^3	Annual*	20	20	AAS/ICP method after sampling on EPM 2000 or equivalent filter paper

*Annual Arithmetic mean of minimum 104 measurements in a year at a particular site taken twice a week 24 hourly at uniform interval.

**24 hourly or 08 hourly or 01 hourly monitored values, as applicable, shall be complied with 98% of the time in a year. 2% of the time, they may exceed the limits but not on two consecutive days of monitoring.

BRIEF BIODATA OF AUTHOR

Mr. Deepak Malik is an Engineering Graduate and holds Master's degree of Environmental Science in Ecology and Environment; Master of Philosophy (M. Phil.) in Environmental Science; Post-graduation in Environmental Management (specialization - Industrial Pollution Management) and pursuing research studies leading to Doctorate in Environmental Engineering. He has over 20 years of Professional experience of addressing environmental issues in various infrastructure Development Projects in the field of Urban Development, Highways, Expressways, Railways, Tunnels, Airports, Hydro Electric Power, Power Transmission & Distribution Projects and Modernization of Irrigation System, Dam Safety & Water Bodies Restoration Projects Funded by multilateral financial institutions such as World Bank, Asian Development Bank, JICA etc. Mr. Malik has vast exposure of working in East Africa (Tanzania) and Indian Sub Continent (about 22 Indian States).

Mr. Malik is an approved Environmental Coordinator under EIA accreditation scheme for Airports, Highways, Railways and Mass Transit Systems from Quality Council of India, Government of India. He is also an approved Chartered Engineer from The Institution of Engineers (India). He is also a Member of Indian Roads Congress and member of Environment Committee of Indian Roads Congress, which formulates guidelines for road development in India.

He is well versed with World Banks Operational Policies and guidelines - OP 4.01 Environmental Assessment; OP 4.02 Environmental Action Plans; OP 4.04 Natural Habitats and OP 4.36 Forests. He is also well versed with ADB's Environment Policy (2002); Environmental Assessment Guidelines (2003) and ADB's Safeguard Policy Statement (2009). Mr. Malik has vast experience in carrying out Environmental Impact Assessment (EIA) relating to infrastructure development projects and preparation of Detailed Project Report (DPR) and Environmental Management Plan (EMP). He is an approved air modeler and is well versed with various air dispersion modelling softwares.

PAPERS PUBLISHED

PAPER 1: ASSESSMENT OF TRAFFIC IMPACT ON AMBIENT AIR QUALITY IN GURGAON CITY

By

Deepak Malik[1], Dr. Mukesh Saxena[2], Dr. Niraj Sharma[3]

([1]PhD. Scholar, University of Petroleum and Energy Studies, Dehradun 248007, India; [2]College of Engineering Studies, University of Petroleum and Energy Studies, Dehradun 248007, India; [3]Environmental Science Division, CSIR- Central Road Research Institute, New Delhi 110025, India,

(Paper published in International Journal of Management and Social Sciences (IJMSS) Vol. 3 (2); pp. 93-106 (2014).

PAPER 2: ENVIRONMENTAL MANAGEMENT PLAN FOR SATELLITE TOWN OF GURGAON

By

Deepak Malik[1], Dr. Mukesh Saxena[2], Dr. Niraj Sharma[3]

([1]PhD. Scholar, University of Petroleum and Energy Studies, Dehradun 248007, India; [2]College of Engineering Studies, University of Petroleum and Energy Studies, Dehradun 248007, India; [3]Environmental Science Division, CSIR- Central Road Research Institute, New Delhi 110025, India,

(Research Paper presented in International Conference organized by IILM Institute for Higher Education, New Delhi on Responsible Management Education and Practice.

The paper is published in a Journal of Management and Change published by IILM, Vol. 18 No. 1, pp 55-71 (2014).

IILM Supported by PRME

IILM International Conference on
Responsible Management Education and Practice
IILM Auditorium, Lodhi Road Campus
January 10-11, 2014, New Delhi

DAY 1– Friday, January 10, 2014

Registration	9.00 -10.00 am
Inauguration : H.E. Mr. Stewart Beck, The High Commissioner of Canada in India	10.00 -10.05 am
Welcome Address, Professor Sapna Popli, Director IILM and	10.05 – 10.10 am
Mr. Jonas Haertle, Head – PRME Secretariat, UN Global Compact, New York	10.10 – 10.15 am
Session 1/1 **Opening Plenary : Keynote Address - Responsible Management: A Pressing Need**	10.15 -11.00 am
H.E. Mr. Stewart Beck, The High Commissioner of Canada in India Mr. Sunil Jain, Managing Editor, The Financial Express	
Tea Break	11.00-11.30 am
Session 2/1 **Responsible Management Practice: The New Imperative for a Competitive Edge**	11.30- 1.00 pm
Dr R Narayanaswamy, Professor of Finance and Control, Indian Institute of Management, Bangalore Mr Deepak Thombre, Values Ombudsman, Dalmia Bharat Group Mr Raman Sidhu, Chairman, European Business Group, India	
Research Paper: Environment Management Plan for Satellite Town of Gurgaon: Mr. Deepak Malik, Dr. Mukesh Saxena, Dr. Niraj Sharma	
Networking Lunch on Campus	1.00- 2.30 pm
Session 3/1 **Framework for Responsible Management Education**	2.30-4.00 pm
Mr. Jonas Haertle, Head – PRME Secretariat, UN Global Compact, New York Mr. Jacob Jacob, Chief People Officer, Apollo Hospitals Enterprise Limited, Chennai Dr. Sunita Singh Sengupta, Professor of Organizational Behaviour, Faculty of Management Studies, University of Delhi	

Page **2** of **4**

PRME IILM

Responsible Management Education and Practice

This is to certify that

Mr. Deepak Malik

has presented a paper on

Environmental Management Plan for Satellite Town of Gurgaon

at the International Conference

organized by

IILM Institute for Higher Education, New Delhi

9th - 11th Jaunuary , 2014

Vandana Srivastava
Dr. Vandana Srivastava
Conference Core Committee

R. Chaudhry
Prof Rakesh Chaudhry
Dean Academics

PAPER 3: ASSESSMENT OF VEHICULAR IMPACT ON AMBIENT AIR QUALITY DUE TO SEASONAL VARIATION: A CASE STUDY OF GURGAON

By

Deepak Malik[1], Dr. Mukesh Saxena[2], Dr. Niraj Sharma[3]

([1]PhD. Scholar, University of Petroleum and Energy Studies, Dehradun 248007, India; [2]College of Engineering Studies, University of Petroleum and Energy Studies, Dehradun 248007, India; [3]Environmental Science Division, CSIR- Central Road Research Institute, New Delhi 110025, India,

(Paper published in International Journal of Social and Allied Research (IJMSS) Vol. 2(2): pp 53-60 (2014)

Abstract: Gurgaon city a satellite town in NCR is also facing air pollution problem due to rapid urbanization. The deterioration of urban air in arterial streets due to vehicular traffic exhaust and its interaction with the environment is causing a perceivable discomfort in daily life. Hence, an effort has been made through this paper to understand the vehicular impact on Ambient Air Quality due to seasonal variation in Gurgaon city.

Keywords: Vehicular impact, Air pollution, Traffic impact on air quality, Air quality, Gurgaon pollution, Ambient air quality