MAPPING OF URBAN TRAFFIC EMISSION AND ASSOCIATED HEALTH RISKS IN DELHI

By

AMRIT KUMAR

Environmental Engineering Department

Submitted

In fulfilment of the requirements of the degree

of

DOCTOR OF PHILOSOPHY

to the

DEPARTMENT OF ENVIRONMENTAL ENGINEERING
DELHI TECHNOLOGICAL UNIVERSITY
DELHI-110042, INDIA

MAY 2018

MAPPING OF URBAN TRAFFIC EMISSION AND ASSOCIATED HEALTH RISKS IN DELHI

A Thesis

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By

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Roll No. 2K12/PhD/ENE/06

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under the guidance of
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MAY 2018

DELHI TECHNOLOGICAL UNIVERSITY

(Formerly Delhi College of Engineering)

Department of Environmental Engineering

Shahbad Daulatpur, Bawana Road, Delhi-110042, India

DECLARATION

Date: /05/2018

This is to certify that the work presented in this thesis entitled **"Mapping of Urban Traffic Emission and Associated Health Risks in Delhi"** is original and has been carried out by me for the degree of **Doctor of Philosophy** under the supervision of **Dr. Rajeev Kumar Mishra,** Assistant Professor, Department of Environmental Engineering. The work presented in this thesis is an original contribution. I certify that the information is true and correct to the best of my knowledge. I declare that this thesis has been composed solely by me and has not been submitted, either in partial or full, to any other university or institute for the award of any degree or other similar title or in recognition.

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CERTIFICATE

Date: /05/2018

This is to certify that the thesis entitled **"Mapping of Urban Traffic Emission and Associated Health Risks in Delhi"** submitted by **Mr. Amrit Kumar** (Reg. No. 2K12/PhD/ENE/06) for the award of the degree of **Doctor of Philosophy** is based on the bonafide research work carried out by him during the period from August 2012 to May 2018 under my guidance and supervision. Mr. Amrit Kumar fulfils the requirements of the regulations laid down for the Ph.D. programme of Delhi Technological University, Delhi. It is further certified that the work embodied in this thesis has neither partially nor fully submitted to any other university or institution for the award of any degree or diploma or other similar title or recognition.

He is allowed to submit the work for award of Ph.D. in Environmental Engineering at Delhi Technological University, Delhi.

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Dedicated

To

My Parents

Sh. Yogendra Prasad Sah

And

Mrs. Shova Devi

ACKNOWLEDGEMENT

I have received encouragement and support from lot of people during my Ph.D. work. I would never have been able to complete my Ph.D. without the guidance and support which I have received from the beginning of my Ph.D. work. I think it is the time to express my gratitude to all of them.

It gives me immense pleasure to express my deep sense of gratitude and sincere thanks to my supervisor ***Dr. Rajeev Kumar Mishra****, Assistant Professor, Department of Environmental Engineering, Delhi Technological University, Delhi, for his consistent guidance and encouragement from inception to completion of this thesis work. It has been an honor to be his first Ph.D. student. Spared me to supportive and motivated me to how the scientific draft writing skill me during my research. He continuously encouraged and helped me for the achievement of all goals of the research work. I am grateful to him for all his contributions of time, suggestions, constructive criticism to make my Ph.D. experience productive and stimulating.*

I wish to express my sincere thanks to Prof. S. K. Singh, Head of Department of Environmental Engineering, DTU, for his valuable suggestions and unconditional help whenever required. I owe my heartfelt gratitude to the administration of DTU, for providing me all facilities for carrying out this research work.

I want to express my sincere thanks to Prof. Nirendra Dev, Head of Department, Civil Engineering, and DRC chairman (Civil and Environmental Engineering) DTU, Delhi for his insightful comments, suggestion and encouragement. My sincere thanks to all faculty members of Department of Environmental Engineering and other departments of DTU for their all kind of support, suggestions and encouragement.

I extend my hearty gratitude to Prof. A.K Gupta, Department of Civil Engineering, DTU, Delhi, Prof. Manorajan Parida, Civil Engineering, IIT, Roorkee and Prof. B. L. Swami, Dept. of Civil Engineering, MNIT, Jaipur, for their valuable time, which they spent to answer my question *whenever I feel any doubt regarding my Ph.D. research work. I am also indebted of their consent support and encouragement.*

I would like to thank Prof. Kiranmay Sarma, Guru Gobind Singh Indraprastha University, Delhi, for giving me his valuble time to learn GIS mapping despite his busy schedule. He has been very kind and always willing to lend his support whenever I approached him. I would also like to express my sincere gratitude to Prof. Govind Pandey, Madan Mohan Malaviya University of Technology, Gorakhpur, for his help during research paper writing and technical discussion. I also express my sincere gratitude and thanks to my faculty members Dr. Anil K. Haritash, Prof. Anubha Mandal and Mrs. Geeta Singh for his/her support during my research work.

I wish to express my special thanks to Dr. Ajay Singh Nagpure, University of Minnesota, USA for his consistent motivation and providing all kinds of support during my research work. I do not have sufficient words to express my feelings and sentiments for Er. Abhinav Pandey, Larsen & Toubro, Delhi, for his constant support and encouragement. I also would like to express my thanks to Dr. Ankita Shukla for valuable discussion on subject matter and for her constant support.

I gratefully acknowledge the academic branch and administration of DTU for providing the environment and facilities to carry out my research work. I also express my thanks to office staff of Department of Environmental Engineering for their all kind of support.

The thesis would not have come to a successful completion, without the help of Mr. Shailendra, Mr. Amit Krishan, Mrs. Vandana Shan, Mrs. Manisha, Mr. Tinkit and Miss. Sakshi.

Presence of supportive, protective and carrying friends are boon for any research scholar. I would like to express my heartiest thanks to Dr. Pankaj kumar, Dr. Ragavendra Gupta, Dr. Mukesh Kumar, Dr. Virendra Kumar , Dr. Vijay Singh, Dr. Than Singh, Dr. Amit Kumar, *Mr. Vinay and Mr. Mrityunjay. I also would like to express thanks to my friend Sushil for their support and encourgement.*

I wish to record my profound gratitude to my parents who has provided me all kind of support and help for my academic achievements, and for their constant love and care. I would to like to express my thanks to my sisters and other family members for the heartiest cooperation and affection. I would like to express my special thanks to Dr. Babita Kumari, CSIR-NBRI, Lucknow, for guiding me throughout my Ph.D. work and for her constant support.

Finally, I thank all who have helped me directly or indirectly in completion of this research. Thank you so much!

Last but not the least, I thank to almighty God for showing me right path to complete this Ph.D. thesis. Thank you all.

Date: *(Amrit Kumar)*

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ABSTRACT

The rapid urbanization and large-scale motorization inevitably bring challenges to the urban environment. Almost all large and mid-sized cities in India are facing problems of population increase, urban sprawl, traffic congestion, air pollution, and high-energy consumption. The profiling of a modern city is of huge importance to its competitiveness in the national and international context. In Delhi, however, mass motorization was introduced spontaneously because of rapid economic liberalization over the past two decades within the framework of a low-income country. Further, this megacity has heterogeneous kind of population, with varying socio-economic background and income levels. This mixed profile of the city is reflected in the different fleet composition across the transport corridors.

Air pollution is considered as one of the prominent killer to human beings. Polluted air was responsible for 6.4 million deaths worldwide in 2015 out of which 2.8 million were contributed by household air pollution whereas 3.6 million from ambient air pollution and it is projected that by 2060, it may be increased to the figure of 6 to 9 million deaths per year. Non-communicable diseases account for 70% of air pollution deaths, and air pollution is a major, insufficiently appreciated cause of non-communicable disease. Worldwide, air pollution was responsible for 24% of ischemic heart disease deaths, 21% of stroke deaths, 23% of lung cancer deaths and 19% of all cardiovascular deaths in 2015. Worldwide, Cardiovascular diseases are known to play major role for mortality and morbidity in South Asia between 1990 and 2020 and are currently a leading health problem in urban India too with 35% of total deaths due to health conditions. Vehicle emissions are not only degrading the ambient air quality of the atmosphere but also responsible for the morbidity and mortality cases of drivers,

commuters and individuals living near major roadways. Study reported that the major health problem occurred on account of time travelled in traffic areas, the exposure duration of rush hours, and congestion of the traffic. The present research work is to encompass the assessment of concentration of different vehicular pollutants at different road transport corridors along with the estimation of the emission of pollutants from vehicles at selected transport corridors. In addition to this, GIS maps of identified pollutants namely CO, PM_{10}, $PM_{2.5}$, NO_x, SO_x and C_6H_6 were developed to estimate the spatial extent of impacts of these harmful pollutants. The questionnaire survey has also been undertaken to correlate public health issues with atmospheric pollutants if any, and providing suggestions and mitigation strategies for the better management of public health with reference to various pollutants.

The study reveals that the vehicular pollution has gradually increasing in recent times. Delhi the capital city of India has distinctly been affected with highly hazards vehicular pollution levels. The present study has been undertaken aimed at pollution estimation at different transport corridors of Delhi city with a view to analyzing the changing traffic composition trends and its impacts on the levels of ambient air pollutants. From the study, it was found that Ring road (Safdarjung) had the highest concentration of CO and PM_{10} as 3,066 and 422 $\mu g/m^3$ while Auchandi Road bore the lowest concentration of the same as 193 and 23 $\mu g/m^3$. The maximum observed value of pollutants concentration were 363 $\mu g/m^3$ of NOx at Maa Anandmayi Marg, 542 $\mu g/m^3$ of $PM_{2.5}$ at ISBT Flyover and 42$\mu g/m^3$ of SOx at Nizamuddin Bridge respectively and the minimum observed values were as 24 $\mu g/m^3$ at Pusa Road, 53 $\mu g/m^3$ at Sansad Marg and 2 $\mu g/m^3$ at Auchandi Road respectively.

The assessment of human health risk regarding mortality and morbidity induced by multiple air pollutants prevailing at 36 transport corridors of the National Capital Territory (NCT) of Delhi, India. The study, covering PM_{10}, $PM_{2.5}$, SO_2 and NO_2, utilized the Risk of Mortality/Morbidity due to Air Pollution (Ri-MAP) model in a bid to assess the direct health impacts in the year 2016. The World Health Organization (WHO) guidelines were used to calculate mortality and morbidity for the population in 4 km2 grid sizes in the vicinity of all transport corridors and the results indicate that aggravated by the vehicular traffic, the excess number of mortality cases due to respiratory, cardiovascular, and the total mortality were studied at ISBT Flyover 365, 1399 and 2136 respectively. The very closed data were observed at Wazirabad Road 362, 1378 and 2096 caused by respiratory, cardiovascular, and the total mortality respectively. These two transport corridors also recorded a maximum number of excess cases of morbidity regarding hospital admission due to COPD (Chronic Obstructive Pulmonary Disease) and cardiovascular illness as 18979 and 4762 as well as 18969 and 4761 respectively.

Further, excess numbers of cases were reported in 4 km^2 grid sizes alongside the transport corridors throughout the megacity of Delhi, thereby presenting a very plausible scenario of traffic-induced human health risk in different residential and other areas. Similar studies with a more focused approach would help not only towards a better transport corridor planning but also help health institutions to be preferable to control excess number of such peculiar health cases in the city and elsewhere.

Assessment of the GIS mapping of traffic induced air pollutants along various transport corridors in Delhi has been studied in this thesis. This part includes the classification of vehicular pollutants parameters into five distribution classes, i.e., low, moderately low, moderate, moderately high, and high. Spatial maps have been developed using Kriging tool in ArcGIS environment for eleven districts covering 36 transport corridors of the city. The study demonstrated concentration of four of the six ambient air pollutants, namely, benzene, NO_x, PM_{10} and $PM_{2.5}$, with highest values in the range of 6.68-13.86 $\mu g/m^3$, 294.10-362.57 $\mu g/m^3$, 203.99-422 $\mu g/m^3$ and 333.71-541.72 $\mu g/m^3$ respectively along the corridors.

Corresponding National Ambient Air Quality Standard (NAAQS) values were found to be grossly violated as reflected by benzene, NOx and PM concentrations having 2-5 times higher values. Remaining two (CO and SOx) were found to be within permissible limits, and most of them exhibited low levels of observed concentrations. The ambient air quality in south, central, east, and New Delhi areas were found to be in high and moderately high classes necessitating adequate control measures.

A questionnaire survey was also conducted in the vicinity areas of selected locations, based on air quality and health risk assessment. This survey was aimed to investigate the understanding of public and their opinion about health effects being caused due to exposure to air pollution during their day to day activities in life. This interviewer-assisted questionnaire was developed on the basis of thorough literature review. Respondents were chosen from nearby residential areas, pedestrians using the walkways, motorists, cyclists, rickshaw-pullers, shopkeepers, students, working labors along the transport corridors, vendors, traffic police, doctors etc. According to experiences of residents and commuters eye irritation, breathing difficulties, running nose and congested nose, sneezing bouts, throat irritation and headache were observed the major health effects. Eye irritation was found as one of the prominent health concern among the people who were in the age group of 26 to 50 years. In Delhi, most of the people spend their 6 to 10 hours (more than 48 %) time outside the home due to their work profile. After the analysis, it is observed that the emission, concentration and associated health risk are aggravated by the high vehicular density, and densely populated areas along the selected transport corridors. Most of such transport corridors were found to be under “severe” or “very poor” class according to Indian air quality index posing a direct health risk to the exposed population.

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OICA	International organization of motor vehicle manufacturers
GDP	Gross domestic produce
MORTH	Ministry of road transport and highways
CSE	Centre for science and environment
MOF	Ministry of finance
MOSRTH	Ministry of shipping, road transport and highways
CO2	Carbon dioxide
CO	Carbon monoxide
PM	Particulate matter
NOX	Oxides of Nitrogen
CAGR	Compounded annual growth rate
UT	Union territory
UP	Uttar Pradesh
NMT	Non-motorised transport
M&HCVs	Medium & heavy commercial vehicles
HC	Hydrocarbons
CPCB	Central pollution control board
GHG	Green house gases
NAAQS	National ambient air quality standards
2W	Two-wheelers
4W	Four wheelers
CH_4	Methane
SO_2	Sulphur dioxide

NGO	Non-government organization
IMD	Indian meteorological department
MSAT	Mobile source air toxic
C6H6	Benzene
PM10	Fine particulate matter
WHO	World health organisation
GBD	Global burden of disease
IMF	International monetary fund
HEI	Health effects institute
CNS	Central nervous system
GIS	Geographic information system
NCT	National capital territory
AQI	Air quality index
SPM	Suspended particulate matter
TSP	Total suspended particulates
RSPM	Respirable suspended particulate Matter
USA	United States of America
GM	General motors
ARIMA	Autoregressive integrated moving average
OMG	Osaka municipal government
APRAC3	Air pollution research advisory committee version3
DMRB	Design manual for roads and bridges
UV	Utility vehicles
CNG	Compressed natural gas
LPG	Liquefied petroleum gas
VOC	Volatile organic compounds
PAHs	Poly-nuclear aromatic hydrocarbons

EPA	Environmental protection agency
AQS	Air quality simulation
LSMs	Line source models
ANN	Artificial neural network
MLP	Multilayer perceptron
DALYs	Disability-adjusted life year
AAP	Ambient air pollution
MPI	Multipollutant index
CNG	Compressed natural gas
NMVOCs	Non-methane volatile organic compounds
NH_3	Ammonia
EBD	Environmental burden of disease
COPD	Chronic obstructive pulmonary disease
IHD	Ischemic heart disease
CVD	Cardiovascular disease
BC	Black carbon
UFP	Ultra fine particles
OSHA	Occupational safety and health administration
MTBE	Methyl-tertiary-butyl-ether
NIOSH	National institute for occupational safety and health
ABD	Association of British Drivers
CDC	Centre for disease control
BAU	Business as usual
ICCT	International council on clean transportation
MCCD	Medical certification of cause of death
O_3	Ozone
HIV	Human immune virus
WEO	World energy outlook
ATV	All-terrain vehicles
GPS	Global positioning system

IDW	Inverse distance weighted
STEMS	Space-time exposure modelling system
TOTEM	Time–activity-based exposure model
GAINS	Greenhouse gases and air pollution interactions and synergies
IVE	International vehicle emission
MLR	Multiple linear regressions
AHV	Analytic Hierarchy Process
SOE	State of environment
HCV	Heavy commercial vehicle
LCV	Light commercial vehicle
APHRA	Air pollution risk health assessment
CRF	Concentration-response-functions
SFU	Solid fuel use
RRs	Relative risk
Ri–MAP	Risk of mortality/morbidity
AP	Attributable-risk proportion
ITO	Income tax office
ISBT	Inter-state bus terminal
ADB	Asian development bank
PN	Particle number
NA	Not available

CHAPTER 1

INTRODUCTION

1.1 General

Presently air pollution has become one of the most sensitive issue affecting millions of people around the world. Air pollution has been considered as a major health risk factor as studied and reported by various researchers. In urban areas, road transport represents a key source of air pollution. Rapid urbanization, vehicular growth, increasing energy demand are putting a lot of pressure on the environment of urban cities (Beig, 2013; Kaskaoutis *et al*., 2013). This leads to the generation of different environmental problems in urban areas like air pollution, noise pollution, water pollution etc. (Aneja *et al*., 2001; Gharehchahi *et al*., 2013).

In megacities like Delhi, the air pollution has been on continuous rise primarily due to the intense use of vehicles. Because of its contrary effect on human health**,** it has become a prime and priority issue for public authorities, policy makers and transport planners in mega cites **(**Neidell, 2004; Pershagen *et al*., 1995). The urban air is continuously polluted due to rapid urban development (Badami, 2005; Johnson *et al*., 2011; Gulia *et al*., 2015). The higher traffic flow as well as high density of the development contribute to the degradation of urban air quality. Because of income rise and rapid urbanization, the vehicular traffic has increased in several developing countries like India. The traffic related environmental problems and associated impacts has become more severe in developing countries due to heavy traffic fleet and lack of adequate traffic management.

In megacities, urbanization**,** industrialization as well as increasing vehicular traffic have resulted in increased contamination of ambient air environment. Presently road transport has become a major source of traffic congestion, noise pollution and atmospheric pollution in urban areas. Urban air quality is gradually leading to violation of permissible limits. They are centers of driving force for economy, education, and infrastructure development. Mobility and transportation are backbone of the megacities and nowadays the increasing number of vehicles in megacities has been putting a lot of pressure on existed transport infrastructure, which leads to increasing vehicular pollution (Chana and Yao, 2008; Drimal *et al*., 2010) and has become an alarming challenge for government, policy makers and researchers.

1.2 Urbanization and transport: global scenario

The worldwide urban population has more than tripled from 2.86 billion in 1950 to 7.35 billion in 2014. As per the study of growth rate of census the world's population is expected to reach up to 9.73 billion by 2050. In terms of population, Tokyo is considered as world's largest city (38 million habitants), followed by Delhi (25 million), Shanghai (23 million), and Mexico (21 million) city. The rapid urbanization and motorization leads to increase in the number of vehicles that brings many environmental risks and problems that can seriously jeopardize the sustainability of countries (Agarwal *et al*., 2006**;** Sharma *et al*., 2011; 2013).

As of now, majority of the population is residing in urban area than in rural areas. Currently urban development has substantially decelerated in developed countries, while developing countries are continuously urbanizing, account for 68% of urban population in 2000. By 2020, 77%, i.e., 3.26 billion of global urban population is expected to be in developing counties. Increasing urbanization is affected by two factors i.e., a natural increase in population (excess of birth over deaths) and migration to urban area. At present, the movement of people from rural to urban area is increasing significantly. Amongst the megacities of India, Mumbai, Kolkata and Delhi accommodated over 65% of the megacity population. However, in 2003, 74% of the population was living in urban area and as per estimation, by 2030, it will become 82% of the population. The increasing urban population leads to unplanned urban development, increase in consumption patterns and growing demand for transport and energy sources, which lead to vehicular pollution. The current scenario of newly registered vehicles in different countries are depicted in Table 1.1.

1.3 Urban transport and vehicle scenario of India

Indian transport sector is growing enormously and hence playing crucial role in economical growth of India. In 2012-2013, it contributed nearly 5.2% of the nation's GDP, from road transportation. Efficient as well as reliable transport system is essential for India to sustain high economic development. Transport system plays a major role in poverty reduction, easy access to labour markets and increases the means of income in poorer communities (Wyler *et al.*, 2000; Estache, 2015; Monteiro *et al.*, 2007). Current status of urban mobility is generating the problems of traffic jam, urban pollution and traffic mortalities in megacities (Wjst *et al.*, 1993; CSE 2012; Lanzafamea *et al.*, 2014). More than one quarter of urban population in India is found to be living below the poverty line, the urban poor mobility has therefore become a major concern of the government at all levels. The financial crisis among poor people does not allow them to take private or public transport to commute from one place to another place.

Due to this, they adopt an alternative transport system like cycle or walk and get exposed to higher concentration of vehicular pollution.

Table 1.1: Global scenario of newly registered vehicles in major countries (in Million)

Country	**2005**	**2007**	**2009**	**2011**	**20013**	**2015**	**2016**
Australia	0.99	1.05	0.94	1.01	1.14	1.16	1.18
Bahrain	0.02	0.03	0.04	0.03	0.05	0.06	0.05
Bangladesh	0.02	0.02	0.04	0.04	0.04	0.05	0.04
Brunei	0.02	0.01	0.01	0.02	0.02	0.02	0.02
China	5.76	8.79	13.64	18.51	21.98	24.66	28.03
Hong-Kong	0.04	0.04	0.03	0.05	0.06	0.06	0.05
India	1.44	1.99	2.27	3.29	3.24	3.42	3.67
Indonesia	0.53	0.43	0.49	0.89	1.23	1.03	1.05
Iran	0.86	1.04	1.32	1.69	0.80	1.22	1.45
Israel	0.16	0.22	0.17	0.23	0.22	0.26	0.29
Japan	5.85	5.31	4.61	4.21	5.38	5.05	4.97
Jordan	0.02	0.01	0.02	0.02	0.03	0.02	0.02
Kazakhstan	0.04	0.05	0.05	0.04	0.17	0.10	0.05
Malaysia	0.55	0.49	0.54	0.60	0.66	0.67	0.58

Source: International Organization of Motor Vehicle Manufacturers (OICA) 2017

The urban dwellers are also facing prolems due to poor transport system. The severity in the urban transportation system is attributable to contribution by various general factors. The transportation systems particularly relate to motor vehicles that have been contributing to air pollution levels in our atmosphere. Many urban cities are facing the aggravated vehicular pollution problems.

Total number of road vehicles, in India corresponded to 72.7 million (MoSRTH, 2007; Shrivastav *et al*., 2013). Presently, motor vehicles are recognized as a primary source behind the generation and aggravation of air pollution problems in atmosphere. Primarily, road transport sector is accountable for the generation of various gaseous and non-gaseous pollutants. Traffic pollution has a significantly to local, regional as well as global air pollution problems. The yearly trend of registered motor vehicles is shown in Figure 1.1.

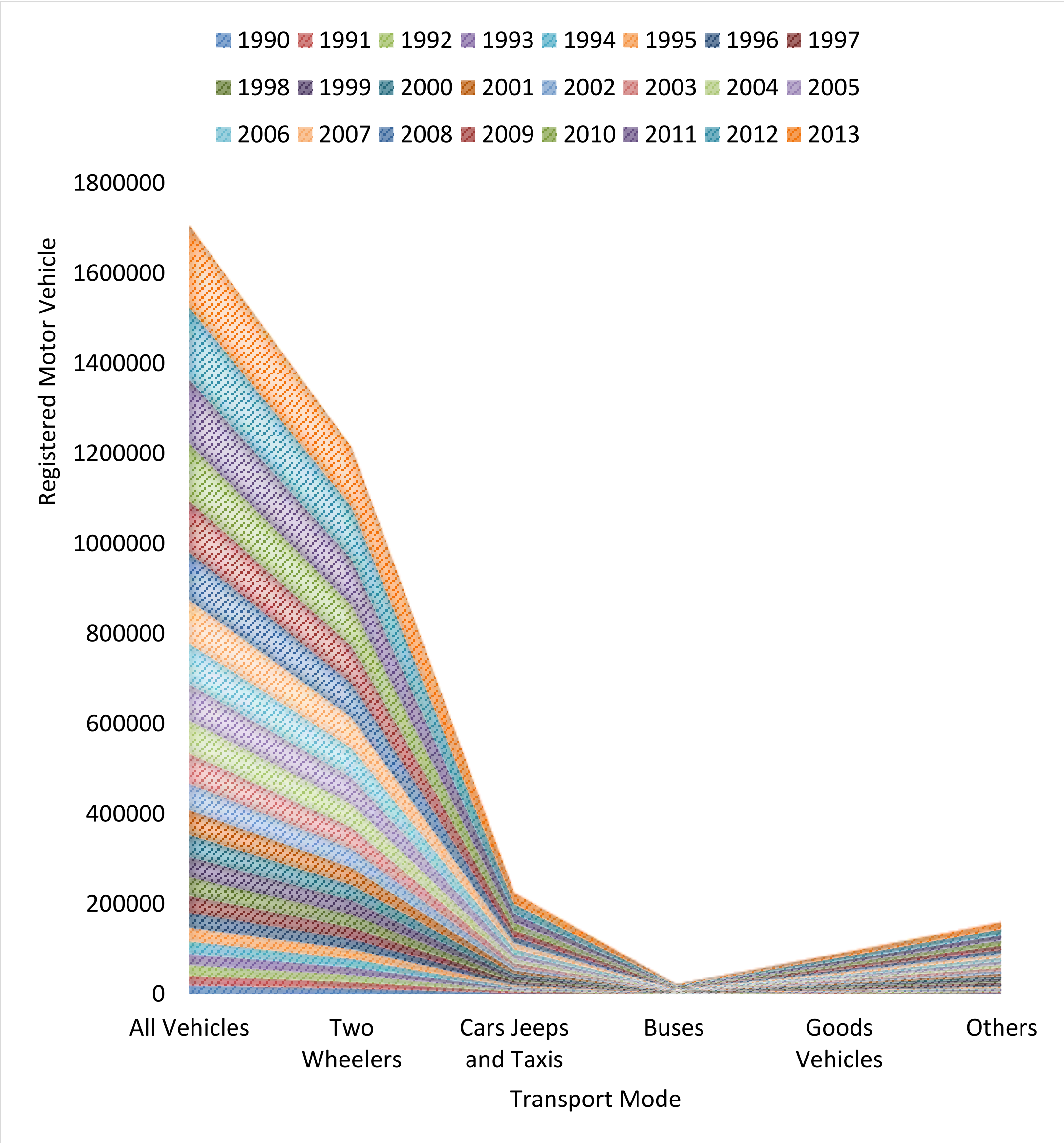

Figure 1.1: Decadal registered motor vehicle trend in India

From Figure 1.1, annual increment (0.3 million in 1951 to 142 million in 2011) is observed in the total number of registered vehicles in India (MoRTH, Year Book 2010-11). In 2015, the total number of registered motor vehicles were 210.02 million in India. State wise registered number of motor vehicles in India is depicted in Figure 1.2.

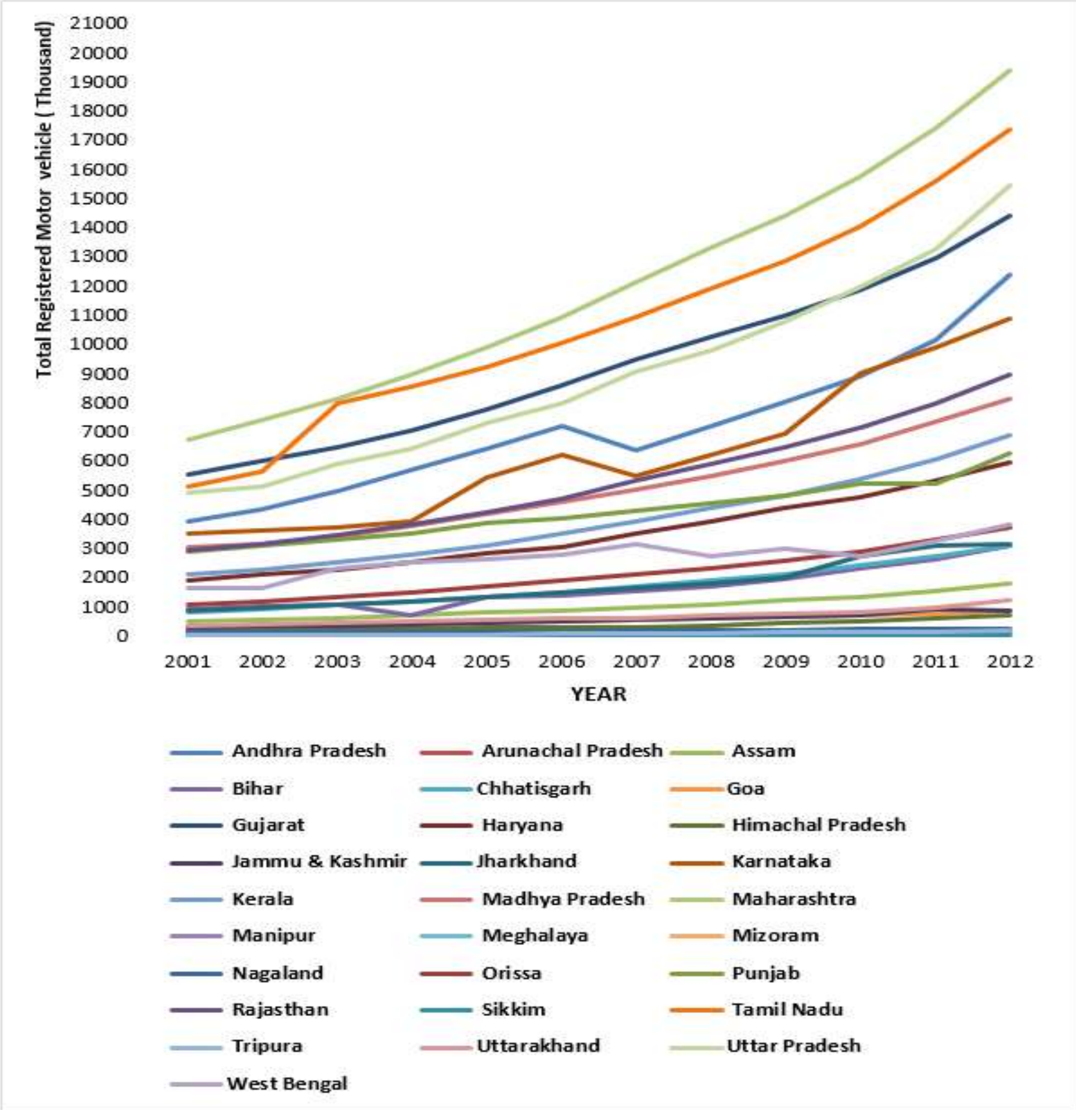

Figure 1.2: State-wise total number of registered motor vehicles in India

Of the total registered motor vehicles in the country, the states of Maharashtra, Tamil Nadu and Uttar Pradesh, Gujarat and Andhra Pradesh accounted for 12.2%, 11.0% and 9.7%, 9% and 7.8% respectively. The lowest number of motor vehicles (i.e., 0.01%) registered in the union territory (UT) of Lakshadweep. Amongst all the above reported states, the lowest number (0.03%) of the registered vehicles was found in Sikkim. In terms of compound annual growth rate (CAGR) of registered motor vehicles, wide range of variation was observed amongst the States/UTs. The highest CAGR for registered vehicles during 2002-2012 was recorded by Arunachal Pradesh (21.8%), followed by Dadra & Nagar Haveli (20.6%) and Tripura (13.6%), whereas the lowest CAGRs were recorded by Nagaland (5.1%), Delhi (7.1%), Lakshadweep (7.1%) and Punjab (7.3%).

1.4 Population growth and urban development of India

The rapid economic growth, industrialization and urbanization in India are primary responsible factors for atmospheric pollution. State wise population in India is depicted in Figure 1.3. The highest population was observed in Uttar Pradesh (U.P.) whereas lowest was found in Lakshadweep. Decadal growth as well as age wise distribution of population in India is presented in Figure 1.4 and 1.5 respectively. Population residing in urban areas has increased from 25.8 million in 1901 to 285.3 million in 2001. It reflects a gradual increasing trend of urbanization. Of the total 1210 million populations, about 68.84% people live in rural areas and 31.16% in urban area. World Meter (2018) reported a growth of 12.2% and 31.8 % in rural and urban areas correspondingly.

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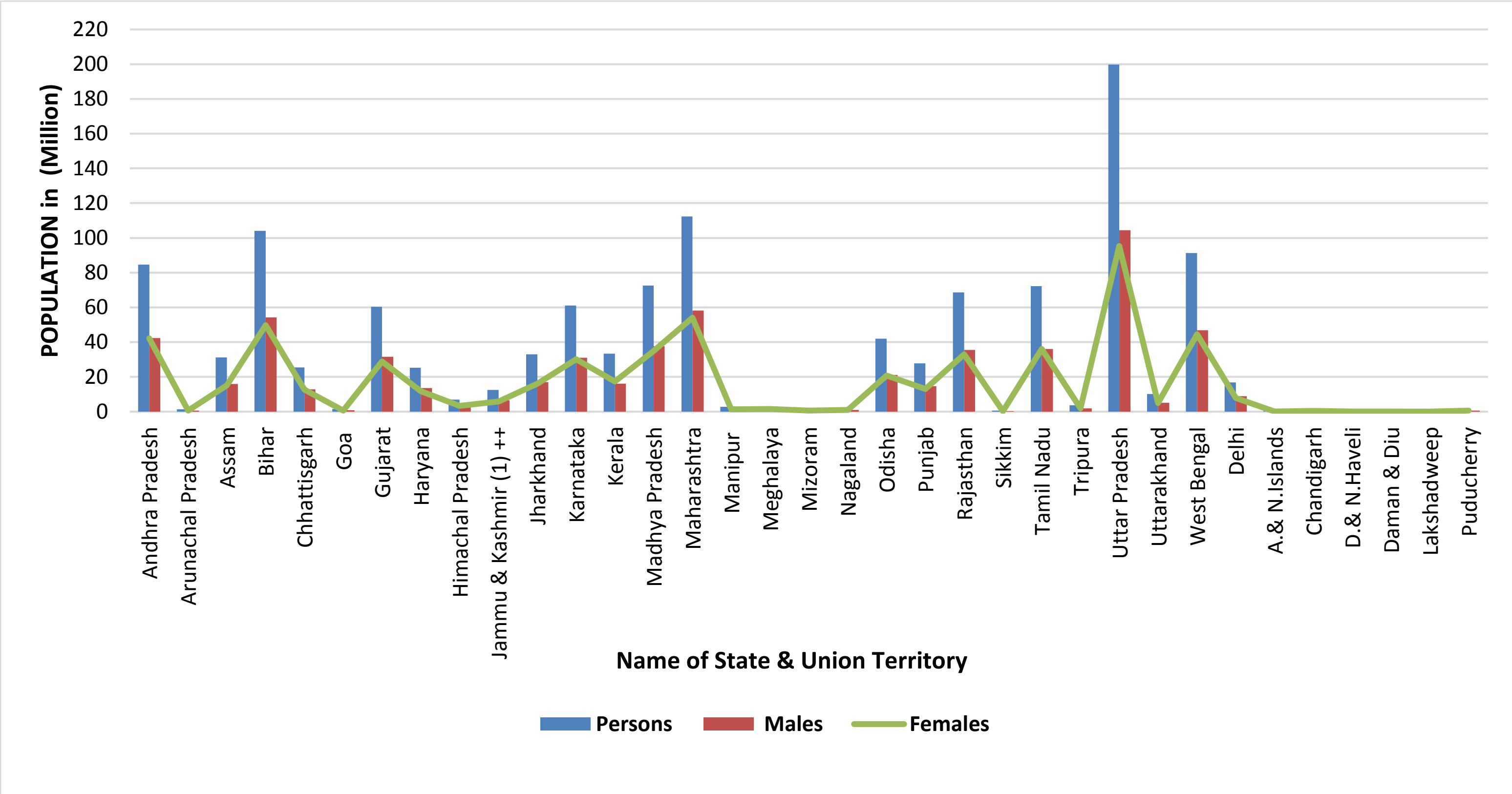

Figure 1.3: State wise population distribution in India

Source: Office of Registrar General of India, Ministry of Home Affairs (2016)

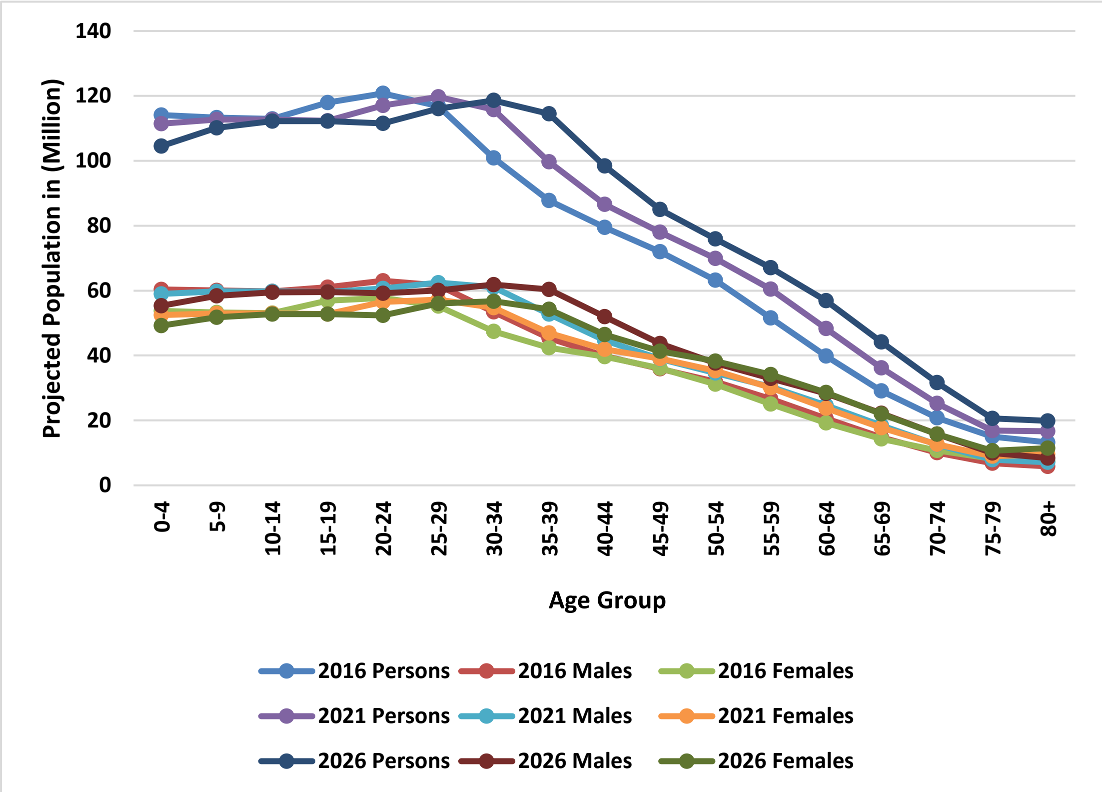

Figure 1.4: Projected population of India in different age group

Source: Office of Registrar General of India, Ministry of Home Affairs (2016)

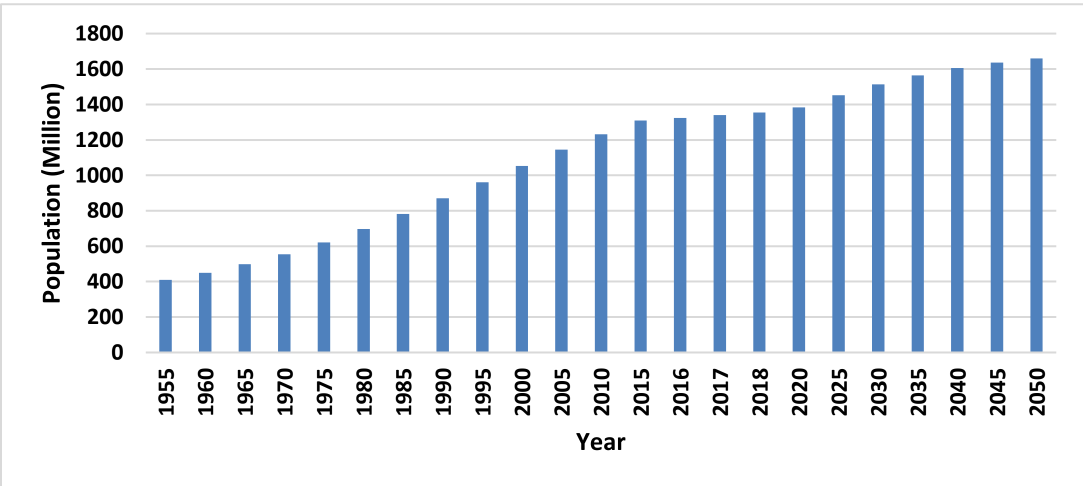

Figure 1.5: Decadal variation of population of India

Source: Office of Registrar General of India, Ministry of Home Affairs (2016)

India is at acceleration stage of urbanization process. From the Figure 1.5**,** between 1955 and 2015, the population has increased more than three times from 409 million to 1309 million and its portion has increased 31.24% (Census of India, 2011). The current population of India is 1339 million in 2017 (world population prospect 2017) out of which, 32.8% are living in urban areas. The population density in India is 450 per km^2. The current population and growing trend of urbanization in developing countries have resulted in increased air pollution and without adequate air pollution control programmes.

1.5 Trends of urban mobility in India

The predominant trends of rapidly rising urbanization and mode of share of motorization and Non-Motorised Transport (NMT) are influcing the mobility of urban population in India (Pokharel et. al., 2002; Mary *et al*., 2012). On account of rapid urbanization as well as motorization in the megacities, the travel demand has also been augmented. In parallel to that, the increasing automobile ownership have started to generate the problems of traffic congestion, vehicular pollution, accidents, and diverse kind of social issues like equity and security.

1.6 Glimpse of vehicle production in India

In 2016, India ranked fourth largest motor vehicle manufacturer in the world. In the year 2016-17, India produced a record of 25.3 million motor vehicles, including 3.79 million passenger vehicles. India ranked first and fourth position in three-wheelers and commercial vehicles manufacturing with 0.78m and 0.81m units respectively. India is the largest manufacturer of two-wheelers (19.9m units) and tractors (sales 0.58m units) in 2016-17. Construction vehicle production was approximately 59,000 in 2014, more than two million (2.03 million) (OICA 2016).

Table 1.2: Various categories of vehicle sale in India (in million)

Category	**2011-12**	**2012-13**	**2013-14**	**2014-15**	**2015-16**	**2016-17**
Passenger Vehicles	2.63	2.67	2.50	2.60	2.79	3.05
Commercial Vehicles	0.81	0.79	0.63	0.61	0.69	0.71
Three Wheelers	0.51	0.54	0.48	0.53	0.54	0.51
Two Wheelers	13.41	13.80	14.81	15.98	16.46	17.59
Grand Total	17.36	17.79	18.42	19.72	20.47	21.86

Table 1.2 shows how the pattern of vehicle demand is growing day by day. The sale of passenger vehicles (PC) raised by 9.23% in 2017 over the previous year. The sales of passenger cars, utility vehicles and vans in 2017 itself increased by 3.85%, 29.91% and 2.37% respectively. In 2017, the overall **c**ommercial **v**ehicles segment registered a growth of 4.16% as compared with previous year. In case of medium and heavy commercial vehicles, the sale has been increased by 0.04%, whereas the light commercial vehicles showed a sale increment of 7.41% in 2017. A declination in sale was observed in case of three wheelers (4.93%) during 2017. During 2017 itself, two wheelers sales registered a growth of 6.89%.

1.7 Emission of pollutants from various transport mode

The motor vehicles like car, three-wheeler, truck and bus are the major causes of atmospheric pollution. In 1950, through studies conducted in Los Angleses, it was clear that emission from automobiles play dominant role in urban air pollution. Automobile are considered as primary source of carbon monoxide (CO) and lead. The various pollutants are releaased from motor vehicles into the atmosphere and cause serious environmental and health problems (Mohan *et al*., 2007; Gehring *et al*., 2010; Luke *et al*., 2010). Figure 1.6 depicted the annual emission of various pollutants from different categories of vehicles in India.

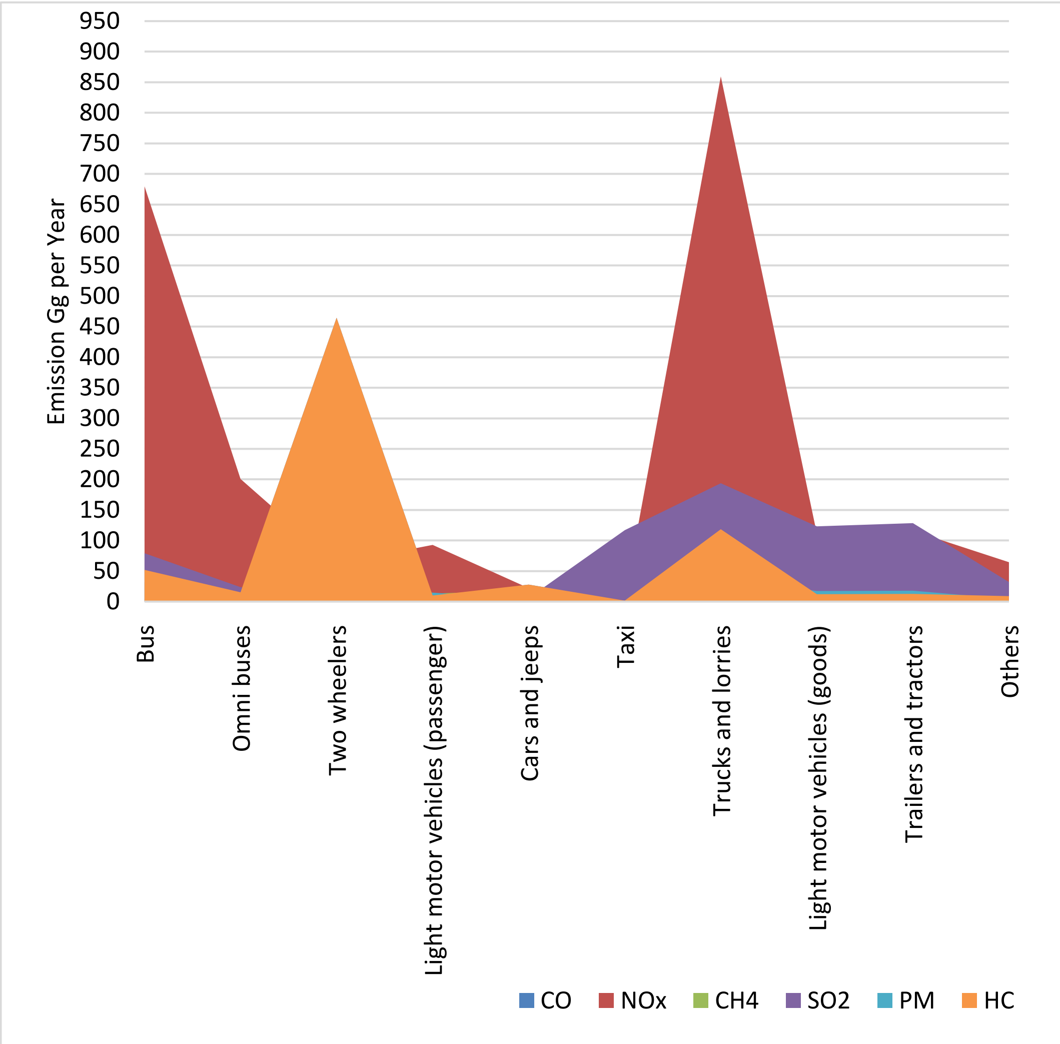

Figure 1.6: Annual emission of various pollutants in India

In worldwide greenhouse gas production, around 14% comes from the transport sector only (CPCB, 2010). Because of inadequate public transport system, increasing traffic density as well as private vehicles, the emissions of different vehicular pollutants would increase in coming years (Sharma *et al*., 2010; Singh and Sharma, 2012).

Vehicular emission has become a serious problem in Indian cities. The exact sources of air pollution in most of the Indian cities are not known due to the lack of source apportionment studies and this has become a great matter of concern. The city air pollution level has already violated the permissible limits as given by the CPCB (CPCB, 2011). The problem has further been aggravated by the high concentration of pollutants due to high motor vehicles to population ratios in the megacities. Two-wheelers (2W) and car {four wheelers (4W), excluding taxis} account for about 80% of total traffic volume. Correspondingly, human population has also risen from 0.36 billion to more than 1 billion during this period. The transport corridors used about 25% of total energy, of which, 98% comes from oil only. Even though gasoline automobiles consitute about 85% of the total vehicular population and the use of diesel is six times more as compared to the petrol. Nowadays, most of the commuter as well as freight movement is shifted from rail transport system to road-based transportation which leads to increase in fuel consumption that may also results in increased emissions of various pollutants. Vehicles in mega cities of India are estimated to account for 70% of CO, 30-40% of NOx, 10% of SOx and 30% of PM of the total pollution load of these cities (Goyal *et al*., 2006; Guttikunda, 2009). Increase in urban population, which constitute about 31% of the Indian population (about 17-28% during 1951-2001) has resulted in greater contribution of vehicles in the urban cities like Delhi, Mumbai, Chennai and Kolkata. The vehicular contribution of these four megacities are more than 15% of the total indian vehicular population. On the other hand, the vehicular contribution of rest

Table 1.3: Vehicular emissions in various cities of India (in Megagram/km^2)

Metropolitan city	CO_2	CO	HC	NO_X	PM	SO_2
Hyderabad	18258.86	281.47	78.05	197.12	13.91	55.94
Visakhapatnam	5034.01	77.6	21.52	54.35	3.84	15.42
Patna	18244.82	189.16	32.91	149.03	10.42	55.6
Delhi	20843.82	284.43	87.74	129.99	9.13	42.38
Ahmedabad	12438.69	165.52	35.49	93.2	7.52	32.99
Surat	10967.65	145.94	31.3	82.18	6.63	29.09
Vadodara	2481.43	21.33	5.52	29.16	1.47	8.66
Bangalore	32013.25	405.25	86.03	323.75	22.18	93.29
Bhopal	3786.22	47.58	11.6	27.29	2.19	12.26
Indore	11973.75	150.46	36.69	86.31	6.92	38.77

Mumbai	8562.01	118.91	24.69	67.8	5.41	23.67
Nagpur	7955.7	110.49	22.94	63	5.03	22
Pune	5366.96	74.54	15.48	42.5	3.39	14.84
Ludhiana	14 847.91	183.9	43.43	98.33	8.09	38.7
Jaipur	6571.53	72.76	17.61	65.61	4.13	18.35
Chennai	34 903.50	429.13	118.95	353.67	23.01	108.04
Kanpur	4570.5	59.85	15.07	32.01	2.65	12.3
Lucknow	5616.32	73.55	18.52	39.34	3.26	15.12
Varanasi	11 370.76	148.91	37.49	79.64	6.6	30.61
Kolkata	22 402.15	213.94	59.66	273.55	14.23	72.07

Source: MoSRTH, 2007a, b; Census of India, 2011 of the urban cities (urban population > 1 million) are about 35% of the overall vehicular population in India. City wise vehicular emission has been summarized in Table 1.3.

1.8 Factors affecting pollutants emission

A number of factors are there that affect the emission of pollutants from vehicles. Vehicle engine operating modes, speed of vehicles, accelerations, and decelerations factors are considered under this category. Certain facility designs also encourage vehicular emissions. Driving pattern of a driver is one of the important factor in the direction of vehicular emission and it may be affected by the traffic condition. Fuel types and fuel quality also affect emission levels significantly. The factors influencing automobile emission can be primarily grouped into four categories based on the vehicle, fuel, fleet and operational characteristics. For instance, older vehicles and longer mileage, and mileage will have worse quality of exhaust emission. Likewise, a poor degree of I/M history of a vehicle will lead to non-compliance of even in-use emission norms. Apart from many vehicle-related parameters, the type of fuel (e.g., petrol, diesel, bio-diesel, natural gas etc.) and its physico-chemical characteristics that are supplied to the vehicle will have effect on exhaust gas quality. Other categories entail fleet and operational characteristics. Some of such parameters are vehicle mix, utilization, age profile, environmental conditions, vehicles use patterns etc.

1.9 Status of vehicular growth and pollution scenario in Delhi

The growth rate of vehicles in Delhi during 2014-2015 stood at 6.89 % (Table 1.4). The highest growth (7.38%) of goods vehicle was observed during the period of 2014-2015. Annual growth rate during 2014-15 in comparison to the previous year was observed in motor cycles and scooter at 7.27%. It is 6.48% in Taxis and 6.30% in case of car and Jeeps. The negative growth of vehicles recorded in other passenger vehicles, tractors and others vehicles during 2014-15.

Table 1.4: Vehicles population growth rate of Delhi

S. NO.	**Details**	**Number of Vehicles**		**Growth Rate Percentage**
		2013-2014	2014-2015	
1	Cars and Jeeps	2625250	2790566	6.30
2	Motor Cycles & Scooters	5296163	5681265	7.27
3	Ambulance	1519	1527	0.53
4	Auto Rickshaws	78750	81633	3.66
5	Taxies	74758	79606	6.48
6	Buses	19641	19729	0.45
7	Other Passenger Vehicles	11289	11284	-0.04
8	Tractors	1651	1637	-0.85
9	Good Vehicles	149147	160156	7.38
10	Others	106	28	-73.58
Total		8258274	8827431	6.89

Source: Economic Survey of Delhi 2014-2015

The percentage traffic volume of different categories of vehicles in Delhi from 2001 to 2015, is presented in Table 1.5. This table basically depicts the percentage contribution of traffic volume from the year 2005-2015, from this table the highest contribution was observed from two-wheelers (7.24%) followed by car, goods vehicles etc.

Table 1.5: Percentage of traffic volume in 2005 to 2015 of Delhi

Vehicle	2005-06	2006-07	2007-08	2008-09	2009-10	2010-11	2011-12	2012-13	2013-14	2014-15
Cars and Jeeps	30.47	30.57	30.74	30.92	31.2	31.34	31.5	31.9	31.78	31.61
Motor Cycles and Scooters	63.74	63.75	63.58	63.2	62.87	62.65	62.46	63.97	64.13	64.35
Ambulance	0.04	0.04	0.04	0.04	0.04	0.04	0.03	0.02	0.01	0.01
Auto Rickshaws	1.54	1.42	1.34	1.39	1.34	1.27	1.18	0.98	0.95	0.92
Taxies	0.43	0.49	0.54	0.66	0.7	0.83	0.93	0.91	0.9	0.9
Buses	0.53	0.51	0.48	0.47	0.47	0.48	0.46	0.26	0.23	0.22
Other Passenger Vehicles	0.38	0.38	0.34	0.33	0.32	0.3	0.31	0.14	0.13	0.12
Tractors	0.1	0.09	0.09	0.08	0.08	0.07	0.07	0.02	0.02	0.01
All Goods Vehicles	2.65	2.64	2.77	2.83	2.91	2.94	3	1.78	1.8	1.81
Others	0.12	0.11	0.08	0.08	0.07	0.07	0.06	0.02	0.001	0.003
Total	100	100	100	100	100	100	100	100	100	100

Source: Delhi Statistical Handbook (2012; 2014; 2017)

Air pollution has remained consistently high and still rising day by day in Delhi (Chelani, 2012). Delhi, the capital of India, is among the ten largest metropolitan areas worldwide with a population of 46.07 million (Census of India, 2011). The road transport system is known to be one of the primary source of vehicular pollution in Delhi. It is also noticed that Delhi is listed in the top most polluted city (Mishra *et al*., 2015; 2016). The various important factors are presented in the environment which are responsible for the bad air quality, but the vehicular pollution is a leading factor to deteriorate the air quality of the cities. About 52% of the car in Delhi has an emission above the permissible limits. About 98% of freight transport either three wheelers or truck have been found to be more polluting vehicles. Delhi has been found to contain 310,57 metric tonnes of hydrocarbons, 651 metric tonnes of carbon monoxide, 86 metric tonnes of led and 126.46 metric tonnes of nitrogen dioxide. Nearly 82% of taxis and about 94% of private bus and Delhi transport corporation buses have been found to be polluters (Indian Express Newspaper, 2015).

In Delhi, more than 42% of all taxis, 28 % of all goods vehicles and 32% of all auto rickshaws are at least 15 years old. A study by the Centre for Science and Environment (CSE), 1997 reported that 52,000 people in Indian cities die prematurely because of air pollution, the figure for Delhi alone is about 10,000. Respiratory diseases are on the rise, particularly among school children (Raaschou *et al*., 2001).

Delhi has the highest road density of 2103 km/100 km^2 in India. Buses are the most popular means of road transport catering about 60% of Delhi's total demand (Das, 2017). The transportation sector is the single largest contributor to air pollution and motor vehicles are the worst polluters apart from most energy intensive modes of transport. Air pollution by vehicle emissions causes the most hazardous environmental impact of the transport sector. It is a product of road transport, which is the backbone of the urban transport system in most of the cities in India (Indian National Academy of Engineering 1996). Delhi, the capital, is spread over 1,483 km^2 with population of 26.45 million in 2016, and it may be 36.06 million in 2030. (The world cities 2016). The transport system in Delhi is predominantly road-based, with railways catering to only about 1 % of the local traffic. Buses are the primary mode of transport, which constitute only about 1% of total vehicles, whereas personal vehicles (two and four-wheelers) account for 94%. The remaining 5% include goods vehicles, auto rickshaws, and taxis. Although the ratio of buses to total vehicles is far smaller than other modes, it caters to the highest percentage of the total traffic load. The annual growth of vehicles in Delhi was found 6.4% in 2015-2016. During the same session, number of vehicles increased from 253 to 436 per 1000 population. The number of vehicles increased to push average annual growth rate as 7.40% private and 9.15% for commercial vehicles (State of Environment SOE, 2010). The vehicle per kilometer of road in Delhi has also increased from 128 to 191 between 2003 and 2009 (Goyal *et al*., 2013; Sharma and Khare, 2002). The road network has also increased from 28,508 km in 2000-01 to 32,663 km in 2011. The annual average distance travelled in Delhi by car, taxi and auto, buses, HCV & LCV and 2-wheeler was found 10000 km, 36000 km, 5000 km and 27000 km respectively (Guttikunda and Goel, 2013; Sahu *et al*., 2011). The status of registered vehicles in Delhi megacity is presented in Table 1.6.

Table 1.6: Motor vehicles growth in Delhi (in million)

Years	Cars and Jeeps	Motor Cycles and Scooters	Ambulance	Auto	Taxies	Buses	Other Passenger Vehicles	Tractors	Goods Vehicle (All Types)	Others	Total
2009-10	2.02	4.07	0.002	0.087	0.045	0.031	0.020	0.005	0.188	0.005	6.47
20010-11	2.18	4.35	0.003	0.088	0.058	0.033	0.021	0.005	0.204	0.005	6.95
20011-12	2.35	4.65	0.003	0.088	0.069	0.034	0.023	0.006	0.224	0.005	7.45
20012-13	2.48	4.98	0.001	0.077	0.071	0.020	0.011	0.002	0.139	0.002	7.79
20013-14	2.63	5.30	0.002	0.079	0.075	0.020	0.011	0.002	0.149	0.000	8.26
20014-15	2.79	5.68	0.002	0.082	0.080	0.020	0.011	0.002	0.160	0.000	8.83
2015-16	2.99	6.10	-	0.198	0.910	0.043	-	0.002	0.159	-	9.70
2016-17	3.15	6.70	-	0.174	0.148	0.038	-	0.003	0.161	-	10.48

Source: Transport Department, Govt. of N.C.T. of Delhi. Mishra *et al*., (2016); Directorate of Economics and Statistics (2017

1.10 Meteorological aspects of air pollution

Meteorology has a vital role in air pollution studies. There is a strong seasonality in the meteorological factors that modulates the air quality levels (Cogliani, 2001; Kandlikar, 2007). Local meteorology that is commonly referred to as micrometeorology has a major role in air pollution. The relation between micrometeorology and dispersion of air pollutants primary involves wind in broader sense. Wind fluctuations over time and space play a crucial role in the dispersion of air pollutants. Wind flow in horizontal direction is a key parameter in the transportation of pollutants. A high wind speed always has high dilution capacity. On the contrary, low or mild wind may favour in accumulation of pollutants. Wind direction also largely influences the pollutants dispersion. Wind direction and wind speed for a given time period in particular space is known as wind rose which helps to understand the prevailing wind speed to predict the dispersion of pollutant from a point to area source. Turbulence and atmospheric stability are also very important parameter in dispersion of air pollutants. The urban surface pattern and temperature or solar isolation is the key parameter to determine these two. Thermal turbulence and unstable atmospheric condition always favours the dilution of the emitted air pollutants whereas, mechanical turbulence and stable atmospheric condition do the reverse. Relative humidity often enhances the formation procedure of some secondary pollutant whereas wash out effect of rain scavenges the air pollutants from atmosphere.

According to India Meteorological Department (IMD) 2005, Delhi has an overlapping climate which is an overlap of semi-arid and monsoon influenced humid subtropical.

Summers start from April and get peak in May, with average temperature around 32°C with occasional heat waves increasing temperatures to over 45°C. Humidity is less and wind velocity is high. Monsoons are from late June to September mid and cause a reduction of particulate matter. Winters start in late November and peak in January with an average temperature of 12-13°C. This is a time when inversion layer forms and the meteorological conditions cause heavy fog formation and reduction of visibility.

1.11 Exposure on human health due to vehicular pollution

Exposure is generally characterized as the instant contact between a person and a pollutant (Lee *et al*., 2010**;** Tabaku *et al*., 2011). The idea of exposure helps researchers and strategy producers to recognize the vital variables connecting contamination and human well-being, and empower the configuration of essential exploration and powerful strategies to guarantee focused on answers for the issue of air quality. Exposure is an especially valuable idea since air contamination in urban ranges is very heterogeneous both spatially and transiently, because of the bunch of emanation sources inside the city, fundamentally vehicular fumes, fossil fuel burning, industries (Buckeridge, 2002). Urban air quality is additionally influenced by scattering and change forms in the climate from the small scale to the local and worldwide scales (Salmond and McKendry, 2005). The air pollution induces exposure on health hazards during short and long term exposure on human health (Hosseini *et al*., 2014; Longley *et al*., 2015). An increased rate of respiratory tract infections, incidence of asthma and bronchitis are among the acute health impacts observed at high concentrations of small fractions of the pollutants.

The epidemiological studies which indicate moderately reliable relationship between movement related air contamination and expanded danger of heart assault and respiratory disease (Hoek *et al*., 2002; Pope and Dockery, 2006; Kumar and Attri, 2016). It has been proposed that for all the inclusive community, activity related air contamination could be a more vital reason for heart assaults than medication misuse, considering the pervasiveness of presentation in the vehicle microenvironment (Xiaozhen and Frey, 2011). The higher traffic volume in urban city will give more contribution towards vehicular pollution even in short duration. If the traffic volume is high then vehicle microenvironment contributes to more pollutants durations i.e., times of extraordinary activity outflows, which are connected with high contamination fixations that contribute essentially to the aggregate day by day introduction for suburbanites (Zuurbier *et al*., 2011). Individual exposure estimations utilizing little and compact sensors set near or on a person as they go about their day give precise information on the genuine air contamination levels to which individuals are exposed (Sindhwani *et al*., 2014). The number of exposure studies taking into account the individual checking approach in the vehicle microenvironment has expanded as of late. Analysts every now and again utilize versatile instruments amid reproduced day-by-day drives. The air quality does not precisely mirror the variability of toxin fixations that individuals are presented to at road level (Gulliver and Briggs, 2005; Kaur *et al*., 2007). Many urban cities having maximum exposure due to vehicular pollution. Maji *et al*., (2016) reported health risks assessment in variicus cities of maharashtra and found the maximum number of hospital admission due to breathing disease and cardiac disease among one million inhabitants i.e. 1,519 and 582 respectively followed by Chandarpur, Navi-Mumbai, Pune and Solapur city.

Pollutants from vehicles are related to vehicle type (light or heavy-duty vehicles), vehicle age, mileage, inspection and maintenance conditions, vehicular exhaust treatment and quality of fuel used, tires and brakes conditions etc. Pollution exposure to movement emanations is an essential segment of contamination in ambient air. The different kind of pollutants like Particulate matter (PM), Nitrogen Oxides (NOx), Sulphur Oxides (SO_x), Caron Monoxide (CO) and Benzene (C_6H_6,) etc. are playing dominant role in exposure to human health and has become serious concern in mega cities. Among all pollutants, fine particulate matter is considered as the most harmful to human health due to its ability to penetrate deep inside the lungs and it remain suspended in air for longer times than coarser particles, while ambient particulate matter may sometimes seem to be a more problematic because of its bigger size. $PM_{2.5}$ fraction is actually having a deeper and more adverse impact on human physiology (Gupta and Kumar, 2006; Bereitschaft, 2015).

WHO confirmed that 92% of the world's population breathes air, which does not meet the minimum standards. Recently, GBD study estimated the death of 4.2 million people in 2015 due to exposure towards fine particulate matter. Due to this, the $PM_{2.5}$ got fifth rank risk factor worldwide**.** It contribute 6.7% of the world's total annual death. The air pollution mortalities, 88% occur in developing and low-income countries (Handbook of IMF facilities for low-income countries, 2017). The premature death due to respiratory illnesses, heart diseases, cancer, and stroke (Brunekreef and Holgate 2002; Cohen *et al*., 2004; 2005; Lim *et al*., 2012).

GBD (2010) reported that increase more than 2 million unexpected losses and 52 million years of sound life lost in 2010 because of surrounding fine molecule air contamination, completely 66% of the weight around the world. Among other danger variables concentrated in the GBD, open air contamination positioned fourth in mortality and wellbeing trouble in East Asia (China and North Korea) where it added to 1.2 million passing in 2010, and sixth in South Asia (counting India, Pakistan, Bangladesh and Sri Lanka), where it added to 712,000 passing in 2010. The investigation found that diminishing the weight of infection because of air contamination in Asia would require considerable abatements in the large amounts of air contamination in those areas (Chen *et al*., 2008; 2012).

The analysis reports that air pollution exposure contributed to some 1.1 million deaths in India in 2015. As the world's air pollution problems has grown, estimates of the number of deaths and years of life lost attributable to outdoor air pollution have proliferated. Future burden of disease from all sources will grow substantially by 2050 in India, which may lead to death of 3.6 million people (HEI, 2017). Annually about 0.8 million people cease prematurely from illnesses caused by outdoor air pollution worldwide. Almost 150,000 deaths are approaching to emerge in South Asia alone. The life loses about 4.6 million life-years, two-thirds of which being within view in the developing nations of Asia alone (Nafstad *et al*., 2003). Air pollution and epidemiological studies shown to be one of the most toxics among the photochemical air pollutants and it is associated with increasing mortality (Dockery *et al*., 1993; 1994; Phung *et al*., 2016; Khaniabadi *et al*., 2017). The particulate matter blocking the air passages and damage pulmonary mucosal pathways. Shahsavani *et al*., (2012), Wang et. al., 2004 and Chan *et al*., (2004) studied that NO_X are produced by high temperature combustion process such as the burning of fuel in motors vehicles. NO_2 toxicity is several times higher than that of NO and cause many health impacts in human such as change in the tissues of the kidney, liver and heart; reduced immunity against infectious diseases and susceptibility to bacterial and viral infections. Nitrogen oxides may increase the sensitivity to respiratory infections (Chauhan *et al*., 1998). It is also shown that SO_2 induced air pollution can be associated with increased risk of mortality and lung cancer (Guoa *et al*., 2016). Some symptoms due to exposure of pollutants are irritation, loss of mucosal transparency in the air passages and shortness of breath (Onat and Stakeeva, 2013; Hoek *et al*., 2013; Jeong, 2013).

Carbon monoxide decreases the oxygen-carrying capicity of the blood and disrupts the mechanism of tissue oxygenation by forming carboxyhemoglobin in the blood leading to a reduction in oxygen supply to body and cerebral (Ott *et al*., 1994; Badman and Jaffe 1996; Phung *et al*., 2016). Costa *et al*., (2017) found that it also damages the central nurveous system (CNS) and heart. Some authours have reported significnt relationship between mortality rate and ambient CO oncentration (Hadei *et al*., 2017).

1.12 Geographic information system (GIS) applications

Geographic information system (GIS) is a computer-based tool for mapping and analyzing geographic phenomenon that exist and occur on earth. Rytkonen (2004) and Noth *et al*., (2011) utilized GIS to study the community level pollutant concentrations and associated health risks. They explored toxic assessment, air quality system, and national emission inventory to identify the risks of exposure to air pollutants at the community level.

GIS integrates baseline data and unique visualization of geographic analysis on the maps. It is very useful to acquire the pollutant spatial distribution, variations and characteristics information because of its flexible spatial data management and effective spatial data analysis methods. It is an innovative and important component of many projects for public health and epidemiology studies. GIS may also involve more sophisticated spatial analysis of disease occurrence and contributing environmental factors. Scoggins *et al*., (2004) used model concentrations, which were converted from point base grid coverage to polygon grid coverage using GIS. Polygon grid coverage concentrations were then converted to census area unit concentration. It creates very informative graphical presentation and is easy to understand. Sahzabi *et al*., (2011) also conducted a study to predict CO_2 dispersion and optimization of the dispersion model.

1.13 Need of the study

At present due to rapid urbanization, motorization and improper traffic management, the various transport relating to environmental problems like traffic congestion, noise pollution and air pollution are rising day by day in Delhi. To address such kind of traffic related environmental issues, a number of studies have already been undertaken by different researchers in the capital city. After going through rigorous review of the past studies, available literature and reports, no studies focus on the health risks due to vehicular pollution among those people who are living in the vicinity of major transport corridors in Delhi. From the research study, it is found that increase in the number of vehicles is a primary reason to higher air pollution level in residential areas located along the transport corridors.

Taking into account the above-mentioned issues, location of residential apartments and the continuous exposure of people towards vehicular pollution, total 36 transport corridors have been selected to conduct this study. During the study, health risks assessment has been evaluated due to traffic air pollution among communities at all the selected corridors. Along with this, vehicular emission as well as concentration mapping of different pollutants like carbon monoxide (CO), oxides of nitrogen (NO_X), oxides of sulphur (SOx), particulate matter (PM_{10}), fine particulate matter ($PM_{2.5}$) and benzene (C_6H_6) has also been performed to show the spatial extent of impact of harmful pollutants on the people who are residing in nearby areas of selected transport corridors. In addition to this, questionnaire based survey has also been carried out to understand the correlation between public health and traffic generated air pollution and their suggestive mitigatory measures to curb the vehicular pollution problems.

1.14 Objectives of the study

On the basis of above research study, the following objectives have been undertaken for this research study.

1. To assess the emission and concentration of different vehicular pollutants at different road transport corridors in a metropolitan city
2. Human health risk assessment at various transport corridors
3. To develop GIS map for the identified pollutants to estimate the spatial extent of impact of these harmful pollutants
4. To undertake community questionnaire survey for correlating public health issues with vehicular pollutants
5. To suggest mitigation strategies for the better management of public health with various pollutants

1.15 Organization of Thesis

The thesis has been divided into five chapters. Each chapter has discussed different defined aspects of research and objectives.

Chapter 1 contains the introductory part of the present thesis. It outlines the sources and type of air pollutants in light of increasing motorization i.e., no. of registered motor vehicles in study area of megacity of Delhi. Factors, which are associated with the degradation of ambient air quality are summarized along with impact of urbanization on transport pattern contributing to this chapter.

Chapter 2 covers comprehensive review of the available literature related to research work. The review of such literature is divided into various subheadings, for e.g., status of urban vehicular pollution, typology of such vehicular fle*et al*ong with vehicle characteristics and fuel consumption, various factors affecting vehicular pollution, GIS mapping, health risk assessment for air pollutants etc. Along with this, the current trends in traffic pollution in various Indian cities have also been presented. The review of literature shows that various studies have been conducted in order to present an assessment of human health risk due to air pollution on national or urban levels in India, however, it is also revealed that attempts to assess health risk due to ambient air pollutants along transport corridors have not been attempted. Such effort is of high significance due to the fact that concentration and emission of air pollutants especially those emitted by vehicular exhaust are relatively higher in the vicinity of such corridors.

Chapter 3 represents the research methodology outlining the framework design. The study area is Delhi-National Capital Territory (NCT), one of the fastest growing areas in India's mega cities, located between 28.6139°N and 77.2090°E. The total geographical area of 1,483 km^2 with various land use patterns. This chapter has discussed about the calculation of vehicular emission and concentration of six pollutants namely CO, PM_{10}, $PM_{2.5}$, NOx, SO_x and C_6H_6. In addition to this, health risk assessment at selected transport corridors has also been discussed. This chapter is also talked about the GIS mapping of the various pollutants at the selected locations

Chapter 4 discusses about the result and discussion part like emission and concentration of the vehicular pollutants computed at selected transport corridors. It is found that the vehicular pollution has increased substantially in Delhi, which has noticeably been accredited with alarming level of pollution. The primary and secondary data analysis and result validation is also discussed in this chapter. In addition to this, assessment of human health risk regarding mortality and morbidity induced by multiple air pollutants prevailing at 36 transport corridors of National Capital Territory (NCT) of Delhi, India has also been discussed. The study covering PM_{10}, $PM_{2.5}$, SO_2 and NO_2 utilized the risk of mortality/morbidity due to air pollution (Ri-MAP) model in a bid to assess the direct health impacts in the year 2016. The World Health Organization (WHO) guidelines were used to calculate mortality and morbidity values for the populations in 4 km^2 grid sizes in the vicinity of all transport corridors. This chapter includes detailed description about assessment of the GIS Mapping of traffic induced air pollutants along various transport corridors of Delhi, India. This part includes the classification of vehicular pollutants parameters into five distribution classes. Spatial maps have been developed using Kriging tool in ArcGIS environment for eleven districts covering 36 transport corridors of the city.

In **Chapter 5** conclusion part of the research work carried out is outlined. Further, the future scope of research plan has also been discussed in brief. The thesis has observed that the emission, concentration and associated health risk are aggravated by the high vehicular density, and densely populated areas along the transport corridors. Most of such transport corridors were found to be under “sever” or “very poor” class according to Indian AQI posing a direct health threat to the exposed population. This scenario needs special attention and measure for the betterment of urban air quality.

1.16 Summary

This chapter focuses the introductory part of the research work. It includes the overview of air pollution scenario all over the world as well as in India. The demographic growth status in India and in various states has also been covered in this chapter. The trends of urbanization and motorization in various countries are also discussed. In addition to this, a very significant module i.e. exposure of vehicular pollution on human health risk has also been discussed. The objectives along with organization of thesis have also been covered by this chapter.

CHAPTER 2

LITERATURE REVIEW

2.1 General

The level of ambient air pollution in various cities in Asia rival the level that existed during the period of the 1st decade of 20th century in North America and Europe (HEI, 2010). In Africa, Asia and Latin America, the majority of the population **are** exposed to high level of air pollution (Katsouyanni *et al*., 2009; Rajarathnam *et al*., 2011; Gilliland *et al*., 2017; HEI, 2017; WHO, 2006). WHO (2016) reported that approximately 92% of the world's population are not breathing clean air. Air pollution is considered as one of the important environmental health determinants.

The mathematical model is accurate and complex in parallel with computer software development. Various air pollution predication model has been developed which are for finite line source as well as for infinite line source. The line source models are used to simulate dispersion from roadways where vehicles are the major contributor to emit pollutants (Mage *et al*., 1996; Calori and Carmichael 1999). These models are based on Gaussian dispersion. Line source model can be for finite length or for infinite length of roadway.

The increasing vehicular traffic is the prime source of air pollution at the global level as well as in India. Presently, the mobile sources or the vehicles are the primary cause of air pollution, and the level of pollutants exceeds the ambient air quality standards (Chen *et al*., 2009; 2010**;** SIAM, 2011). The worst phenomena of vehicular pollution are its unavoidability as the pollutants are emitted very near to the ground level and are directly exposed to human beings. The pollution from vehicles is discharged in the form of CO, lead compound, suspended particular matter (SPM), HC, NO_X, carbon particle concentrations and particular matters (Ghio *et al*., 2004; Fensterer *et al*., 2014).

Pollution from vehicles often results in increased morbidity and mortality (Samet *et al*., 2000). A report of recent studies reveals that many school going children are also exposed to traffic pollution. Due to that, most of the children in Delhi are suffereing from asthma like deseases (Akinbami *et al*., 2010). According the study of WHO (2012), 7 million people were died due to air pollution exposure. WHO has identified suspended particulate matter (SPM) as the menacing one, regarding its effect on human health. SPM has a number of constituents and is measured and characterized in various forms like TSP (diameter < 50-100 µm), RSPM (diameter <10 µm) and thoracic particles (approximately equal to RSPM particles) and PM (diameter < 2.5 µm) and black smoke. Taking into account the health-damaging property of the particulates, recently the researchers have started to focus towards PM_{10}, $PM_{2.5}$, and even PM_1 particles. The diverse kind of vehicular pollutants can have local, regional and global effects as well. In the mega cities of developing countries, the air pollution problem is a very critical issue. Urban population growth may also be a significant probable reason for air quality problems. Many studies related to traffic air pollution have been done at national and global level.

2.2 Worldwide scenario of traffic air pollution

Noll and McGuire (1971) found out the relation between air pollution concentration and averaging time. They studied five different air pollutants in 17 cities of California, USA and developed an equation to show the following relationship.

$$C_{max(t)} = C_{\max(h)}t^{b} \quad \text{…. (2.1)}$$

Where

$C_{max(t)}$ = maximum concentration for t hours.

$C_{max(h)}$ = maximum concentration for one hour

T = averaging time (in hours) corresponding to $C_{max(t)}$

b is exponent which change according to pollutants parameters and sampling location.

This equation gives maximum concentration for different averaging times. This relationship is sufficiently accurate in the prediction of maximum concentration for averaging time up to one year.

A solid, multipurpose urban diffusion (APRAC-1A) model is a modified form of the receptor-oriented Gaussian plum formulation, which was developed by Clark (1996). This model is mainly used for predicting the concentration of inert, vehicle-related pollutants. As input, it requires meteorological and traffic data and gives actual concentration, in hourly, and frequency distribution. This model is beneficial to predict the present and future impacts of transport pollution on ambient air quality in urban communities.

McCollister and Wilson (1975) developed Liner Stochastic Model by using the methods of time series analysis. Two-time series related models were established to forecast the concentration of various air pollutants. Chock (1977) set up an experiment of dispersion of different pollutants near the transport corridors. General motor (GM) model describes the downwind dispersion of pollutants near the roadway. There are so many models, which represent the dispersion of pollutants from the roads.

Finzi *et al*., (1979) studied about stochastic predictors of daily and hourly SO_2 concentration and concluded that the wind speed and direction related information gives adequate enhancement of one day ahead forecast concerning Autoregressive Integrated Moving Average (ARIMA) models. Kumar and Jain (2010) applied autoregressive integrated moving modeling approach in their study to estimate the daily mean ambient air pollutants concentration. Petersen (1980) used HIWAY-2 model to measure air pollution concentration at receptor location. Finzi and Tebaldi (1982) depicted ARMAX model to forecast the concentration of SO_2 in urban areas. It was a real-time predictor, and from this model, they developed a technique to predict the pollution for different regions (Mishra *et al*., 2013).

Benson (1989) developed CALINE 4 model to predict the pollutant concentration for receptors sites. Juda (1986) estimated the SO_2 concentration in Cracow, Poland by using three level single parameter i.e. wind speed, direction, and temperature and evaluated the performance of air quality model. Kono and Ito (1990) used Osaka Municipal Government (OMG) Volume Source Model to predict the pollutant concentration of motor vehicle exhaust. This model is useful in an urban area within the range of 200 meters from the side of the road.

Bardeschi *et al*., (1991) examined the concentration of CO and NO_X pollutant emitted from motor vehicles. It calculated and measured pollutant concentration and finally wrapped up that the (Air Pollution Research Advisory Committee Version3) APRAC3 is to be a helpful instrument in making strategies intended to reduce pollution from motor vehicles.

Alexopoulos *et al*., (1993**)** developed an emission model for temporal and spatial estimation of traffic emission in urban cities. It is used to forecast the emission of carbon monoxide. In the process of the estimation of pollutants, the spatial and temporal distribution of traffic load act as a significant factor. The raw data has been used to refer traffic condition during the period of 1986-1988. During their study, they utilized all the available traffic data and determined the pollutant emission of the pollutants. His study revealed that the private automobiles are responsible for about 85% of CO emission.

Qin and Chan (1993) applied the receptor method to estimate the concentration of traffic emission at transport corridor of South China. During their study, they took the data in vehicle idle condition and derived the composite emission factors of vehicles. On the whole, they concluded that the only NOx is the most significant pollutant of traffic emission which influences the ambient air quality.

Torp and Larssen (1996) estimated the exposure value of NO_2 and PM_{10} along the main road network of Norway by using Road Air Model. By using this model, they calculated the concentration of different pollutants, and the result showed the maximum concentration of NO_2 and PM_{10} outside the home of people living next to main transport corridors. Smit *et al*., (2007) presented VERSIT+LD Model to estimate hot traffic emission from light-duty vehicles. They focused to predict specific emission for any particular traffic situation at different spatial levels as a function of parameters that characterize the dynamic of the vehicle driving situation.

Costabile and Allegrini (2008) analyzed the functional relationship linking air quality, air pollution emission, and air quality of ambient air. They observed that integrated transport system could connect transport corridors.

Parrish *et al*., (2009) measured the concentration of hydrocarbon, carbon dioxide and nitrogen oxides from three – megacities, i.e. Beijing, Mexico and Tokyo. Emission from gasoline-fueled vehicle dominates in all of these cities, which helped to develop appropriate air quality control strategies through emission inventory development.

Dziubanek *et al*., (2017) found the significant correlation between the sizes of the chronic exposure of the inhabitants of the cities of Silesia. Various size of particulate matter exposure on the inequalities in the life expectancy of men and women among the cities.

2.3 National scenario of vehicular pollution

With an increase in urbanization, industrialization and commercials activities in the urban area, the demand for transport has also increased considerably (Census 2011). India is facing problem of air pollution because of economic boom and improvement in urban lifestyle. Atmospheric pollution is a widespread problem in urban areas and are caused primarily due to vehicles. Due to inadequate public transport system in the various major cities, the use of personal vehicles has been increased steadily. In addition to 70% two and three wheelers, petrol driven vehicles with four-stroke engines constitute about 14%, and diesel driven vehicles are about 8% of the total vehicles on the road. Two wheelers are rising at the rate of about 20% per year, and it has been estimated that there will be about 36 million two-wheelers by the turn of the century against 7 million in 1987. In 2015, the total registered vehicles in India was 210.023 million and everyday 0.053 million vehicles are increasing.

In 2017, more than four times vehicles were challenged as compare to 2016 vehicle figures. In addition to this, in 2016, the transport department had penalized 13,122 vehicles that were visibly polluting, while this number has reached up to 49,532 in 2017. In Delhi, the monthly average measured ambient concentrations of $PM_{2.5}$ varied from 130 $\mu g/m^3$ to 250 $\mu g/m^3$ (Goel et. al., 2015). Life in Delhi is badly affected due to vehicular pollution (Chhabra *et al*., 2001). Random industrial development, the exponential growth of traffic density, an imperfect transport policy turned to Delhi into the fourth most polluted city in the world due to which public life is under the constant threat. The World Health Organization (2014) classified Delhi as the world's most polluted capital.

The vehicular population is gradually becoming the source of pollution-related respiratory problems in the capital. The emission of CO from vehicles exceeds that of any other sector of the economy. Further oxides of nitrogen are 50% more, and oxides of sulphur particles are emitted from the transport sector. The principal pollutants emitted by the vehicles are hydrocarbon (HC), carbon monoxide (CO), an oxide of nitrogen (NOx) and particulate matters (PM_{10}, $PM_{2.5}$, fine particulate ≤ 2.5).

It is observed that vehicular pollution sources are of different kinds and a heterogeneous mix of different makes and models are plying on the road. The mix could be regarding fuel used, i.e., diesel, petrol, liquefied petroleum gas (LPG) compressed natural gas (CNG), or blended fuels or engine type, viz. four-stroke or two-stroke and combinations of these. Petrol-powered engines are of two types, i.e., four-stroke and two-stroke.

The incomplete combustion of petrol leads to the emissions of CO and HC. Due to high temperature as well as the presence of nitrogen and oxygen in the combustion chamber leads to the formation of oxides of nitrogen. The unburnt and partially burnt oil is responsible for SPM and smoke emission. The various studies indicate that 15-25% unburnt fuels exhausted by two-stroke engines (Pandey *et al*., 2016).

Fuel combustion as well as fuel evaporation process are responsible for the vehicular pollution. The sources of emission in the vehicles are fuel tank, carburetor, engine and tailpipe emissions. Oxides of sulphur are produced from the sulphur contained in the fuel. Incomplete combustion in diesel engine at idling and heavy loads enhances the production of particulate matters. Heavy-duty gasoline motorized vehicles contribute more NO_x and PM release and light motor gasoline driven vehicles, and motorcycles are the major contributor to CO and HC emissions. The concentration of air pollution in the troposphere because of vehicles is not only a simple function of the emissions but also determined by on the height of the emissions, meteorological factor, topography and several other factors. The exposure of vehicular pollutions is comparatively more because these are ground level emissions.

The impact of vehicular pollution is moderately more because it emits ground level emissions and dispersion. In urban cities, high rise constructions and structure close to the roads also affect the dispersion of various pollutants. The vehicular pollution contributes about 70% of the total NO_x emission while its regional impact is about 98% of total exposure (Lawrence *et al*., 2007). The pollution load from vehicular exhaust depends upon characteristics of fuel and efficiency of combustions. The main pollutants from gasoline are lead, carbon monoxide, hydrocarbon and sulphur dioxide, the quantum of which varies with the quality of fuel. The exhaust from diesel driven vehicles contains a significant number of unburnt hydrocarbons, oxides of nitrogen, sulphur dioxide, carbon monoxide, and particulate matter. Diesel vehicles pollute the environment largely through NO_x, smoke, and particulate. They also emit CO and hydrocarbons, but their contribution to these pollutants is relatively low as compares to that for gasoline vehicles. Gaseous pollutants, volatile organic compounds and suspended particulate are the broad categories of the vehicular emissions, which may include various individual components of divergent toxicological effect.

Bhanarkar *et al*., (2005) observed 28% of the total NO_2 emissions in the air are contributed by vehicular emissions. It was assessed in Jamshedpur through air pollution dispersion modeling. The concentration of SO_2 and NO_2 was predicted with the help of ISCST3 model. Guttikunda *et al*., (2013); Gulia *et al*., (2015) reported that CO, NOx, and PM are emitted with the rate of 509 tons/day, 194 tons/day and 15 tons/day, respectively in Delhi city. The peak value of these pollutants emission is found generally in the morning and evening time. Gurjar *et al*., (2004) developed emission inventory of Delhi city for ten years' period from 1990 to 2000. GBD (2017) reported that air quality in the city is normally worse during cold weather because the temperature acts as a blanket keeping the pollutant trapped.

2.4 Emission estimation of vehicular pollution

Environmental planning for any urban area can be achieved using various tools, which requires the data of emission inventory and meteorology. Rapid progress has been made in studies on mathematical models of urban air pollution for the past ten years. Various air pollution prediction models have been developed which are based on Gaussian dispersion phenomenon. Line source models can be used for finite length or for an infinite length of roadway. Some of the most popular air quality predication models are discussed below.

2.4.1 Deterministic model

This model is basically theoretical model, based on analytical approach. The line source emission model was available earlier 80's. It received attention in the U.S. in the early eighties, after the US National Environmental Policy Act-1969. The model was developed by Beaton (1972). It is also mentioned under the deterministic category of models. In the series of Gaussian models, works of Csandy (1972) and Fay and King (1975) are significant. Csandy assumed a hypothetical line source, existing along the direction perpendicular to that of the wind. The expression gives the concentration of pollutant of C at the receptor, presented in Equation 2.2.

$$C = Q_L/(2\pi\sigma_y\sigma_z\bar{u})[exp\{-1/2((Z-H)/\sigma_z)^2\} + exp\{-1/2((Z+H)/\sigma_z)^2\}] * \int_{-1/2}^{+1/2} exp\left[-1/2\left((y-y_1)/\sigma_y\right)^2\right] \quad ....(2.2)$$

Where Q_L is the source strength, σ_y *and* σ_z are the horizontal and vertical dispersion coefficients respectively, y_1 is the receptor distance from the line source, z is the receptor height above ground level, H is the height of line source, $\bar{u}$ is the mean ambient wind speed at the source height and L is length of roadway under consideration. This model has been developed for the finite line source and for wind perpendicular to the roadway. CALINE (Beaton *et al*., 1972), HIWAY (John *et al*., 1975) and GM (Chock, 1977) are some of the commonly used models developed by the USEPA. The results use information specific to sources, dispersion model, and consideration of context of the emissions including the atmosphere, topography, and location of sensitive study area. The computational requirements for dispersion modelling are much greater than for emission estimation. It preforms the necessary calculations and product summary of the pollutant concentration at each receptor. The gaseous pollutant like nitrogen oxides and sulfur dioxide show dissemination properties and are ordinarily amorphous liquids that change to the fluid or strong state just by a consolidated impact of expanded weight and diminished temperature. Particulates matter found scattered in the atmosphere, stable or fluid, in which the individual totals are bigger than single little atoms (~0.0002 mm in measurement) yet smaller than approximately 500 micrometers (mm). The particulate matter equivalent to or under 10 mm in size, with this size scope of concern in respect to potential human health impacts. Air toxics are available in the air and show conceivably harmful effects to people as well as to the general biological community.

2.4.2 Gaussian plume model

An urban Air Quality Simulation (AQS) model is a kind of numerical technique, which is used to estimate pollutants concentration in space and time (Khare, 1999; 2012). Ghenai and Lin (2006) reported that the pollutant concentration distribution changes that are expected to result from simulated changes in the emission changes that are expected to result from simulated changes in emissions distribution. There are two widely differing spatial scales of interest for this application like urban scale 1 to 25 kilometers and local scale 10 to 100 meters. It is mostly used for the local scale planning. AQS models are mainly required for the analysis of transport related pollutants sources, particularly near congested downtown street, highways, airports, and heavy traffic areas. In this model crosswind, plume concentration distributions are taken to Gaussian in form. It is valid for 1 hour longer and long diffusion times and for homogeneous, stationary condition. The sum of dispersion for pollutants of infinite points sources are calculated from the in-line source pollution and then, is estimated the concentrations of emitted pollutants at receptor point (Goyal *et al*., 2006; ARAI, 2007; Nagpure *et al*., 2016).

2.4.3 Speed of vehicles and deterioration factors

The hourly speed survey data of the various types of vehicle at various transport corridors in Delhi are presented in Table 2.1. The sample vehicles where processed to obtain the average, maximum and minimum speed of the vehicles at a point on a road stretch. The average spot speed may be used as an indicator of the speed of traffic stream. In calculation of pollutants emission, the age deterioration factor and speed of vehicle are the key factors at any transport corridor. Age deterioration factors of gasoline and diesel vehicle presented in Table 2.2 and Table 2.3 respectively.

Table 2.1: Speed of vehicles

Vehicle category	Average Speed Km/hr	Max. Speed Km/hr	Min. Speed Km/hr	Percentage of Deviation from the average speed
2Ws	41.03	51.01	35.06	116.64%
Car	40.41	49.33	33.23	114.89%
Auto	32.08	37.72	26.80	91.22%
Bus	31.33	38.26	26.30	89.07%
Mini Bus	33.33	40.50	26.27	94.76%
Truck	32.85	39.98	25.48	93.41%

Source: Nagpure *et al*., 2013; Kumar and Mishra, 2017

Table 2.2: Age deterioration factors of gasoline vehicle

Age of Vehicle	Two wheelers	Three wheelers	Passenger car gasoline	Multi-utility vehicle gasoline
0-5	1.2	1.475	1.097	1.19
5-10	1.3	1.7	1.28	1.255
10-15	1.4	N.A.	1.17	1.25
15-20	N.A.	N.A.	1.35	N.A.

Source: ARAI, 2007; 2008

Table 2.3: Age deterioration factors of Diesel vehicle

Age of Vehicle	Passenger car			Taxis			Buses			Truck			MUV+LCV		
	PM	CO	HC & NOx	PM	CO	HC & NOx	PM	CO	HC & NOx	PM	CO	HC & NOx	PM	CO	HC & NOx
0-5	1.09	1.05	1	1.18	1.09	1.19	1.19	1.01	1	1.35	1.17	1	1.19	1.09	1
0-10	1.28	1.14	1	1.26	1.13	1.35	1.35	1.18	1	1.59	1.33	1	1.25	1.12	1
10-15	1.17	1.08	1	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	1.80	1.47	1	1.25	1.10	1
15-20	1.35	1.18	1	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.

Source: ARAI, 2007; 2008; Goel *et al*., 2015

2.4.4 Estimation of emission load

Emission estimation is the first step to develop an emission control strategy for selected pollutants. Emission inventory is an integral part of any urban air quality management plan (Miller *et al*., 2006). The output emission estimation is the product of emission factor and, traffic volume provides emission rate of various categorized motorized traffic. Emission factors are normally expressed in the form of grams of pollutant per unit distance covered at transport corridors. The emission factors depend on the type of vehicle, fuel consumption along with, type of engine, vintage of vehicle, driving cycle and average speed (ARAI, 2008). The fleet structure, technology proportions, vehicle activity and proportions of driving condition to estimate emission and total fuel used by vehicle. In Mexico, Wolf *et al*., (2009) reported that the line source emission of pollutants are responsible for 16%, 52%, 99%, 82%, 31%, and 22% from PM_{10}, $PM_{2.5}$, CO, NO_X, NMVOC (non-methane volatile organic compounds) and NH_3 (ammonia) respectively. The following equation can be used to estimate the total emission on the annual basis (Transport Fuel quality, 2010).

$$P(i, y) = \sum[J * \sum(Ky) * N(J, Ky) * TL * DF(I, J, Ky) * EF(I, J, Ky)] * 10^{-6} \quad \text{…. (2.3)}$$

Where,

P (I, y) = Annual Emission of Pollutant I in year y in ton

N (J, ky) = Number of vehicles of a particular Type j and Age ky in year y

TL = Average trip length (km)

DF (I, J, ky) Deterioration Factor for component I in the vehicle type j and age ky in year y (gm/km)

EF (I, J, ky) = Emission factor for component I the vehicle type j and age ky in year y (gm/km)

I = Pollutant component

J = Type of vehicle

ky = Age of vehicle in year y

2.5 Estimation of human health exposure due to air pollution

Different researchers developed the source-to-receptor theoretical structure to understand and analyze the path and effect of pollutants and contaminants on human beings as well as biological system. This structure joins issues of contamination to human wellbeing reaction, highlights the distinctive variables that add to one's introduction to different stressors, and considers input systems (Bartonova *et al*., 1999; Lioy and Smith, 2013).

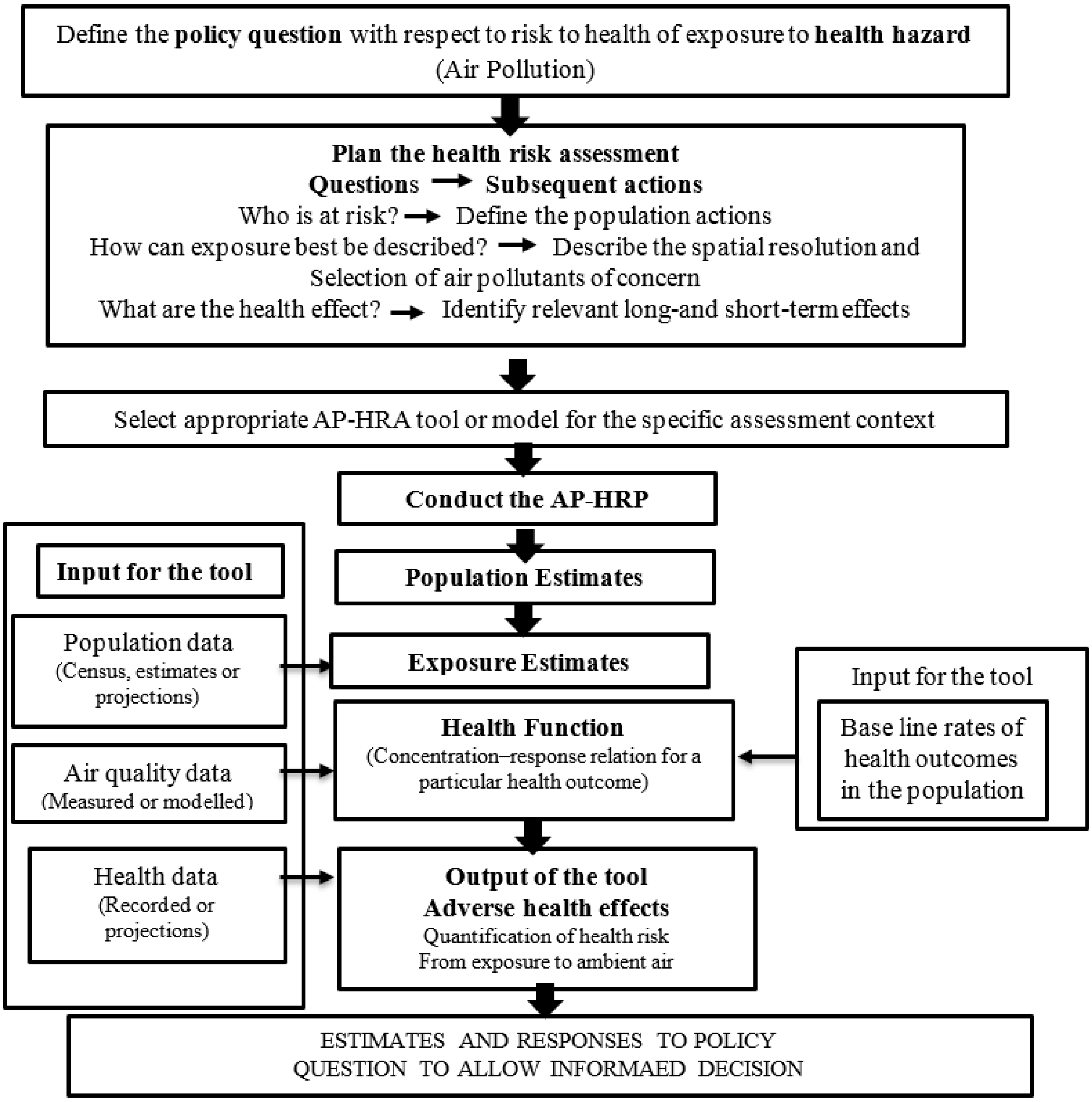

Figure 2.1: Layout diagram of AP-HRA process

Source: WHO, 2016

The average time-weighted exposure of mean pollutant concentration measured in the diverse microenvironments where the individuals live, work, and play (Liu *et al*., 2013). The layout diagram of AP-HRA process is depicted in Figure 2.1. In addition to this to assess the air pollution related health risks, a number of tools has already been used by different countries worldwide. A list of worldwide available diverse kind of health risk by air pollution assessment tools are presented in Table 2.4.

Table 2.4: Worldwide air pollution health risk assessment tools

Tool	Developing Institute	Geographical scope	Health endpoint addressed
Air Counts	Abt Associates	Global (42 cities, additional 3000 under development)	Mortality
AirQ2.2	World Health Organization	Any population with specified size, mortality and morbidity characteristics	Mortality and morbidity
Aphekom	French Institute of Public Health Surveillance	Global (current version focuses on Europe)	Mortality and morbidity
Economic Valuation of Air Pollution (EVA)	Aarhus University	Northern hemisphere, continental, national, city	Mortality and morbidity
EcoSense	University of Stuttgart	Europe	Mortality and morbidity
Environmental Benefits Mapping and Analysis Program – Community Edition (BenMAP-CE)	US Environmental Protection Agency	Continental USA and China pre-defined; any other as defined by user	Mortality and morbidity
Environmental Burden of Disease (EBD) Assessment tool for ambient air pollution	World Health Organization	Global	Mortality and morbidity
GMAPS2	World Bank	Global	Mortality and morbidity
IOMLIFET	Institute of Occupational Medicine	Can be used anywhere where there is background mortality data and measured or predicted pollutant concentrations	Mortality and morbidity
Rapid Co-benefits Calculator	US Environmental Protection Agency, Stockholm Environment Institute	Under development for all countries globally	Mortality

Source: WHO, 2016

Chan *et al*., (2004) reported that vehicular emission exposure is increasing as a leading environmental issue and becoming problematic for the global environment. The urban cities with large and medium land area are mostly affected due to vehicular pollution. These pollutants are associated to several long as well as short-term adverse health effects which leads to increase are increasing in the number of hospital admissions and life years lost due to asthma, acute respiratory infections etc. (Blams, 1987; Dockery, 1994; Nielsena *et al*., 2016). However, more focused studies on health effects via traffic pollution exposure are attentive in faster growing developed countries facing problems on health impacts from vehicular pollution along with transport corridors and high population density populations (Fullerton *et al*., 2008).

In the relative risk valuation performed by Lim *et al*., (2012), almost 1.04 million early deaths were reported. Indoors and outdoors, air pollution extremely affects on the morbidity and mortality via respiratory and cardiovascular diseases (Grahame and Schlesinger, 2010; Balakrishnan *et al.,* 2011).

Table 2.5 represent the emission inventory annual emission of various sources of pollutants. The urban city emits various trace gases and particle emissions in the atmosphere. Table 2.6 shows the age wise percentage contribution of various categories of vehicles in Delhi. Gurjar *et al*., (2008) proposed the multipollutant index (MPI) allowing for the mutual level of the three criteria pollutants of WHO guidelines for ambient air quality. The megacities with the highest MPI such as Dhaka, Beijing, Cairo, and Karachi demand urgent need of vehicle pollution reduction.

Table 2.5: The emission inventory (tones/year) from various sources

Various Sources	**$PM_{2.5}$**	**PM_{10}**	**SO_2**	**NOx**	**CO**	**VOC**
Transport	10,850 (17%)	14550 (13%)	700 (2%)	198850 (53%)	256200 (18%)	132150 (51%)
Diesel gen sets	7500 (12%)	8950 (8%)	2050 (6%)	2900 (1%)	204700 (14%)	17250 (7%)
Brick Kilns	9250 (15%)	12400 (11%)	4000 (11%)	6750 (2%)	171850 (12%)	24200 (9%)
Industries	9000	12650	8500	41500	219600	13250

	(14%)	(11%)	(23%)	(11%)	(15%)	(5%)
Construction	3250 (5%)	10750 (9%)	100 (1%)	2850 (1%)	3600 (1%)	50 (1%)
Waste burning	5300 (8%)	7550 (7%)	350 (1%)	2000 (1%)	27800 (2%)	2250 (1%)
Road Dust	3850 (6%)	25450 (22%)	N.A.	N.A.	N.A.	N.A.
Power plant	10150 (16)	16850 (15%)	20250 (55%)	27200 (7%)	442150 (31%)	34900 (13%)
Total	62700	113900	36950	375900	1424250	260450

Source: CPCB 2010; 2012; Guttikunda and Goel 2013.

Table 2.6: Percentage of vehicles in each age profile of vehicles based on the data collected during the PUS testing Delhi

Age (years)	**2Ws (petrol)**	**Cars (Diesel)**	**Cars (petrol & CNG)**	**Bus (CNG)**	**Auto Rickshaws (CNG)**	**Light-duty (CNG)**	**Tempos (Diesel)**	**Trucks (diesel)**
0-5	67	6.8	51.8	22.2	39	84	53.8	48.5
6-10	24.8	27.3	32.1	69.6	56	13	31	35.1
11-15	6.6	3.6	14.2	8.2	5	3	15.1	17
15+	1.6	0.3	1.8	0.1	0	0	0.004	0.4
All Age	100	100	100	100	100	100	100	100

Source: Goel *et al.*, 2015

The infiltration power of particles towards respiratory tract are decided by their size distribution. Smaller particles have more potential to enter in the deeper part of the lungs and possibly can enter into the circulatory system, which may further have transported to different parts of the body (Katsouyanni, 2003; Oberdörster *et al*., 2005). The two primary molecule size portions are PM_{10} and $PM_{2.5}$, which relate to the aggregate mass groupings of particles of streamlined breadths up to 10 μm and 2.5 μm, individually. As per the research conducted by Oberdörster *et al*., (2005), the nasal entries of the human beings are capable to keep around 80% of the particulate and fine particulate matter. On the other hand, the ultrafine particulate matter (particle < 100nm) can infiltrate in the respiratory system of the human body. The small size combined with a high surface territory to unit mass or unit volume additionally builds the molecule's ability to adsorb cancer-causing mixes which might be retained in the blood, expanding the danger of undesirable effects (Lighty *et al*., 2000; Oberdörster *et al*., 2005). Mass fixations, PM_{10} and all the more as of late $PM_{2.5}$, are still the most broadly utilized measurements as a part of epidemiological studies, which frame the fundamental proof for the present molecular air quality norms (Burnett *et al*., 2003; 20014).

Gurjar *et al*., (2010) developed a model in MS-Excel sheet to estimate the human health risks in urban cities like Delhi, Bombay etc. due to air pollution. During his study, he also applied RI-MAP model to predict the excessive numbers of illnesses and death. Vehicular emissions related heart diseases like ischemic heart disease (IHD) and total cardiovascular disease (CVD) at cohort, Greek were assessed by Cuia *et al*., (2005).
Sousa *et al*., (2012) reported air pollutants produces oxidative stress and inflammation. It is countered that high levels of air pollutants cause a higher number of hospitalizations. Gilliland *et al*., (2017) found that due to air pollution the lower

respiratory tract infections (LRTI) found bronchitis, bronchiolitis or pneumonia, and wheezing.

Lipfert *et al*., (2006) suggests that heath risk due to vehicular pollutants and severe acute frailty and subsequent risk is imminent. These pollutants are strongly affecting ecosystems, population and climate. The high concentrations of ozone during hot summer days and PM_{10} also affect human health (Zhang, 2013). He also found the significant correlation with ambient PM_{10} and mortality in Beijing. Siddique *et al*., (2011) observed the harmful effect due to air pollutants on body growth, health and wealth of children.

Rajarathnam *et al*., (2011) also reported that for every 10 ug/m^3 changed concentration value of outdoor PM_{10} associated with a 0.15% growth in total natural cause mortality. Rizwan et. al., (2013) conducted health exposure study in Delhi and calculated that the exposure of human beings to PM_{10} is continuously increasing due to higher vehicular and industrial pollutants. Mukhopadhyay and Forssell, (2005) also observed emissions of different pollutants (CO_2, SO_2, and NO_x) due to fossil fuel combustion in India. They also found out a relationship between pollutant emission and human health. On the basis of his study, David *et al*., (2012) established an association between CO, NO_2, PM and pregnancy outcome. He reported reduced birth weight and birth rate in relation to exposure to CO, NO_2, PM_{10}, $PM_{2.5}$.

Nagpure *et al*., (2013) reported that the emission loads are increasing from the transport sector. The two-wheelers are found as a major contributor towards the emission of CO, HC, TSP, VOC and Pb whereas cars and goods vehicles emit most of the CO_2 and buses plus goods vehicles dominate in the emissions of NOx and SO_x.

Guttikunda and Calori (2013) reported the multi-pollutant emissions inventory for National Capital Territory of Delhi. They reported that cardiovascular diseases are playing a major role in mortality and morbidity in South Asia Between 1990 and 2020. Cardiovascular disease is currently a leading health problem in urban India. Thirty-five percent of all cardiovascular diseases deaths occurred in India.

Pant *et al*., (2017) found traffic as a prime source of urban air pollution in metropolitan's areas. The high concentration of pollutant on the road has potential to affect human health. Zhang *et al*., (2013) published that the vehicle emissions degrade ambient air quality of the atmosphere. The morbidity and mortality for the drivers, commuters and individual living near major road ways are greater. He also suggested that the major health problem occurs due to the time traveled in a traffic area, during the duration of rush hours and congestion of the traffic.

Dey *et al*., (2010) reported that the particulate matter 2.5 shows that 51% of the subcontinent's population are affected due to pollution. That is exceeded the WHO highest annual air quality threshold of 35 $\mu g/m^3$, while another 13% and 18% are exposed in the ranges of 25-35 and 15-25 $\mu g/m^3$ respectively.

Merbitz *et al*., (2012) found high concentrations of metals and PAHs in urban, suburban and rural areas. It enhanced the risk for the coincidence of temperature stress and particulate matter pollution on human health.

2.6 Vehicular transport emissions of pollutants

Incomplete combustion of fossil fuels leads to the emissions of various pollutants (Larssen *et al*., 1993). Vehicles can emanate particles through exhaust emission, abrasion process, brake linings, and road surface material and mechanical turbulence help in the resuspension of the particles (Charron and Harrison, 2005). In the atmosphere, particles can experience further transformative procedures, including nucleation, coagulation, dissipation, build-up, and agglomeration, which change their shape, size, and piece (Lighty *et al*., 2000). Diesel-fuelled vehicles additionally transmit more nanoparticles, making a bigger contribution to add up to particle number (PN) contrasted with gas-fuelled vehicles (Kittelson *et al*., 2004). There has been an exploration of the effects of alternative energy fuels. The enormous use of compressed natural gas (CNG) in Delhi, India during 1995 to 2001 brought about a drop in the yearly mean concentration of surrounding suspended PM from 405 to 347 $\mu g/m^3$ (Goyal and Siddhartha, 2003). Biofuel was likewise found to prompt huge abatements in the PM and vaporous toxins (counting CO and CO_2), however, brought about higher PN emanations contrasted with routine diesel or gas (Kurre *et al*., 2016)

Driving condition can also influence the molecule mass and number outflow rates. In spite of the fact that diesel vehicles by and large radiate higher molecule numbers than gas vehicles, the highly loaded motor and speeds (~120 kmh^{-1}), gas-fueled motors have been found to be emanate PN practically identical to that from diesel motors (Kittelson *et al*., 2004). As a rule, higher motor loads and speeds produce higher amounts of molecule discharges, particularly as far as PN (Kittelson *et al*., 2004). Percentage share of pollutants emissions from different mode of transport is summarized in Figure 2.2.

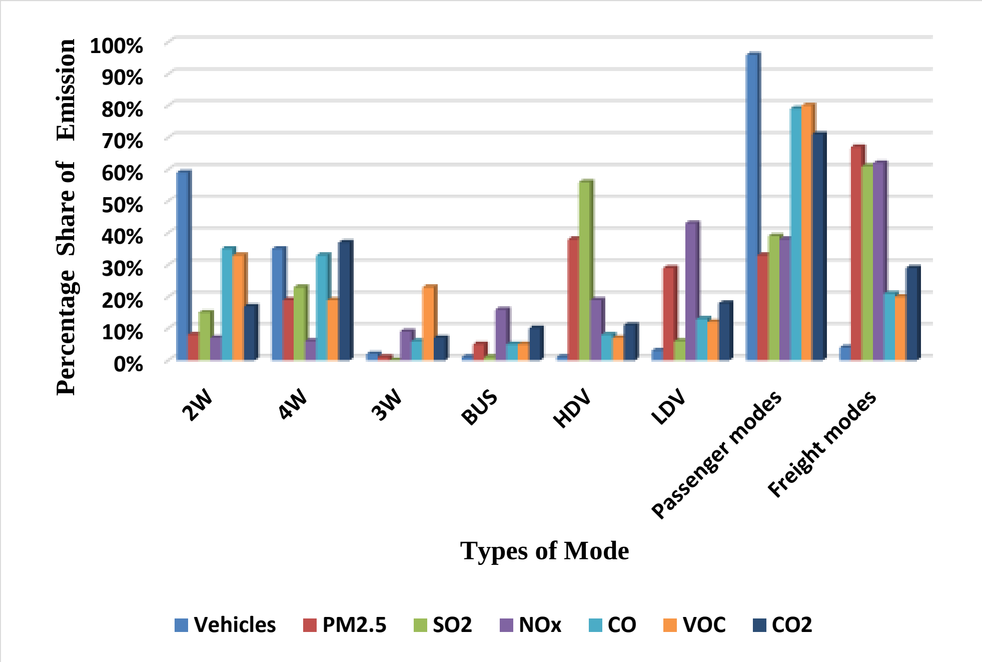

Figure 2.2: Share of emissions by passenger (2Ws, 3Ws, 4Ws and buses) and freight modes (LDVs and HDVs) for year 2012.

Source**:** Goel and Guttikunda, 2015

Control over ambient atmospheric pollution has now become a big challenge not only due to the rising numbers of traffic volume but also due to the contribution of toxic risk resorted by the growing numbers of diesel cars. Diesel cars with Euro III norms emit 7.5 times more toxic PM as compare to gasoline cars. Keeping in mind the emission scenario, it is very much essential to create awareness among the people to make their vehicles environmental–friendly in order to reduce emissions.

2.6.1 Benzene

Real-time analysis of benzene in automobile exhaust gas has been carried out in the past with reports that the concentration varied based on car types, driving conditions, and catalyst conditions. Oral or inhalation of high levels of benzene may be fetal for the human and animals. Other effects may also be appear like drowsiness, dizziness, and headaches. The normal blood production in human being may be affected by long term exposure to benzene, and it may result in severe anemia bone marrow resulting in decreases in the numbers of circulating blood cells, and ultimately, and internal bleeding (Sender 2012).

2.6.2 Oxides of Nitrogen

Under high temperature and pressure, the reaction of nitrogen with oxygen leads to the generation of oxides of nitrogen. The Oxides of nitrogen (NO_X) itself is reposnible for the generation of nitrogen dioxide (NO_2) which can cause diverse kind of health effects among people (Gauvin 2001; Burnett *et al*., 2004). As per the research study conducted by Zmirou *et al*., (2004); Burra *et al*., (2009); and Lawson *et al*., (2011), the different oxides of nitrogen can cause lung irritation, reduction in the body's immune system. High levels of exposure may cause respiratory difficulties and chronic lung diseases in human beings (Zmirou *et al*., 2002; Kunhikrishnan *et al*., 2006; Rice *et al*., 2015; Yang and HE, 2016). These oxides also play important role in the formation of particulate matter as well as troposheric ozone formation (Akimoto 2003; USEPA, 2008)

2.6.3 Oxides of Carbon

It is produced due to the incomplete combustion of fuel. At low concentrations, **it** may pose a different kind of health risks among people who are young as well as sensitive to any particular disease. It can lessen the oxygen carrying capacity of blood, and blocks the oxygen movement to the different vital organs of the body like brain and heart (Liu *et al*., 1994; 2016; Lia *et al*. 2015). WHO (2016) has also analysed the link of CO with different body functions and found its direct relationship with working capacity, learning capacity, headaches, mental ability and death also. Motor vehicles contributing to 50% nitrogen oxide (NO_X) and hydrocarbons (HCs) in urban areas are most harmful sources of CO.

2.6.4 Particulate Matter

Being tiny solid particles, particulates can clog the respiratory tract. Its accumulation can cause a number of respiratory as well as lung diseases (Marshall *et al*. 2015; Joshua *et al*., 2011). $PM_{2.5}$ consists of particles less than one-tenth the diameter of a human hair and poses the most serious threat to human health. PM_1 consists of ultra-fine particulate matter having a size less than 1µm, which exhibit a very high rate of retention in the human respiratory system. As per the study conducted by Maantay, (2007) and Kumar *et al*., (2011) Nano-particles are more hazardous to human health than larger particles.

2.6.5 Oxides of Sulphur

Oxides of sulphur are mostly present as sulfur dioxide and some sulfur trioxide released from the burning of coal or unrefined oil. Sulfur dioxide (SO_2) is released both by power plants and motor vehicles. Young children are suffered from asthmatics due to reaction of SO_2 with atmospheric fine particles. It may also combine with water vapor to cause acid rains. According to the Centre for Disease Control (CDC), SO_X exposure can create a number of health issues like sweating, papillary constriction, muscles cramp, dizziness, excessive salivation, vomiting, nausea and unconsciousness etc.

2.7 National Ambient Air Quality Standards (NAAQS)

Air quality standards are used to measure the air quality with respect to its effects on health. It identifies the amount of exposure permitted to the population and ecological system. The permissible air quality standards prescribed by WHO, NAAQS and CPCB are mentioned in Table 2.7 and 2.8 respectively.

Table 2.7: WHO standard of ambient air quality

Serial No.	Pollutant	Time Weighted Average	Guideline values
1	Particulate Matter (Size less than 10µm) or PM_{10}, µg/m^3	Annual	20
		24 Hours	50
2	Particulate Matter (Size less than 2.5µm) or $PM_{2.5}$, µg/m^3	Annual	10
		24 Hours	25
3	Sulphur Dioxide (SO_2), µg/m^3	24 Hours	20
		10 minute	500
4	Nitrogen Dioxide (NO_2), µg/m^3	Annual	40
		1 Hour	200
5	Carbon Monoxide (CO), mg/m^3	1 Hour	30
		Annual	50

Source: WHO, 2005

Table 2.8: National Ambient Air Quality Standards

Serial No.	Pollutant	Time Weighted Average	Concentration in Ambient Air	
			Industrial, Residential, Rural and other Areas	Ecologically Sensitive Area (Notified by Central Government)
1	Sulphur Dioxide (SO_2), µg/m^3	Annual 24 Hours	50 80	20 80
2	Nitrogen dioxide (NO_2), µg/m^3	Annual 24 Hours	40 80	30 80
3	Particulate Matter (Size less than 10µm) or PM_{10}, µg/m^3	Annual 24 Hours	60 100	60 100
4	Particulate Matter (Size less than 2.5µm) or $PM_{2.5}$, µg/m^3	Annual 24 Hours	40 60	40 60
7	Carbon Monoxide (CO), mg/m^3	8 Hours 1 Hour	02 04	02 04
9	Benzene (C_6H_6), µg/m^3	Annual	05	05

Source: CPCB; 2009

2.8 Emission factors of vehicular emissions

Vehicular emissions basically goverend by the fuel type, engine operation mode, combustion process, inspection and maintenance of the vehicles, speed of vehicles as well as vehicle age etc. The emission factor is an important key factor in vehicular pollution. Table 2.9 represents the emission factors of various pollutants in India.

Exposure of air pollution caused by motor vehicles mostly affect 0.89 million asthmatics in Delhi. Every year, 7500 people in Delhi, 5700 in Mumbai and 4500 in Calcutta are dying due to air pollution. Indians spend 45000 million annually to make up for health damages caused by air pollution. Most of the Indian cities like Delhi, Kolkata, Mumbai, Kanpur, Nagpur Ahmedabad etc, with million plus population has shown dangerous level of ambient air quality and found much higher than WHO permissible limits.

Table 2.9. Emission factors of pollutants

Vehicle Category	**Vintage**	**gm/Km**					**mg/Km**	
		CO	**HC**	**NOx**	**CO_2**	**PM**	**C_6H_6**	**Total PAH**
HCV CNG Bus (>6000 cc)	Post 2010	3.72	3.75	4.35	806.5	0.035	0	0
Passenger Cars (Petrol)(>1400 cc)		0.84	0.12	0.09	172.95	0.002	0	0.05
Passenger Car (CNG) (<1000)	BSIII	0.06	0.46	0.74	143.54	0.006	0	0.016
LCV Diesel (> 3000 cc) BSIII	BSIII	3.66	1.35	2.12	401.25	0.475	0.196	8.268
HCV Diesel Truck (>6000cc)	BSIII	6	0.37	9.3	762.39	1.24	0.005	3.971

MUV Diesel (<3000)	BSIII	0.25	0.19	0.67	255.98	0.096	0.268	0.125
Motorcycle (4S(100-200CC)	POST 2010	0.7	0.25	0.71	24.82	0.028	0.009	0
Three Wheeler (4 STOCK) (<200CC)	POST 2010	1.534	0.52	0.36	73.8	0.012	0	0.332
Tractor		9.88	1.09	9.73	799.95	1.09		3.78

Source: Gurjar *et al*., (2004); Nagpure 2013; 2016; CPCB (2010).

The dust and carbon particles coated with toxics gases are found at least three times higher than WHO standards. The main culprit is vehicular exhaust, which accounts for 65% of air pollution in Delhi, 52% in Kolkata and 30% in Mumbai. In Delhi, industry and thermal power plants contribute only 25%, the rest part comes out from domestic activities. Vehicle exhaust contains NO_2, SO_2, CO, lead, hydrocarbons, polycyclic aromatic hydrocarbons (PAHs) and particulate matter less than 10 micrometers. About 80% of particulate matter is deposited in the respiratory system. Table 2.10 represents the percentage of medical certification of cause of death (MCCD) in Delhi.

Table 2.10: Percentage of total MCCD death in Delhi 2015

Serial No.	**Main causes of Death under MCCD**	**Total MCCD Death (%)**
1	Tuberculosis	5.83
2	Diseases of pulmonary circulation and other forms of heart disease	4.07
3	Cerebrovascular diseases	2.43
4	Diseases of the liver	2.72

5	All other ischaemic heart diseases	1.25
6	Lower respiratory diseases	1.92
7	Hypoxia, birth asphyxia and other respiratory conditions	1.78
8	Chronic rheumatic heart diseases	1.06
9	Hypertensive disease	2.63
10	Leukemia	1.08

Source: Delhi MCCD report 2015

Vehicle emissions are characterized with the presence of various pollutants. High concentrations of these pollutants cause adverse health effects. The transport vehicles at the transport corridors are the primary means of commuter and freight during the course of the evolving development world for the reason of their adaptability, flexibility and lower or less economical transport modes. Urbanization is an important factor behind rapidly increasing in automobile ownership and usage. Automobiles are the largest source of vehicular emissions in most Asian cities. At present the concentration level of pollutants like CO, NOx, SO_2 and O_3 has been exceeded the international and national norms in developing countries. The table 2.11 represents the distribution of major cause of infant's death.

Table 2.11: Percentage distribution in infant's death in Delhi

Serial No.	**Distribution of major causes of infant deaths as per MCCD**	**Total (%)**
1	Hypoxia, birth asphyxia and other respiratory conditions	16.58
2	Diseases of pulmonary circulation and other forms of heart disease	1.7
3	Tuberculosis	0.75

Source: Delhi MCCD report 2015

The recent study of WHO reported driving reasons are also accounted for an increased number of death (WHO, 2013). As per the data of the year 2000 and 2011, ischemic coronary illness was found at first position followed by stroke, lower respiratory contaminations, COPD second, third and fourth position respectively (Balakrishnan *et al.,* 2013)

2.9 Health risks due to air pollution: a research review

The air pollution-induced human health impacts have been reported by various researchers world-wide, in particular, those sourced from road transport and are demonstrated to be not the only factor behind increased risk of respiratory and cardio-vascular diseases including cancer (Pope and Dockery, 2006; Favarato *et al*., 2014), but also overall mortality increase, lung cancer cases and various other respiratory ailments (Brauer *et al*., 2002; 2003; Nasari *et al*., 2016). WHO (2016) has reported that as many as 50% of the cities, especially those in southeast Asia, Eastern Mediterranean and Western Pacific regions have recorded an increasing trend of PM_{10} or $PM_{2.5}$ values over the last five-year span. WEO (World Energy Outlook) reported that no country in the world having immune to air pollution as 80% of different cities were failed to meet the air quality standard set by WHO due to high pollution levels. The projected premature death due to outdoor air pollution will reach from 3 million (2015) to 4.5 million by 2040 in Asian counties. Figure 2.3 represents the pattern that how the contribution of pollutants changes in a source causes related to exposure in the environment. Here the transport of pollutants from the source to the receptor-like human beings is represented every source of the path of pollutants. The duration of movement of pollutant from source to the receptor is shown as the rout of exposure. A choice of mode of transport, for e.g., metro train and bus corridors and with the advent of measures like odd-even driving schematic, push towards adoption of hybrid and electric cars, low emission zones, especially in developing counties have emerged as keys to abatement of an ever-increased levels of urban air pollution largely contributed by automobile emission.

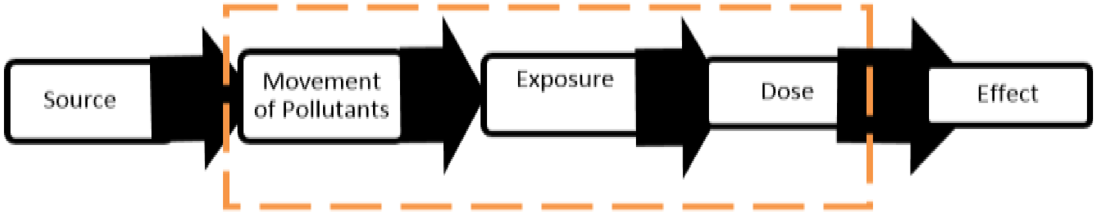

Figure 2.3: Five component of the conceptual full risk model

During his research study Franchinia *et al*., (2016) found link of PM exposure to a wide array of cardiovascular and respiratory disorders. Exposures on a human are dominant degree of severity, covering a range of minor effects to serious illness, or premature death in various studies. It directly affects the respiratory and cardiovascular systems of human as well as animals. The pollutants concentration is higher than standards, then it will be surly increased mortality, morbidity and impaired pulmonary function.

Exposure to air pollution has harmful effects on both physical and mental health. It's exposure occurs via two routes: directly and indirectly. Both of these routes by means of increasing morbidity and mortality in cardiovascular (Brook *et al*., 2010) and respiratory systems, lung development and function of central nervous system etc. have detrimental effect on life expectancy at birth and positive effect on infant mortality (Janssen *et al*., 2001; Jaafari 2014; Janke 2014). Zhang and Batterman (2013) reported that the residents living near major roads face elevated rates of several adverse health consequences. This has forced transportation agencies to apply roadway air dispersion models to analyze the impacts of new and expanded roadways, bus terminals, truck stops, and other sources. Toxic air pollutants has now become a matter of utmost concern in urban area because people and the emission sources are concentrated in the same geographic area. In megacities school due to walking, travelling everyday via buses to school, the children got expose to extremely high level of vehicular pollution. Further, traffic congestion has also become a prominent issue of concern in metro cities because everyone in congestion is directly or indirectly exposed to traffic pollution. Population exposure to air pollution places a substantial burden on public health and on society. The burden on public health is measured by the Global Burden of Diseases (GBD), Injuries, and Risk Factors project, which is the largest and most comprehensive effort to measure epidemiological levels and trends worldwide. The 2015 update of the GBD involved more than 1,800 from more than 120 countries and three territories. GBD (2015) estimated the burden of disease attributable to 79 risk factors that are, behavioural, environmental and diet-related metabolic factors that can affect human health in 195 countries and territories over a 25-year period (1990–2015) (GBD 2015 Risk Factor Collaborators 2016). In 2015, particulate matter (PM) air pollution from several major sources was responsible for approximately 1.1 million deaths, or 10.6% of the total number of deaths in India. Combustion sources are among the leading contributors. Transport, distributed diesel, and brick production are also important contributors to $PM_{2.5}$ attributable disease burden. In 2015, transportation contributed 0.023 million deaths, distributed diesel contributed 0.020 million deaths, and brick production contributed 0.024 million deaths (Oakes 2014; GBD, 2015).

2.10 Integration of geographic information system

The geographical information systems (GIS) are a computer-based system for the integration and analysis of geographical data. Geographical data are spatial data that result from observation and measurement of earth phenomena referenced to their locations on earth surface. The baseline data, integrated with GIS to evaluate the assessment of air quality differences in particular area. (Briggs *et al*., 2000; Brauer *et al*., 2002; 2003; Levy *et al*., 2003). Development of GIS technology and techniques of spatial analysis and cartography relevant long before the innovations in digital computing that made GIS possible (Kumar *et al*., 2014; Sun *et al*., 2017). At the same time, technological developments in geographic information system have opened and supported exploration of new avenues of scientific inquiry. The GIS rely heavily on computer hardware and peripheral equipment like large format scanner and printers that may not be the part of hardware part configuration available to public health analyst. The definition of GIS as computer-assisted system for capture, storage, retrieval, analysis, and display of spatial data might lead one assuming that the acronym is simply a catch almost any type of automated geographic data processing . In fact, GIS is a part of the larger installation of computer technologies for capturing and processing geographic data. Some of this technology like the global positioning system (GPS) and remote sensing are used to collect geographic data. Computer technology also plays a part in the collection of secondary geographic data from existing maps. Scanning is a technique for capturing map in digital form. The scanner is used as an optical laser of another electronic device to read a map and convert its feature to a computer database of dark and light values. To use the scanned image as more than just a backdrop in the

GIS display, vectorization technique implemented with GIS software can use to recognize specific element and convert them to points, lines, and areas representing features of interest (Kumar *et al*., 2015; Adms and Kanaroglou, 2016). Jensen (2001); Lin and Lin (2002); Elbir and Muezzinoglu, (2004); Farhat *et al*., (2013) reported that the gaseous and particulate matter pollutants are affected due to various trends of the meteorological condition wind speed, solar radiation and humidity of the study area. Digitization requires the use of a table and cursor to record coordinate locations of map features from a map placed on a digitizing table (Pantaleoni, 2013). It is possible to construct a GIS data layer by screen digitizing, using a pointing device like a mouse to move over and capture coordinate location from a digital database or image file displayed on the monitor. Scanning and vectorization are becoming more important as produces for data acquisition, and there is less emphasis on digitizing, at least with tables. Screen digitizing, however, is still widely used. Remote sensing, GPS, scanning and digitizing are the main methods for spatial data collection. One or more of these methods may be used, either by the person using the GIS or by the government organization or commercial vendor from whom a spatial database is purchased. The nature of spatial data and important issues related to scale, resolution, accuracy, storage, and retrieval of health and health-related data must be considered at data capture.

It is software tool and technique to explore an innovative method expanding data analysis of traffic count data and population density calculation to generate a traffic density surface with a resolution. Kang (2009) suggested that the GIS could be used as a platform to organize the data and implement urban air pollution research. Hoan (2006) reviewed that the PM, CO, NO_X , NO_2 VOCs and PAHs are having impact that is more significant on the developing world. Behera (2011) evaluated the transport-related air pollution dispersion models in urban areas. Chang *et al*., (2012) used GIS application, and simulative system with which the graphical interference is built as the GIS platform develops more effective flexible and accurate data. Lindén *et al*., (2012) and Gaur *et al*., (2014) also evaluated the spatial variations of ambient air pollutants like PM_1, $PM_{2.5}$, PM_{10}, CO, NO_x, O_3, toluene and benzene.

Tsilingiridis *et al*., (2002) proposed the exposure assessment with geographical information system techniques. They also calculated the air pollutant emissions at different spatial resolutions (1 and 2 Km^2) in order to support air quality simulations in the region. Waked *et al*., (2012) developed spatially distributed emission inventory for quantitative information of air pollution studies as well as for use as input to air quality models. Gulliver and Briggs (2011) also evaluated the air pollution mapping with the help of GIS for the pollution exposure on human health. It examined the spatial variations with focus on effects for variations in potential exposure to air pollution. Gulliver and Briggs (2005) modelled journey-time exposures of human beings to vehicular pollution into STEMS (Space-Time Exposure Modeling System) through the application of GIS platform. Wang *et al*., (2008) developed the high-resolution map to estimate the vehicle emission for the china country. They conducted the study with the help of resolution inventory method over a region of 1 km and reported the total daily fuel consumption and vehicular emission of CO_2, CO, HC, and NOx.

The adverse health affects of high concentrations of $PM_{2.5}$ and its mitigation was studied by Dholakia *et al*, (2013). They used a model named as Greenhouse Gases and Air Pollution Interactions and Synergies (GAINS). Katsouli *et al*., (2014) also estimated future forecast based on a spatial-temporal land use regression model linking geo-coded residential addresses to long-term average NO_2 and PM_{10} concentrations (Chen *et al*., 2007; Kaushar *et al*., 2013). Based on GIS, Joseph *et al*., (2014) reported that 62% of residents live in areas of very low or low environmental quality with less than 40% of the land, which indicates a grave situation of environmental injustice. Goyal *et al*., (2013) developed the new grid base mobile source emission inventory. The criteria pollutants like carbon monoxide (CO), nitrogen oxide (NOx) and particulate matter (PM) due to vehicles were considered during the study. Emission was estimated with the help of International Vehicle Emission (IVE) model while Vlachogianni *et al*., (2011) used the multiple linear regressions (MLR) technique to assess the air pollution in Athens and Helsinki. During his analysis, he used two kind of variables namely pollutants concentration and various meteorological parameters. Based on his study, he found the multiple liner regression as a very useful and fair tool to assess the air pollution.

Zhang *et al*., (2008) estimated PM_{10} emission with the integration of GIS and found industry as a third highest emitter (17.1%) of PM_{10} total emission in china. The annual emissions of SO_2, NO_X, and PM_{10} were found as 41385.9, 54780.4, and 24239.2 ton in china (Chak *et al*., 2008). Dadhich *et al*., (2017) found that the GIS tool is very useful to investigate the spatial pattern of ambient air pollution and its association with weather conditions along with visualization and statistical analysis. Wang *et al*., (2015) monitored five air pollutants namely NO_2, SO_2, PM_{10}, O_3, CO and used ArcGIS10.0 software to see the spatial distribution of pollutants. Along with this, he also applied ordinary Kriging model for the temporal-spatial specific air pollutants exposure level for each individual pollutant. They also explored the spatial association between ambient air pollutants and hospitalizations (Moghtaderi *et al.,* 2016).

GIS tool for personal exposure to particulate matter (PM_{10}) was experienced by the inhabitants of Dublin while commuting to work. It was calculated with various modelling tools built in in a GIS environment. They calculated PM_{10} concentration level of pollutants and to correlate this with other thematic layers, like land use and population density, it shows peaks in air pollutants with particular activities (Pilla and Broderick, 2015). Naves *et al*., (2015) used geographical influences on epidemiology study in Brazil.

Requia *et al*., (2016) evaluated air pollution risks to guide environmental and public health policies. Liu *et al*., (2017) used GIS mapping for the spatial-temporal variation of $PM_{2.5}$ distributions in China. A strong link was found between $PM_{2.5}$ and short-term as well as long-term exposures with respiratory diseases. Even though air quality assessment studies are being regularly conducted in most of the Indian cities by various agencies like Central Pollution Control Boards, State Pollution Control Boards etc. Very few efforts have been made to model the concentration of air pollutants for Indian conditions. The models that have been developed by certain institutions have not been tested for their reliability and applicability throughout the country. Also, some attempts have been made to use the existing software in India by calibrating them.

2.11 Summary

This chapter presents a comprehensive literature review on vehicular pollution, health risk assessment, air quality standards, GIS mapping, and its scenario in all over the world as well as in India. Along with the various health exposure problem, vehicular emission and concentration models related various literature also have been discussed in detail under various section and subsections.

CHAPTER 3

RESEARCH DESIGN AND METHODOLOGY

3.1 General

Delhi is highly urbanized city. It has primarily road-based transportation network. The number of vehicles is also growing day by day in the city. It has not only reduced the mobility of people but also increased the pollution level, journey time and average fuel consumption. This chapter discusses about the survey of the study area, collection of traffic volume data, vehicular pollution data, land use patterns, geographical position system (GPS) and questionnaire survey. Along with this, pollutant associated health risk along the selected transport corridors has also been outlined in this chapter.

3.2 Selection of study location

In view of the rapid vehicular growth in urban area, it is necessary to study the status of vehicular pollution and their impact on communities living along the transport corridors. The various models are frequently used to predict the air pollution from the various automobile, including their temporal and spatial variations. The systematic literature search was conducted for the emission and concentration of vehicular pollution at transport corridors.

Delhi being a part of Indo-Gangetic Plains it is located at an elevation ranging from 198 to 220 m above mean sea level (Gupta and Sarma, 2016; Lodhi *et al*., 2013). It is located between 28.3°24'15" N and 28°53"00" N latitudes and 76°50'24" E and 77°20'30" E longitudes with a total geographical area of 1,483 Km^2 with various land use patterns.

It is surrounded by key socio-economical districts of neighboring states viz., Gurgaon, Ghaziabad, Faridabad, Noida, Greater Noida, Sonipat, and Bahadurgarh. Infrastructure has not grown in adequate proportion making the existing network system function beyond its capacity.

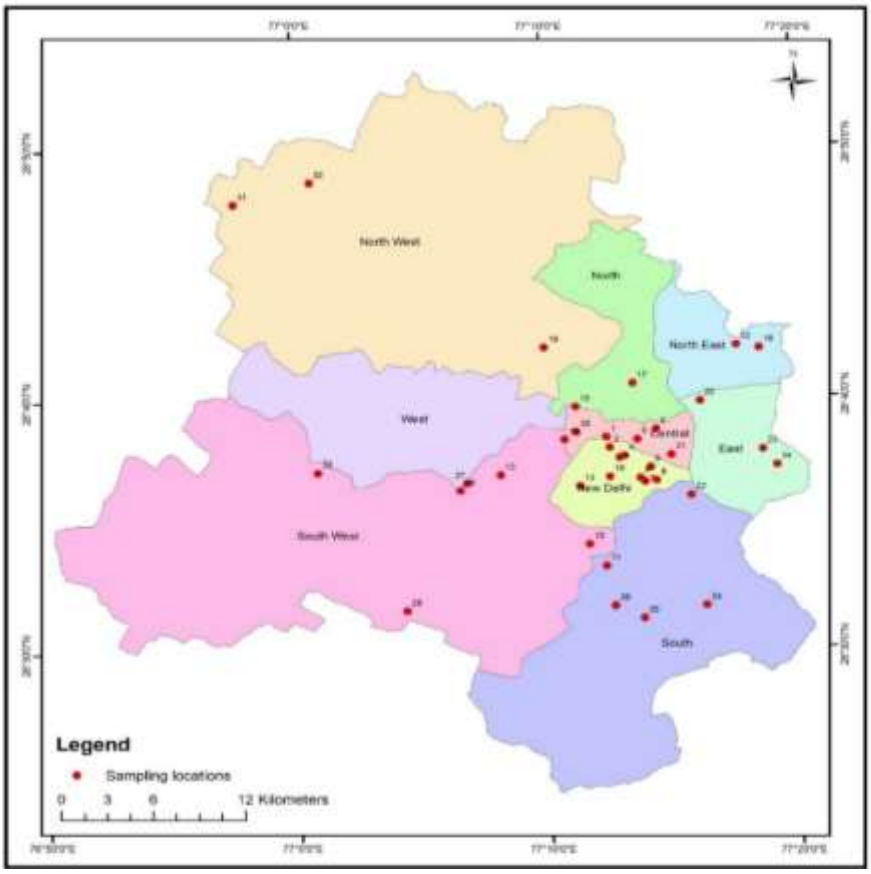

Figure 3.1: Map of study sites

This has led to serious traffic problems of congestion, delays, safety, pollution and system management. On account of continuous vehicular pollution exposure of those communities who are living either along the transport corridor or in the vicinity of the transport corridors, total 36 road transport corridors are taken up to conduct this research study in Delhi. These corridors cover the major area of Delhi due to its existence in the 11 districts of Delhi. It has widespread distribution along the residential area. Delhi is poly-nucleated urban structure and has hierarchical system of the commercial and shopping center. The residential areas are located around the economic activities. The shorter trip lengths and inadequate public transport system leads to fuel consumption of private modes at transport corridors.

3.3 Framework of the study

The research framework of this study includes the identification and selection of transport corridors. During this study, 36 transport corridors namely Minto Road, Punchkuian Road, SBS Marg, Sansad Marg, Janpath, Netaji Subhash Marg, Tilak Marg, Zakir Hussain Marg, Mathura Road, India Gate, Ring Road (Safdarjung), Aurobindo Marg, Ring Road (Naraina), Sardar Patel Road, Shankar Road, New Rohtak Road, Ashok Vihar Road, Sham Nath Marg, Wazirabad Road, ISBT Flyover, G.T. Shahdra Road, I.T.O. Bridge, Nizamuddin Bridge, Patpadganj Road, Maa Anandmai Marg, Madangir road, Press Enclave Road, Janak Setu, Pankha Road, Old Gurgaon Road, Najafgarh Road, Qutabgarh Road, Auchandi Road, Loni Road, Ghazipur Road and Pusa Road were selected. All the identified locations are used to monitor the traffic volume data along with different road related geometrical parameters. In addition to the primary data, some secondary data has also been gathered from different sources. On the basis of primary as well as secondary data, GIS mapping has been done for both concentration as well as emission of different vehicular pollutants like CO, PM_{10}, $PM_{2.5}$, NO_X, SO_X and Benzene at all the selected transport corridors. The monitored data has also been used to assess the overall air quality. Along with mapping, with the help of AirQ 2.2.3 and Ri-map model, the human health risks due to CO, PM_{10}, $PM_{2.5}$, NO_X, SO_X are also assessed at all the selected transport corridors. In the last, perception-based analysis has also been conducted to understand the real existing issues among residents and their suggestions to curb the vehicle related air pollution problem in the city. The overall adopted research methodology during this study is presented in Figure 3.2.

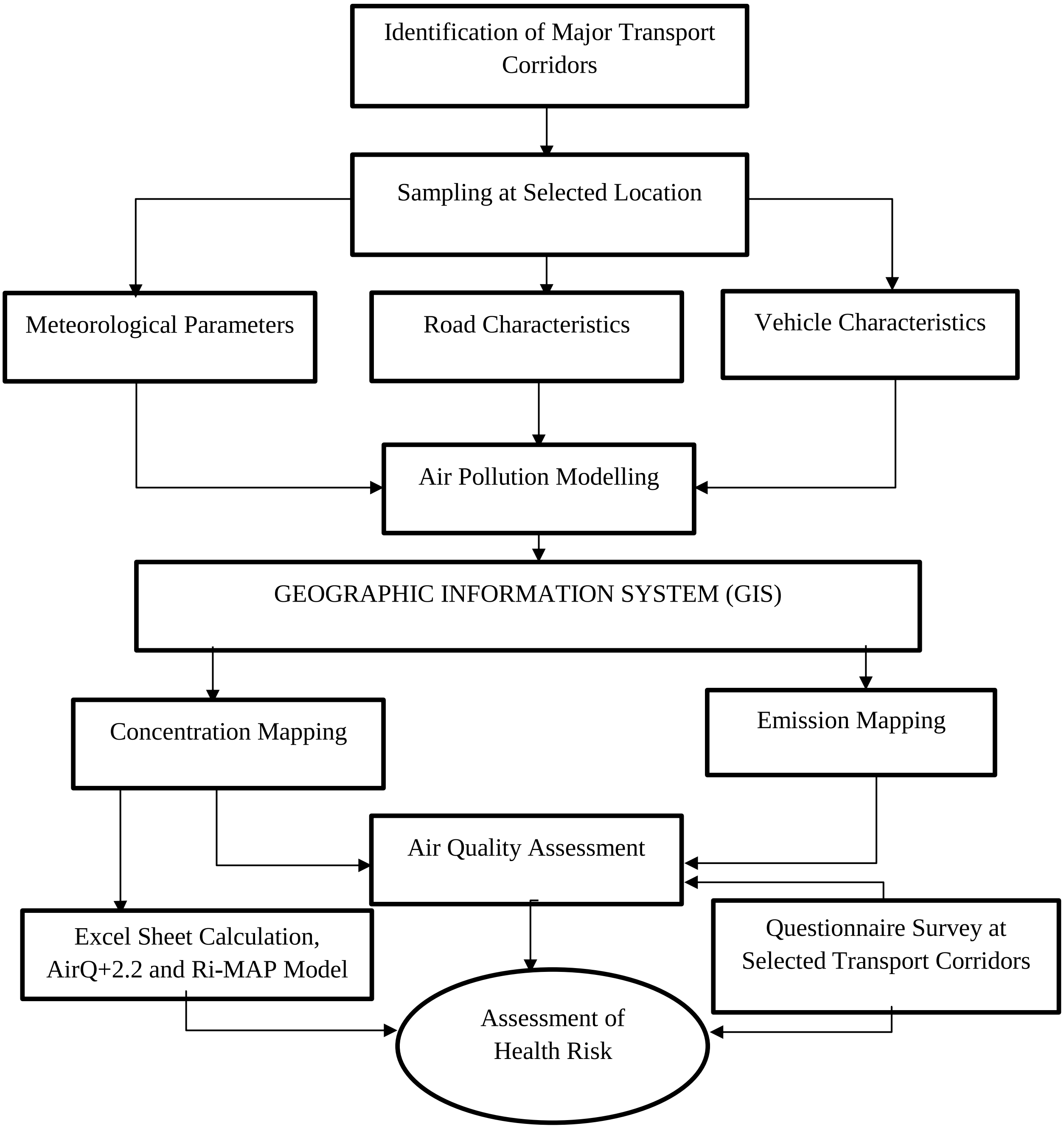

Figure 3.2: Research framework for the Study

3.4 Box model application

Air pollution modeling is a numerical tool used to describe the causal relationship between emissions, meteorology, atmospheric concentrations, deposition, and other factors. Ambient concentration of the pollutants in a specified volume is equated to the total air mass in the box divided by volume. Mass balance within a specified volume of air can also be simulated using complex dispersion models such as receptors or sink, transport, turbulent diffusion and possible chemical reaction. To predict the ambient air concentrations that will result from any planned set of emissions for any specified meteorological conditions, at any location, for any time period (Tiwari *et al.*, 2014).

The atmosphere turbulence is complete but contained only up to mixing height. It is strong in the upwind directions and lower on the downwind side. This produces uniform concentration of the pollutant. The wind velocity and direction are uniform through the box all along the height. The concentration of pollutant entering the box is constant. The pollutant enters only from the bottom or from one side of box. These pollutant**s** have long residence time in atmosphere and there is no receptors or skin in the box. The box represents a uniform atmosphere throughout its volume (Tiwary and Colls, 2010).

The Box Model is used for the calculation of emission and Gaussian equation for concentration of the pollutant emitted from various vehicles. Figure 3.3. Shows the sampling location as grid shape with four square kilometers area 2 km × 2 km (Chow *et al*., 2002; Gurjar *et al*., 2004; Wang and Mauzerall, 2006; Goyal and Kumar, 2013; Gargava *et al*., 2014). The short and long range transport of air pollutants from line source as well as polluted areas can affect regionally and at global scale (Garg *et al*.,2006; Gurjar *et al*., 2004; Guttikunda *et al*., 2001; 2003; 2013).

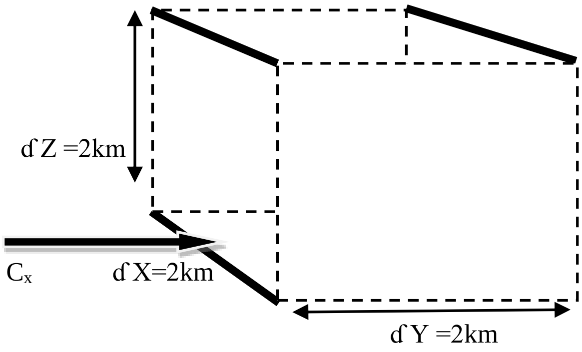

Figure 3.3: Box model for estimation of vehicular pollutants

C_X = Outside concentration of pollutant, Emission Q_A = mass/Area Time

Accumulation=Input to the Box (mass/time) - (Output Box mass/time)

So Q_A or E_T = Emission

$$E_T = \Sigma\ (Vehl \times D_l) \times EF_{l,\ km} \qquad \text{….. (3.1)}$$

Where,

E_T = Total Emission rate of compound (g/Sec), Vehl = Number of vehicle per category per hour, D_l = Distance travelled (Km), EF_l, km = Emission Factor of pollutant, vehicle type per driven kilometer.

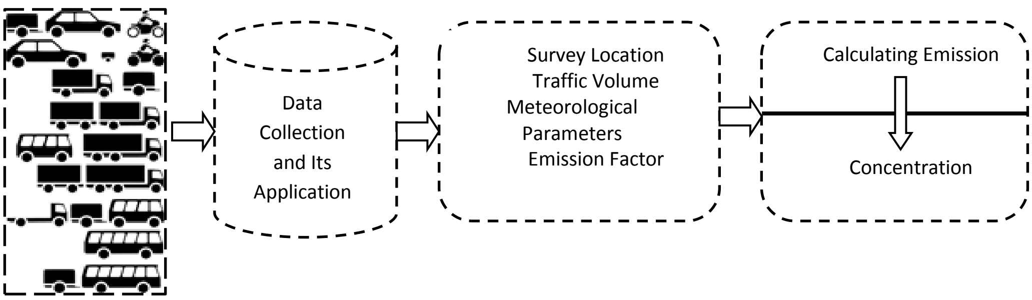

Figure 3.4: Methodology for the assessment of vehicular emission

Figure 3.4 shows the methodology of flow of input data for emission and concentration. Emission inventories are essential to assess the status of air quality of local regional and global scales (Parrish, 2005; Marrapu, 2012; Marrapu *et al*., 2014).

The Gaussian theory is used to predict the concentration of gaseous pollutants and particulate matter at different selected transport corridors. The Gaussian solution for linear sources emission is based on the concept of overlaying various factors. The sum of dispersion for pollutants of infinite points sources are calculated from in-line source pollution and then, is estimated the concentrations of emitted pollutants at receptor point (Goyal *et al*., 2006). The Gaussian plume equation, presented below, is developed with combination of finite and infinite line sources emission and is used for the calculation of pollutant concentration from equation 3.2.

$$c(x,y,z) = \frac{Q}{2\pi u \sigma_y \sigma_z} exp\left[\frac{-1}{2}\left(\frac{y}{\sigma^2{}_y}\right)\right]\left[exp\left(-\frac{(z+H)^2}{2\sigma^2{}_z}\right) + exp\left(-\frac{(z-H)^2}{2\sigma^2{}_z}\right)\right] \quad \text{…. (3.2)}$$

Where *C(x,y,z)* = concentration of pollutant unit (µg/m^3) at receptor, coordinates x,y,z represent points.

Q = rate of emission of pollution source (µg/sec)

u = average speed of wind (meter/second)

y = cross wind distance (meter)

z = vertical distance (meter)

σy = standard deviation of plume in direction of y coordinate (meter)

σz= standard deviation of plume in direction of z coordinate (meter)

Assessment of Line source emission of pollutants is shown in line of infinitesimal point source.

The ground level concentration of gaseous pollutants can be estimated by integration of Equation (3.3) along the length of the line source.

Source of emission at ground level, *y=0, z=0*

Therefore, the concentration is $c(x, 0,0) = \frac{Q}{\pi u \sigma_y \sigma_z}$ ….(3.3)

The concentration is calculated distance x = 0.02 km far from the emission points i.e., all transport corridor, where wind velocity u=2 m/sec, $\sigma_y = 37$ $\sigma_z = 20$ (Turner, 1994).

3.5 Application of GIS for air pollution mapping

GIS is used for visualizing model results and better analyses of CO_2 concentration status at a particular geographical area. Morality rates were calculated using the number of people exposed to pollution in 2-km^2 area. It plays a vital role in the planning of air quality management in megacities. In present scenario, the GIS techniques are used for air quality assessment. It simulates traffic, emission, and dispersion patterns of the pollution. The GIS and modeling characteristics are presently used for air quality assessment. The analysis of transport planning and transport systems management can also be done through GIS technology. The GIS maps show a combination of data layers as presented in Figure 3.5. The GIS database is systematic on the basis of geographical base line data, which consists of inputs of attributes in the GIS software.

The road corridor network map of the study area is digitized with GIS software. These linked maps are integrated with a number of various topographic morphological attributes of the study area. In particular, the whole territorial database, which has been set up within GIS, is designed according to the details of inputs. The use of GIS as a database integrator for a transport study area and schematic diagram represents a set of individual databases for the study area, which comprise a mixture of spatial, numerical, and perhaps textual data. The GIS is a very dynamic technology capable of integrating large quantities of geographic spatial data. The GIS database is provided by road networks corridor data, traffic demand characteristics, driving cycles and fleet composition. GIS integrating models are aimed at reproducing traffic behavior, emission and dispersion scenarios.

3.6 Framework design for fieldwork and calculation methodology

The Gaussian theory is used widespread to predict the concentration of gaseous pollutants and particulate matter with the help of emission factor of vehicles and speed of different category of vehicles along various transport corridors. The Gaussian solution for linear source of emission is based on the concept of overlaying various factors. The sum of pollutants dispersion of infinite point sources are calculated from in-line source pollution, and then, the concentrations of emitted pollutants are estimated at receptor point (Goyal *et al*., 2006; ARAI, 2007; Nagpure *et al*., 2016). The baseline data, integrated with Geographical Information Systems (GIS) to assess the neighborhood differences in air pollutant concentrations as a function of proximity to roadways (Briggs *et al*., 2000; Brauer *et al*., 2003; Hoek *et al*., 2002; Levy *et al*., 2003).

This GIS-based regression analysis is called land-use regression modeling (Jerrett *et al*., 2005). Kriging methods are considered for mapping spatial variations using spatial correlations between sampled points (Ella *et al*, 2001). GIS is an important tool for dealing with such types of data. Colberg and Mutius, (1993) and Gilbert *et al*., (2003) reported that people are exposed to traffic-related air pollution and elevated risk near transport corridors.

In the present study, air pollution assessment was done for various transport corridors as well as traffic flow for both sides of the road. Various input parameters were used to estimate the concentration of pollutants at selected transport corridors. Figure 3.5 shows the input parameters and design framework of the study. The acquired data were used for the generation of spatial variability maps with the help of ArcGIS 10.2 and ERDAS 2014 software (Elbir *et al*., 2004; 2010; Sohrabinia and Khorshiddoust, 2007; Santini *et al*., 2010).

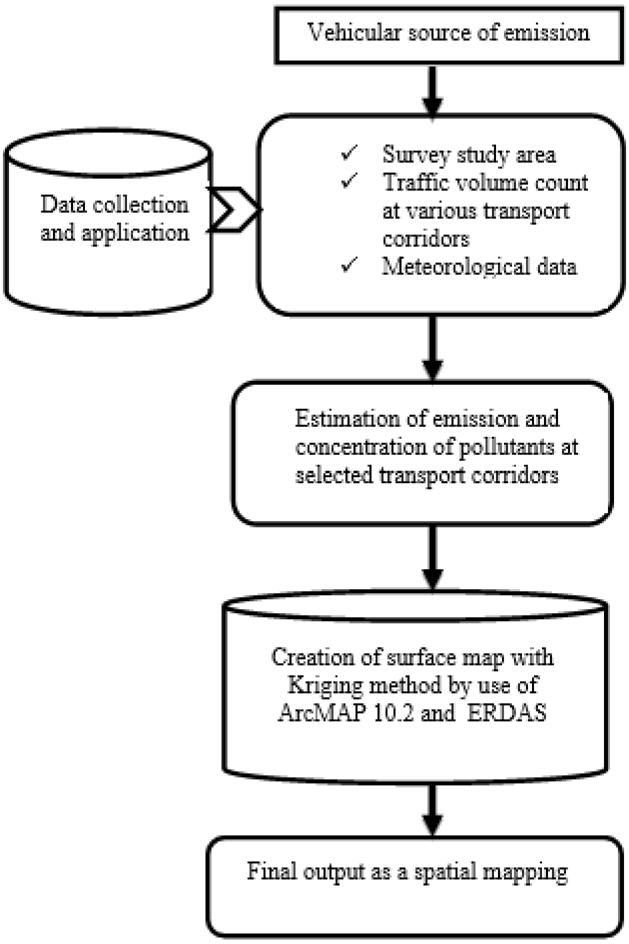

Figure 3.5: Vehicular pollution mapping with the integration of GIS.

3.7 Spatial dispersion of the pollutants (Kriging Method)

Kriging is a geo statistical methodology for the spatial interpolation of any primary data showing a local and stochastic method of interpolation as better output from the deterministic analysis. In addition to the resolution of the results of prediction error with estimated variances (Watson and Philip, 1985; Chang, 2012), it also generates a map of the study area and, technically, interpolation analysis gives the predictive values for the unmeasured study area. The mechanism of Kriging's function in respect of data interpretation can be understood from Figure 3.6.

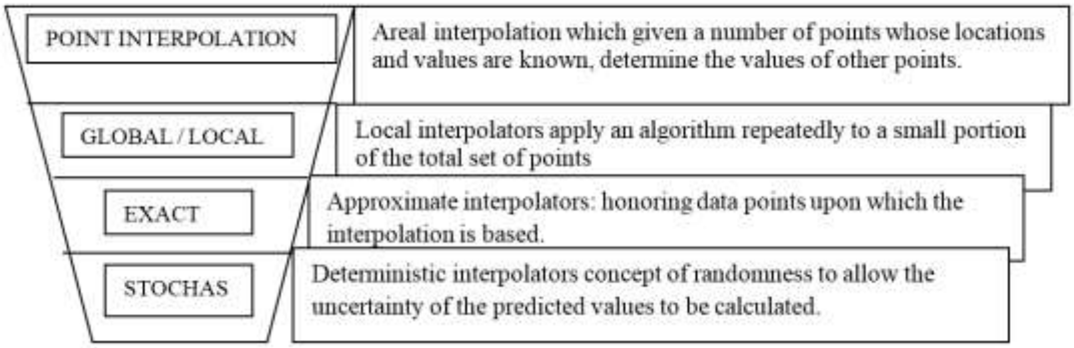

Figure 3.6: Mechanism of Kriging's function for data interpretation

Ordinary Kriging, which has been applied in the present study, provides interpolated values from equations that minimize the variance of the estimation error. The coefficients of the linear combination known as weights that depend on the distance between the sample point and the estimated point and the spatial structure of the variable. Ordinary Kriging is based on the assumption that the mean of the process is constant and invariant within the spatial domain. The Equation 3.4 given by Dash *et al*., (2010) is as follows:

$$z(x) = \mu + \in (x) \qquad \text{.... (3.4}$$

Where, μ = Unknown constant and generally considered the mean value of the regionalized variable, z(x) = Regionalized variable at any location x with stochastic residual, $\in$ (x) with zero mean and unit variance.

3.8 Deign framework of health risk analysis

Epidemiological and toxicological studies have been shown as a robust indicator of risk associated with exposure to air pollutant from diverse sources in the different environment. For the implementation of more effective local, national, and global policies to reduce air pollution, quantitative estimation of health risk assessment now becomes important for policy makers and stakeholder. Therefore, it is important to choose the appropriate policy question, specific pollutants of the area and targeted population in air pollution risk health assesment (APHRA). Health risk assessment is a scientific evaluation of potential adverse health effects resulting from human exposure to air pollution and its aim to estimate the fate of exposure past, current or future to air pollution. APHRA may be quantitative or qualitative which generally assesses (1) the amount of air pollution present (pollutant concentrations), (2) the amount of contact (exposure) of the targeted population, and (3) how harmful the concentration is for human health; e.g. the resulting health risks to the exposed population. In selecting an APHRA, the aim should be to maximize scientific rigor within the resources available. Several computer-based tools are available (AirQ+, AirCounts, Aphekon, EcoSense, etc.) that automate the process of an air pollution health risk assessment. Theses tools offer several advantages to the practitioner and end-user, with its simplicity like lowering the barrier to consistency, conducting assessments, comparability among assessments, and quality assurance. Automated tools are typically preloaded with health and demographic data and concentration-response-functions (CRF), and some allow for user-specified inputs. Several number of research has been done to assess the health risk due to the air pollution with the help of AirQ+ (Ghozikali *et al*., 2016; WHO, 2016).

3.8.1: AirQ+ tool application

AirQ+ software tool is developed by World Health Organization (WHO). It is open source software with the capability of presenting health risk due to air pollution. It manages the pollutant like PM_{10}, $PM_{2.5}$, NO_2, O_3 and black carbon. $AirQ^+$ incorporates into an easy to understand route strategies to evaluate the impact of long-term and introduction of surrounding air contamination. It can also assess the effects of indoor air pollution related to solid fuel use (SFU). Figure 3.7 present 4 step for the analysis AirQ$^+$ tools. This software tool is integration of mathematical application and analysis of exposure of health risk. It works by logarithmical functions, matrix calculations (at least 40,000 matrix elements), statistical functions. AirQ+ is useful for any region/city/country to estimate, how much of a particular health outcome is attributable to selected air pollutants and compared to the current scenario that what would be the change in health effects if air pollution levels changed in the future.

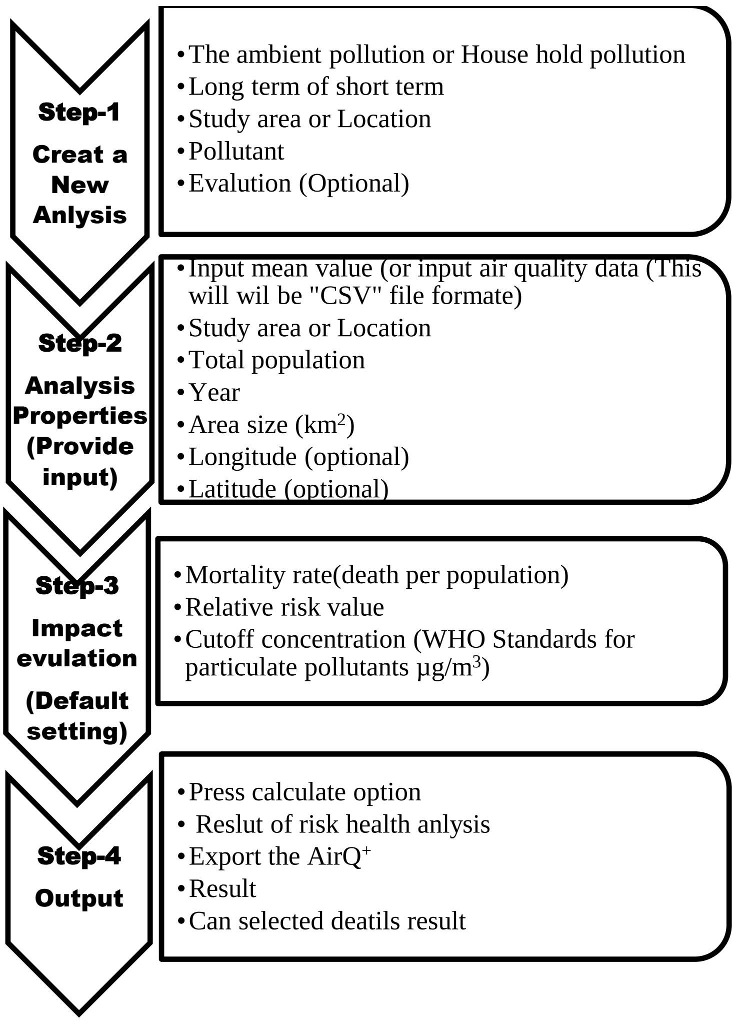

Figure 3.7: Flow Digram of basline data input for AirQ+.

All calculations performed by AirQ+ are based on methodologies and concentration-response-functions (CRF) established by epidemiological studies. Different health result identified with mortality and morbidity both as far as the serious and endless condition can consider for the counts. The essential logical proof on the health impacts from encompassing primary studies directed western Europe and North America. It has limitation too, but it will be easy to understand , to help the consideration with alert and includes master judgment (Brauer *et al.*, 2012; WHO 2014; 2015). Figure 3.8 shows integratigation of six steps for the assessment of the air pollution health risk analysis.

AirQ^{+} also has different entry field colour codes for data entry like White, Green, Yellow, and Red Colour (Table 3.2).

Table 3.1: Colour codes for data entry

Colour	Description
White	The White colour of analysis properties of tab represents the optional data.
Green	Green colour represents or indicates the correct values in mandatory and voluntary fields. For AirQ+ Mandatory fields must be. Filled for computations.
Yellow	Voluntary fields it is strongly recommended to fill in those fields for documentation purposes. Voluntary fields are not necessary for the computation.
Red	If incorrect values are supplied in a mandatory field, the field turns red. For example, concentration mean values must not be negative

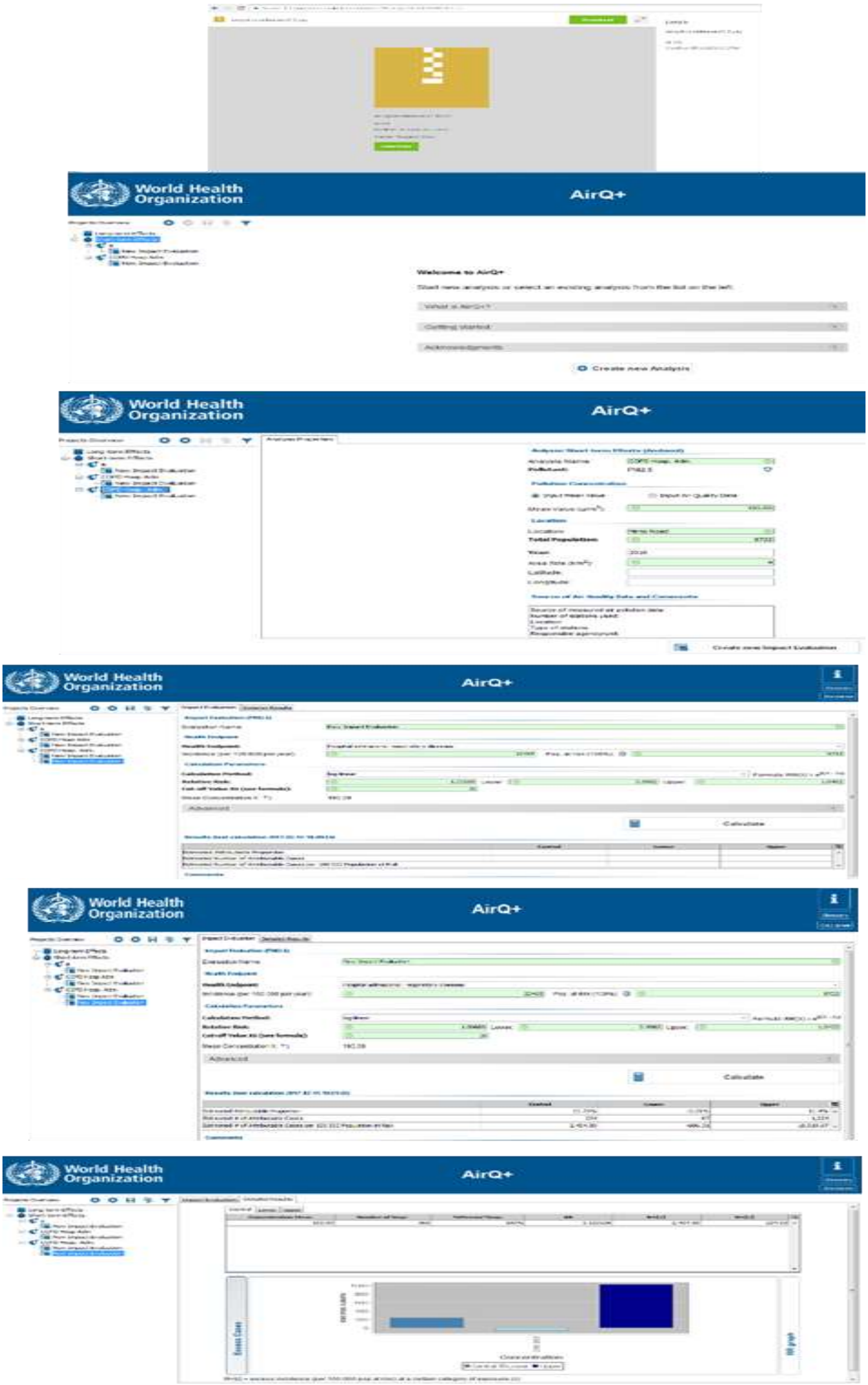

Figure 3.8: The flow digram for health risk assessment with AitQ+ model

3.8.1.1: Input for AirQ+ analysis

For air AirQ+ tool, input data have three major categories, (1) ambient air pollution, (2) household population (3) Ozone. The ambient air quality has two option for input of pollutant concentration. One option is for long term exposure effects in which average concentration of a pollutant is needed and the second option is for short term exposure effects in which frequency of days with particular pollutant values are needed. Data of targeted population at risk (e.g., the total number of adults aged ≥35 years) and a cut-off value of pollutant (standard value) for consideration in $\mu g/m^3$ and relative risk (RRs) values should be provided. Relative risk value is calculated by the concentration-response-function (CRF), which enumerate the health impact of targeted population per concentration unit of a particular air pollutant. Typically, these CRFs are established in epidemiological studies. For ozone input, the user should provide the data same as in ambient air pollution in prescribed format. In household air pollution, the user needs to input data for the population at risk, the percentage of the total targeted population using solid fuel (SFU) for cooking heating and lighting in indoor, health data, and relative risk (RRs) values. Health data is the baseline rates of health outcomes in the population studied. AirQ+ have some default values like RRs, conversion factor between $PM_{2.5}$ and PM_{10} at the national level and International level.

3.8.1.2: Results output of AirQ+

It estimates the attributable proportion of cases, number of attributable cases, number of attributable cases per 100,000 population at risk, proportion of cases in each category of air pollutant concentration, and the years of life lost. One screen display of numerical values, including matrices form, it stored in CSV file and Microsoft Excel compatible with XML format. Any further processing like the production of graphs generates outside of AirQ+ in spreadsheet programs like Excel. AirQ+ can give fallowing output.

- Analysis of the City/Country/Area Data: ambient air pollution specific pollutant long-term adult mortality
- Analysis of City/Country/Area Data: ambient air pollution, specific pollutant, short-term mortality.
- Analysis of the City/Country/Area Data: ambient air pollution, a specific pollutant. longterm, adult mortality use of the integrated exposure-response function (IER).
- Analysis of the City/Country/Area Data: ambient air pollution, Ozone, long-term, adult mortality.
- Analysis of the City/Country/Area Data: ambient air pollution, solid fuel use, long-term, children mortality
- Analysis of the City/Country/Area Life Table data, ambient air pollution $PM_{2.5}$ long term adult mortality, use of life tables.

The $AirQ^+$ represent an epidemiological reviews health risk (Nagpure, 2014; Maji, 2016). These air pollutants parameters (PM, NOx, CO, O_3, BC) show the relationship between air pollution and serious health exposure.

3.8.1.3: Limitations of $AirQ^+$

This particular tool has also some limitations like any other health risk assessment (HRA) tools. It considers ambient air pollution monitoring data as a proxy indicator of population exposure. AirQ+ calculations do not account for multiple exposure cases or multipollutant scenarios and its morbidity estimates present low reliability due to difficult conformity in the assessment of health outcomes related to hospital admissions and in this tool indoor air pollution RRs are based on studies carried out in situations of very high pollution level.

These models consider encompassing air contamination checking information as an exposure of pollutants on human health. Its calculation do not represents various investigation of cases or multi contamination situation in the environment. AirQ+ also represents mortality, morbidity estimates, health outcomes; as well as low reliability due to difficult conformity related to hospital admissions. It is helpful for household air pollution relative health risk which depends the ambient air pollutants concentration is in that particular area.

3.9 Risk of Mortality/Morbidity (Ri-MAP) model

The mortalities assessment in Ri–MAP model is based on long-term exposure (1 year) to the air pollutants like $PM_{2.5}$, and NO_x, whereas the assessment of morbidity is based on the basis of short-term exposure in 24 hours. Maynard *et al*., (2007). This study helps in giving a fair idea of how the pollution due to vehicles can lead to increased number of mortality and morbidity with respect to various diseases in the concerned area (Revich and Shaposhnikov, 2013).

3.9.1 Description of the method

Vehicular emission data was collected on a 24-hour basis and then implemented the population attributable-risk proportion concept on this data for the calculation of mortality/ morbidity due to cardiovascular and respiratory diseases. The calculation of mortality/morbidity was performed over sub-district populations of the NCT of Delhi. The population for the year 2016 was projected on the basis of data of population taken from the census of India 2011.The projected population was obtained using growth rate for the period 2011-2015.

3.9.1.1 Relative risk and baseline incidence

In epidemiology, the probability of developing an illness caused by the exposure to various pollutants is called the relative risk (RR). Table 3.3 shows values of relative risk [per 10 µg/m^3 increase in daily averages for fine particulate matter ($PM_{2.5}$) and nitrogen dioxide (NO_2)] and baseline incidence (per 100,000) corresponding to different types of mortality/morbidity and disease (e.g., cardiovascular, respiratory, etc.) Anderson (1992; 2004); Atkinson and Anderson (1997); Sunyer (2001); WHO (2001).

Table 3.2: WHO-Specified and Adopted Values of Relative Risk and Baseline Incidence

S. No.	Health Risk Parameter	Pollutant	Relative Risk (RR)[b]	Baseline Incidence Per 100,000 (I)[c]	Reference
Mortality					
1	Respiratory mortality	NO_2	1.00016	147	Aggarwal & Jain, 2015
		$PM_{2.5}$	1.12824	147	
		PM_{10}	1.012	66	Maji et at., 2016
		SO_2	1.010	66	Nagpure *et al*.,2014
2	Cardio-vascular mortality	NO_2	1.00100	325	Aggarwal & Jain, 2015
		$PM_{2.5}$	1.01502	325	
		PM_{10}	1.008	497	Maji et at., 2016
		SO_2	1.008	497	Nagpure *et al*.,2014
3	Total mortality	NO_2	1.002	497	Nagpure *et al*.,2014
		PM_{10}	1.0074	1013	Maji et at., 2016
		SO_2	1.004	1013	Nagpure *et al*.,2014
Morbidity					
4	Respiratory morbidity (COPD[d] hospital admission)	NO_2	1.0038	101.4	Maji et at., 2016
		$PM_{2.5}$	1.00685	20465	Aggarwal & Jain, 2015
		PM_{10}	1.008	1260	Maji et at., 2016
		SO2	1.0044	101.4	Maji et at., 2016
5	Cardio-vascular morbidity (hospital admission)	NO_2	1.06138	2533	Aggarwal & Jain, 2015
		$PM_{2.5}$	1.0456	2533	
		PM_{10}	1.009	436	Maji et at., 2016

[a]*general values only; references are provided citing exact source of adopted values in calculation.*
[b]*average of lower and upper limits (range) of the 95% confidence interval.*
[c]*based on threshold limit given in WHO guidelines.*
[d]*Chronic Obstructive Pulmonary Disease.*

3.9.1.2 Concentration response equations

The attributable-risk proportion (AP) is defined as the fraction of health impacts, which can be attributed to the exposure in a given population for a certain time period (assuming a causal association between exposure and the health effect and the absence of major confounding effects). Equation 3.5 has been used to calculate the attributable risk proportion.

$$AP = \frac{\sum[(RR(C)-1)*P(C)]}{\sum RR(C)*P(C)} \qquad \text{.... (3.5)}$$

Where,

RR(c) = the changed relative risk for the health outcome in category c of exposure

P(c) = the proportion of the population in category *c* of exposure which could vary according to the degree of exposure in a different area.

However, in this study the same exposure has been assumed at all transport corridors throughout the megacity due to the lack of data availability.

$$\text{RR(C)} = \frac{(C-T)}{10*(RR-1)+1} \qquad \text{.... (3.6)}$$

where,

C = the ambient air concentration of a pollutant,

T = the threshold level of the pollutant as recommended by the WHO, and

RR = the relative risk for the selected health outcome.

We used the arithmetic mean of selected concentrations for each time unit (daily or yearly).

The obtained average value was then used as an indicator of the whole population's exposure (i.e. one population-one value for a specified time period). For this, daily concentrations data from 15 monitoring stations were used and taken the yearly average value of them. Knowing (or often assuming) a certain baseline frequency (at threshold concentration value given by WHO guideline) of selected health outcomes (i.e., I), the rate (or a number of cases per unit population) attributed to the exposure in population (i.e., IE) can be calculated according to this Equation 3.7.

$$IE = I \times AP \quad \text{.... (3.7)}$$

Then IE can be used to estimate the number of cases attributed to exposure (i.e., NE) in the whole population of given size N, using the following Equation 3.8,

$$NE = IE \times N \quad \text{.... (3.8)}$$

Consequently, the frequency of the outcome in the population that is free from exposure (i.e., INE) can be estimated by the following Equation 3.9,

$$INE = I - IE = I \times (1 - AP) \quad \text{.... (3.9)}$$

The RR value at a certain level of pollution and the estimated incidence in non–exposed population, can be further used for obtaining the excess incidence [i.e., $\Delta I(c)$], and excess number of cases [i.e., $\Delta N(c)$], respectively, at a certain category of exposure (c) can be calculated using the following Equations 3.10 and 3.11,

$$\Delta I(c) = (RR(c) - 1) \times p(c) \times INE \quad \text{.... (3.10)}$$

$$\Delta N(c) = \Delta I(c) \times N \quad \text{.... (3.11)}$$

All of the above mentioned equations are based on the assumption that the RR estimate is adjusted for any possible confounding variables. When the limits of the confidence interval for the RR estimate are used in the first equation, we obtain the corresponding range for AP and the respective range for the number of cases in the population that can be attributed to pollutant exposure. The last equation is used to calculate the excess number of morbidity cases, which denotes the number of mortalities in the exposed population. In practice, however, the uncertainty of the impact (and the range of the estimated effect) is greater due to the presence of errors in exposure assessment and non–statistical uncertainty of the exposure-response function.

3.10: Questionnaire Survey

Questionnaires survey may be defined as two types like quantitative and qualitative methods; it depends on the nature of question. Surveys are a very traditional way of conducting research. The survey approach may be used to establish the prevalence or incidence of a particular condition. In this approach is frequently used to collect information on attitudes and behaviour of the person related to daily life activity.

A questionnaire is often the first tool that people consider when undertaking a research analysis. The questionnaire designing is a complex and time-consuming and quality of the data collected is determined by the quality of the questionnaire used for the research. It may be more appropriate to consider alternative methods to focus along vicinity of study area. The questionnaire performa is attached as annexure I.

A systematic method of gathering information from a target population, a survey makes use of statistical techniques primarily used in quantitative research. The different steps as in mention Figure 3.9 are included in the process of conducting a survey, as well as several questions have been too asked to one's self during each step. The questionnaire survey was conducted at each transport corridor of the study locations. During the description survey, only that population was considered which were residing in around 2 km^2 area. The respondents were from various sectors. Door-to-door survey was also conducted in those residential areas, which were located in the vicinity of the selected transport corridors. The survey was also target the shopkeepers, students, driver, working labors along the transport corridors, vendors, traffic police, doctors. The figure 3.9 the various steps taken during the preparation of questionnaire survey.

Specifically, answers obtained through closed-ended questions with multiple choice answer options are analyzed using quantitative methods and they may involve pie charts, bar charts and percentages. Answers obtained to open-ended questionnaire, and the questions are analyzed using qualitative methods and they involve discussions and critical analyses without use of numbers and calculations.

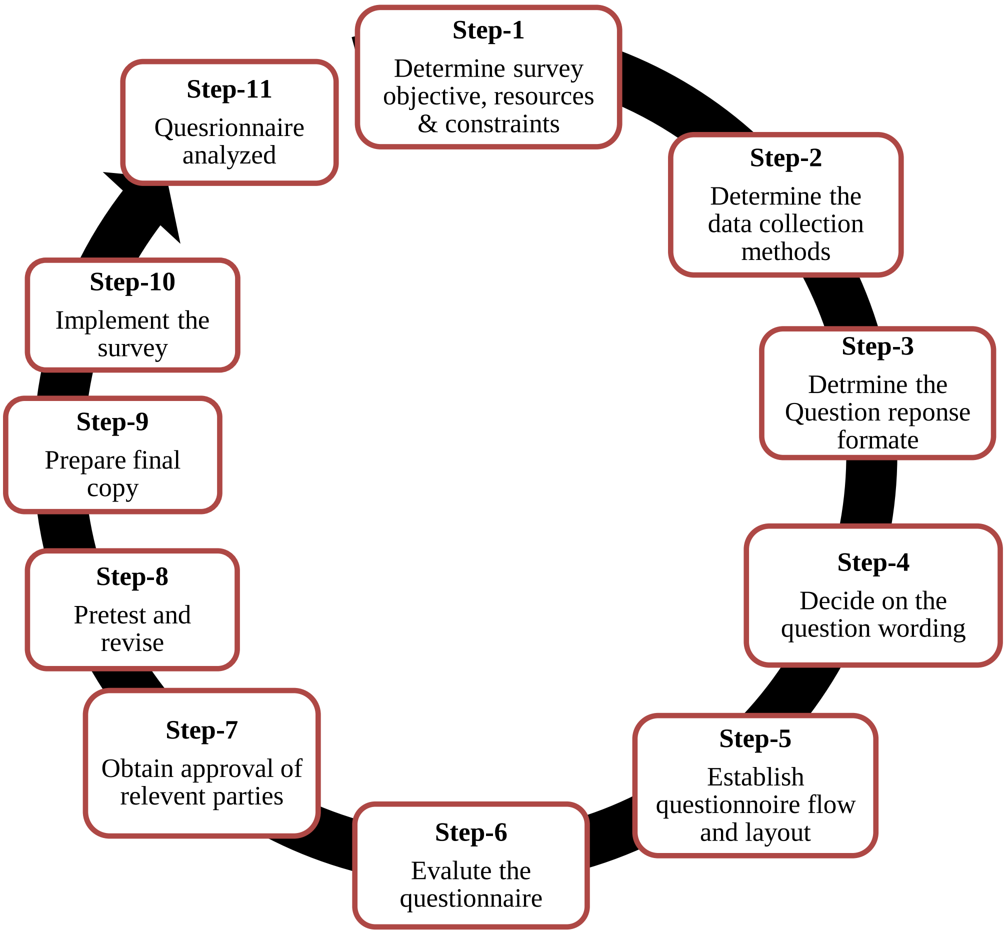

Figure 3.9: Design framework of questionnaire for vehicular pollution awareness and health risk.

3.11: Summary

In this chapter present a brief description about the methodology adopted during the research study. A detailed discussion on the research design, various tools and technique and research framework of the study is covered in this chapter. Along the research framework, the different models like AirQ2.2, Ri-MAP has been thoroughly discussed in the present chapter. In addition to this, questionnaire-based survey and its design framework has also been covered in this chapter.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 General

Delhi has primarily road-based transportation network. Due to lack of road space there is hardly any space for future expansion of road network and yet motorization is increasing continuously day by day in Delhi, which leads to increase in vehicular pollution and health risks. The communities living in the vicinity of major transport corridors are more exposed to vehicular pollution. Nowadays, in highly urbanized city increased vehicles number is directly to increase the pollution level of city. The present day's people are very much worried about the vehicular pollution problems. The present study is mainly focused on the outcome of data analysis of emission and concentration of various pollutants. Along with this the study also covers the analysis of health risk assessment due to vehicular pollution. Another important component i.e. GIS mapping of selected pollutants over the study area. In this chapter all the results and discussion are summarized under the following sections.

4.2 Fleet characteristics and meteorological parameters

Vehicle transportation is an important component of the economic development of India. Growing urbanization has led to an increase in the consumption of goods and services and thus an increase in transport services for urban areas. A comprehensive classification of the vehicles is adopted. Various characteristics, such as vehicle age, fuel type used, mileage by fuel type used, and kilometers travelled, as well as emission standards of current fleet have been explored. The total traffic volume of different categories of vehicles at all the selected 36 transport corridors is depicted in Figure 4.1 After analysing the traffic scenario at all the corridors, the highest traffic volume was found at ITO bridge, whereas the lowest was found at Aunchandi road. In addition to this, the average travelled distance by vehicle, the age of different categories of vehicles and average speed along with emission factor of different vehicles are presented in Figure 4.2 as well as in Table 4.1 and 4.2 respectively.

Table: 4.1 Age of different categories of vehicles

Age (years)	Two Wheeler (petrol)	Cars (diesel)	Cars (petrol & CNG)	Bus (CNG)	Auto Rickshaws (CNG)	Light-duty (CNG	Tempos (Diesel)	Trucks (Diesel)
0-5	67	6.8	51.8	22.2	39	84	53.8	48.5
6-10	24.8	27.3	32.1	69.6	56	13	31	35.1
11-15	6.6	3.6	14.2	8.2	5	3	15.1	17
15+	1.6	0.3	1.8	0.1	0	0	0.004	0.4
All Age	100	100	100	100	100	100	100	100

Source: Goel *et al*., 2015

Table: 4.2. Average speed and emission factor of different categories of vehicle

Vehicle category	CO (gm/km)	NOx (gm/km)	$PM_{2.5}$ (gm/km)	PM_{10} (gm/km)	SOx (gm/km)	Avg. speed (Km/Hr)
Cars	1.98	0.2	0.243	0.04	0.053	40.41
Auto	4.3	0.11	0.149	0.35	0.029	32.08
2 Whelers	2.2	0.3	0.053	0.04	0.023	41.03
Bus	3.6	9.6	0.487	0.7	-	31.33
Goods vehicles	3.6	6.3	7.925	1	0.037	32.85

Source: Nagpure *et al*., 2013; Goel *et al*., 2015

Meteorological conditions play a crucial role in ambient air pollution by affecting both directly and indirectly the emissions, transport, formation, and deposition of air pollutants. In this study, it was attempted to investigate the relationships between meteorological parameters and ambient air pollutants' concentrations and emission along 36 transport corridors. Maximum horizontal wind speed of 0.66 m/s was reported at about 9 transport corridors, namely, Minto Road, Punchkuin Road, Sansad Marg, Janpath, Tilak Marg, Zakir Hussain Marg, India Gate, I.T.O. Bridge and Nizamuddin Bridge while minimum horizontal wind speed of 0.11 m/s was reported at 2 transport corridors, namely, Ring Road (Safdarjung) and Aurobindo Marg. At remaining 23 corridors, this meteorological parameter was recorded in the range of 0.15 – 0.55 m/s. On the other hand, minimum vertical wind speed of 0.1 m/s was reported at least 6 transport corridors, such as, Netaji Subhash Marg, Shankar Road, New Rohtak Road, Ashok Vihar Road and Sham Nath Marg. The maximum vertical wind velocity of 0.8 m/s was reported at Qutabgarh Road. Some moderate vertical wind velocities in the range of 0.7 – 0.3 m/s was recorded at least 6 transport corridors, for instance at, Maa Anandmai Marg, Madangir Road, Press Enclave Road, Old Gurgaon Road, Najafgarh Road and Auchandi Road.

Ambient temperature ranged from minimum 22.8 ^{0}C at three corridors, namely, SBS Marg, Janak Setu and Pankha Road to 29.59 ^{0}C at one corridor called Auchandi Road. At least 26 corridors reported the ambient temperature between 25.56 and 29.23 ^{0}C, e.g., Ring Road (Safdarjung), Aurobindo Marg, Netaji Subhash Marg, Shankar Road, New Rohtak Road, Ashok Vihar Road, Sham Nath Marg, Patpadganj Road, G.T. Shahdra Road, Loni Road, Mathura Road, Najafgarh Road, Pusa Road, Wazirabad Road, ISBT Flyover, Ghazipur Road, Qutabgarh Road, Minto Road, Punchkuin Road, Sansad Marg, Janpath, Tilak Marg, Zakir Hussain Marg, India Gate, I.T.O. Bridge and Nizamuddin Bridge.

Similarly, for about 26 corridors, namely, SBS Marg, Janak Setu, Pankha Road, Minto Road, Punchkuin Road, Sansad Marg, Janpath, Tilak Marg, Zakir Hussain Marg, India Gate, I.T.O. Bridge, Nizamuddin Bridge, Najafgarh Road, Pusa Road, G.T. Shahdra Road, Loni Road, Wazirabad Road, ISBT Flyover, Ghazipur Road, Netaji Subhash Marg, Shankar Road, New Rohtak Road, Ashok Vihar Road, Sham Nath Marg, Patpadganj Road and Mathura Road, the relative humidity varied from 44.02 to 47.75 %. Remaining 10 transport corridors, e.g., Old Gurgaon Road, Ring Road (Naraina), Sardar Patel Road, Maa Anandmai Marg, Madangir road, Press Enclave Road, Auchandi Road, Qutabgarh Road, Ring Road (Safdarjung) and Aurobindo Marg reflected a greater variation, i.e., from 51.03 to 60.86 %. The metrological parameters of various location of Delhi are attached as annexure II.

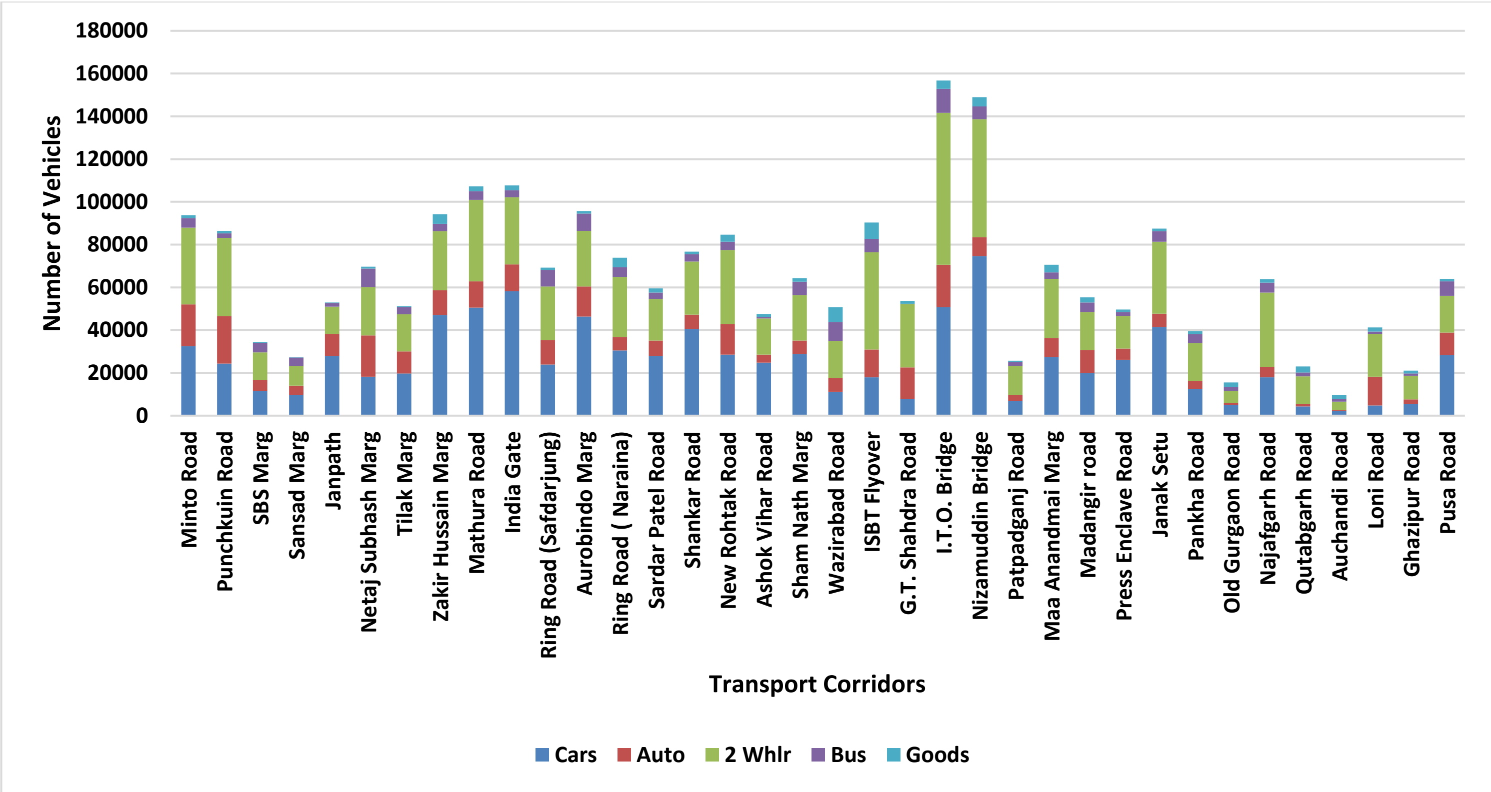

Figure 4.1: Traffic volume of different types of vehicle at various transport corridors

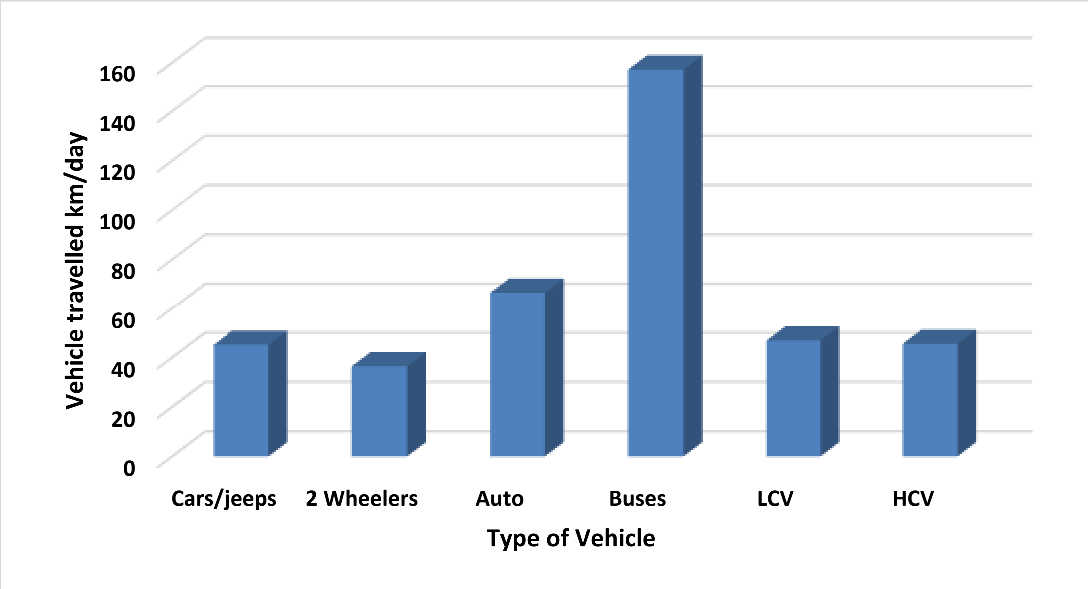

Figure 4.2: Average travelled distance of vehicle in Delhi

Source: Goel *et al*., 2015

4.3 Emission and concentration

The emission inventory of the key criteria pollutants, e.g., CO, NOx, SOx, PM_{10}, $PM_{2.5}$, C_6H_6 due to vehicles at the various transport corridors of Delhi was analysed along with classified traffic volume at 36 transport corridors. The emission inventory for each type of vehicles with respect to above-mentioned criteria pollutants has been calculated individually. The estimation of the concentration of different primary pollutants is based on the emission rate of pollutants from various categories of vehicles plying on the selected transport corridors. Emission as well as average concentration loads of different pollutants at various transport corridors are presented in subsequent figures which indicate that the two-wheelers are the major source of the emission of CO, whereas the car and goods carriers are found as a primary emitter of the PM, NO_x and SO_x (Tiwari and Kumar, 2015).

4.3.1. Carbon monoxide (CO)

The emission and concentration of CO at different transport corridors are presented in Figure 4.3a and 4.3b respectively. The maximum emission of CO from vehicles was recorded at two locations, namely, Ring Road (Safdarjung) and I.T.O. Bridge followed by Nizamuddin Bridge. The roads like Ghazipur Road, Old Gurgaon Road, Patpadganj Road and Qutabgarh Road were reported to emit lower ranges of CO values. Maximum observed emission value for CO was reported as 821 Kg/Day at Ring Road (Safdarjung), whereas lowest values were recorded as 52 Kg/Day and 79 Kg/Day respectively at Auchandi Road and Old Gurgaon Road.

Figure 4.3b interprets the actual measured concentration of CO at major roads of Delhi. The figure indicates three roads to exceed the concentration of CO (2000 $\mu g/m^3$) as prescribed by National Ambient Air Quality Standards (NAAQS). The maximum concentration level was found at Ring Road (Safdarjung) 3066 $\mu g/m^3$ > I.T.O. Bridge (2964 $\mu g/m^3$) > Nizamuddin Bridge (2571 $\mu g/m^3$). The remaining 33 roads were reported to be within the standard value. The lowest concentration was reported at Auchandi Road (193 $\mu g/m^3$).

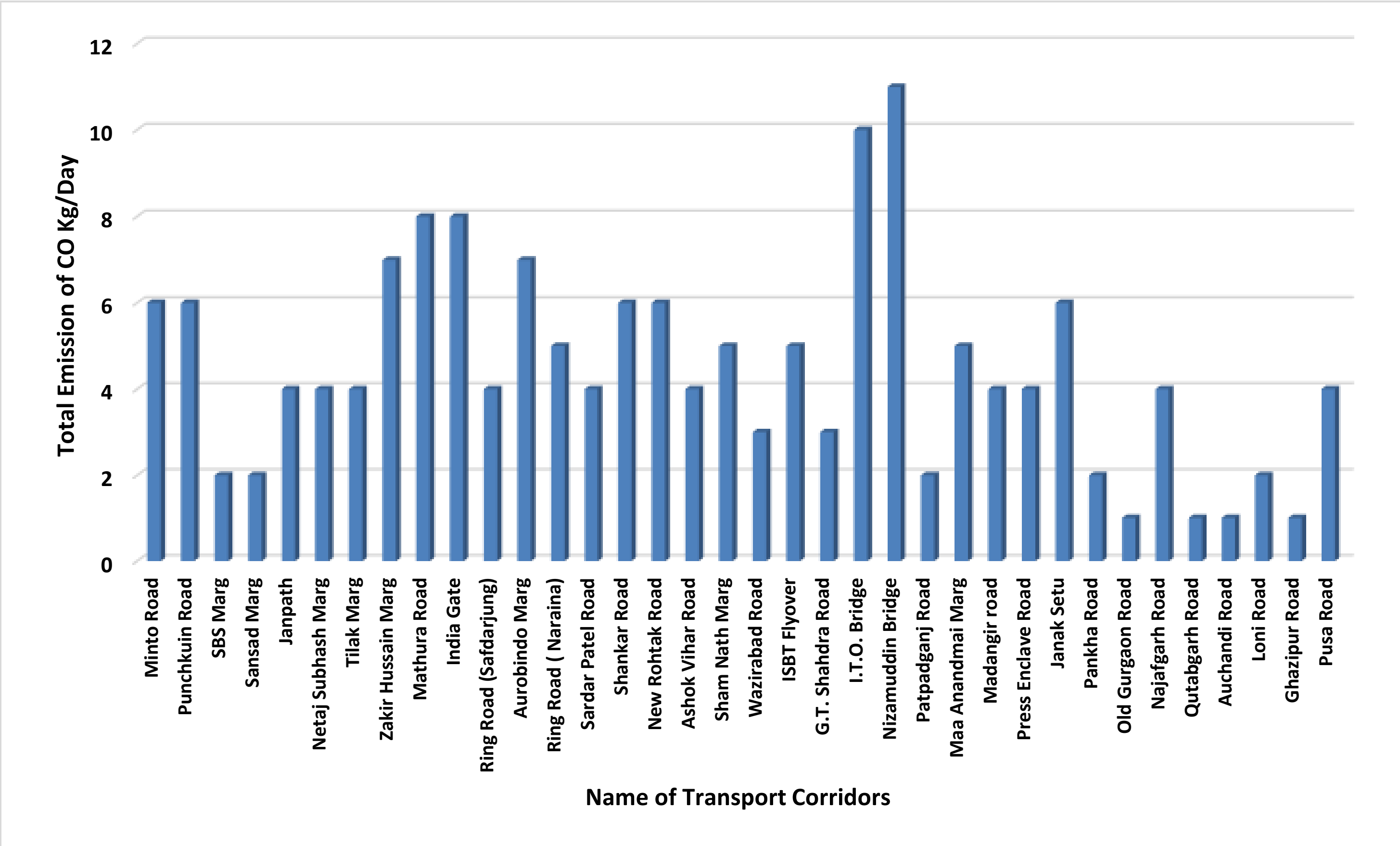

Figure 4.3 (a): CO emissions from transport sector at transport corridors

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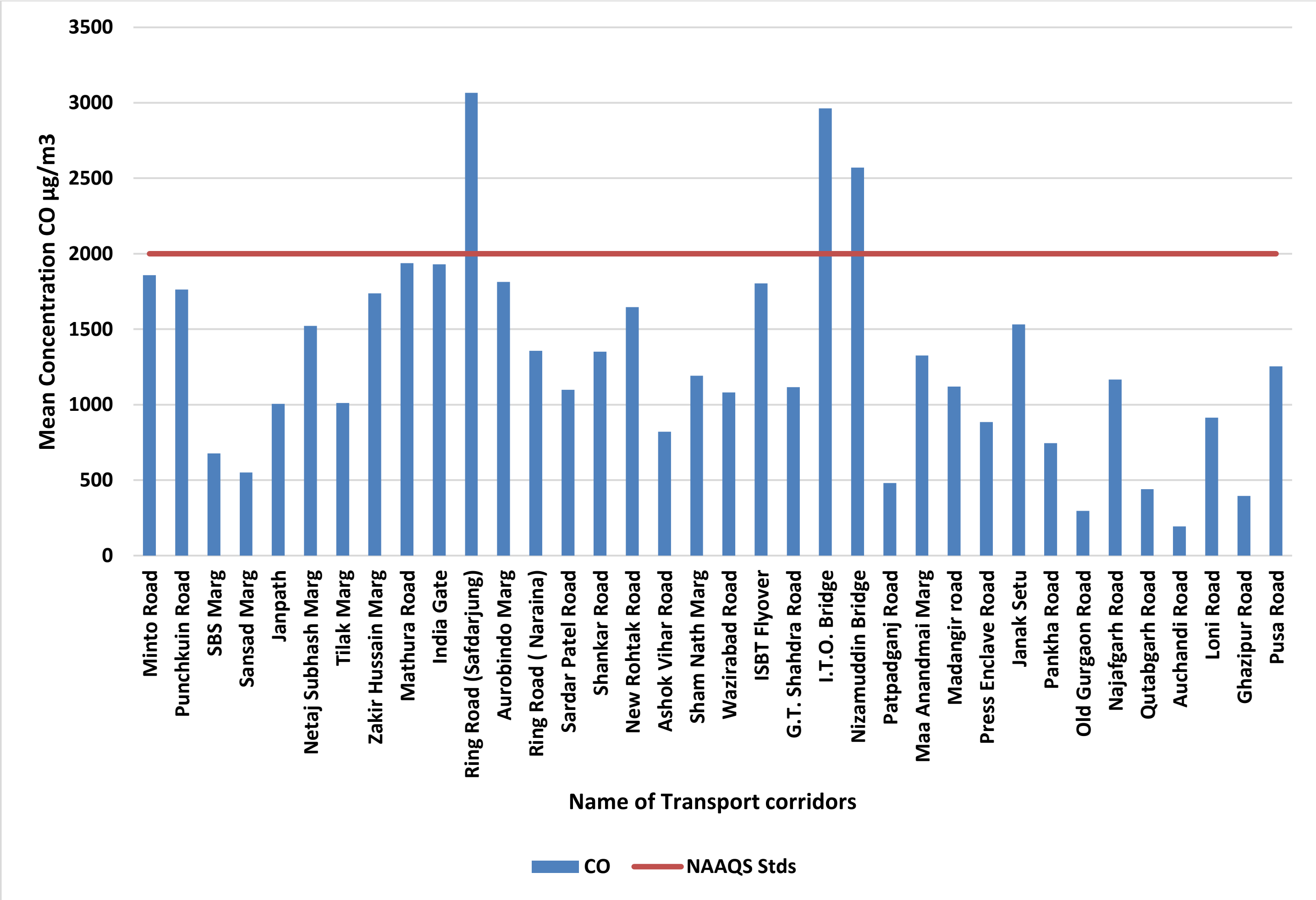

Figure 4.3 (b): Average concentration of CO at transport corridors

4.3.2 Oxides of nitrogen (NO_x)

The highest emission of NO_x due to vehicles plying on city road was found at Maa Anandmai Marg (24 Kg/Day), Madangir road (19 Kg/Day) followed by Ring Road (Naraina) at 15 Kg/day. (Figure 4.4a). Roads such as ISBT Flyover and Janpath were reported to emit relatively lower NO_x emission compared to the transport corridors like Ring Road (Safdarjung), I.T.O. Bridge and Wazirabad Road which showed higher values. Interestingly, it was observed that roads, viz., Sansad Marg, Aunchandi road and Pusa road recorded very low ranges of NO_x emissions respectively.

The spatial variation of NO_X concentration has been represented in figure 4.4b. It can be pointed out from the above figure, that the concentration of oxides of nitrogen is exceeding at all locations when compared to the NAAQS values. The maximum concentration is reported at Maa Anandmai Marg (363 µg/m^3) followed by Madangir Road (282 µg/m^3) and Ring Road (Naraina) which exhibited the value as 225 µg/m^3. During the study, the diesel trucks are encountered as a major source of $NO_{X,}$ and that is why the above three stretches recorded relatively very high concentration of NOx. These corridors had worst compliance status of NOx when compared to permissible limits. The lowest concentration of NOx was found at Pusa Road and Auchandi Road (24 and 35 µg/m^3).

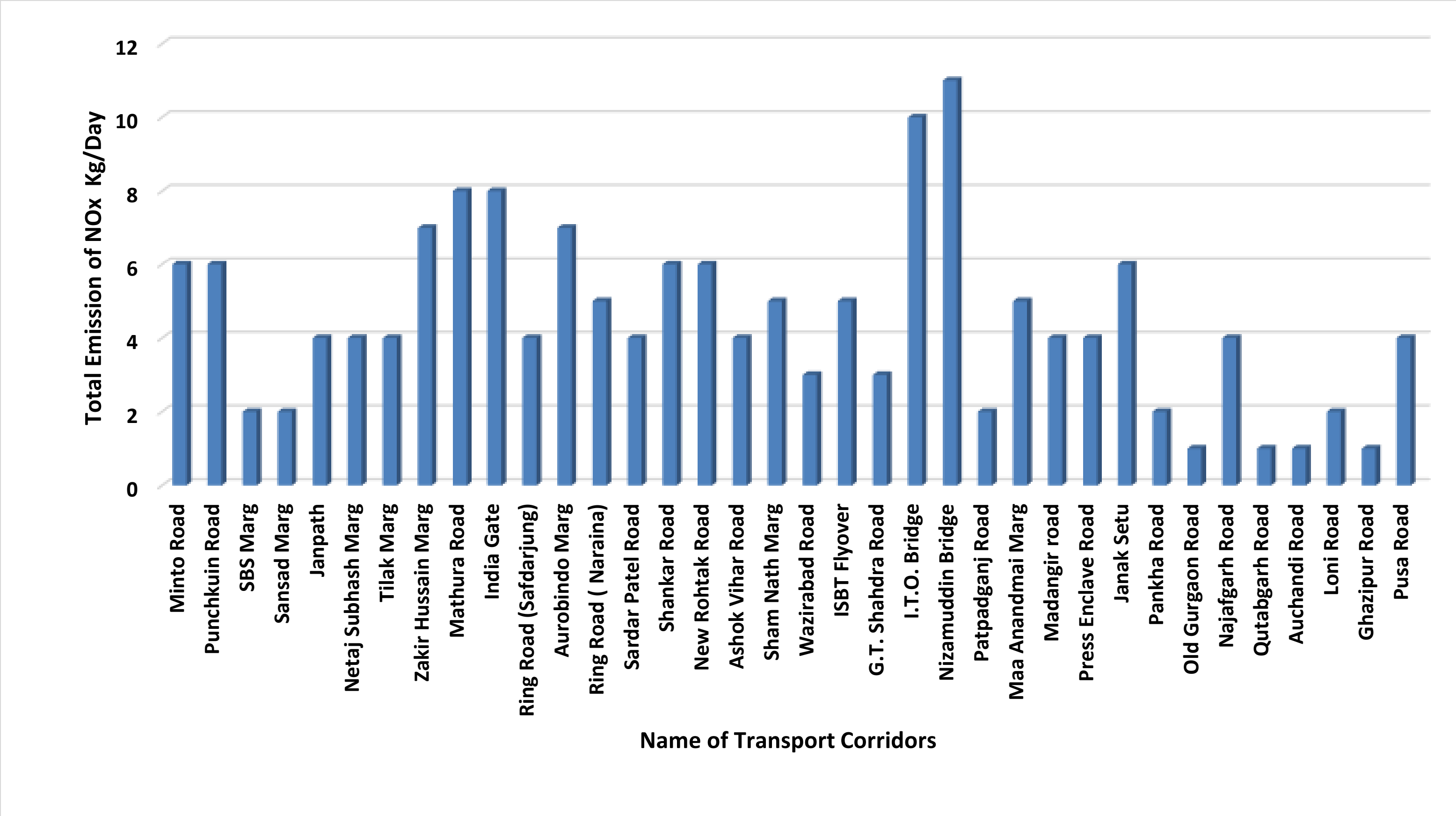

Figure 4.4 (a): NOx emissions from transport sector at transport corridors

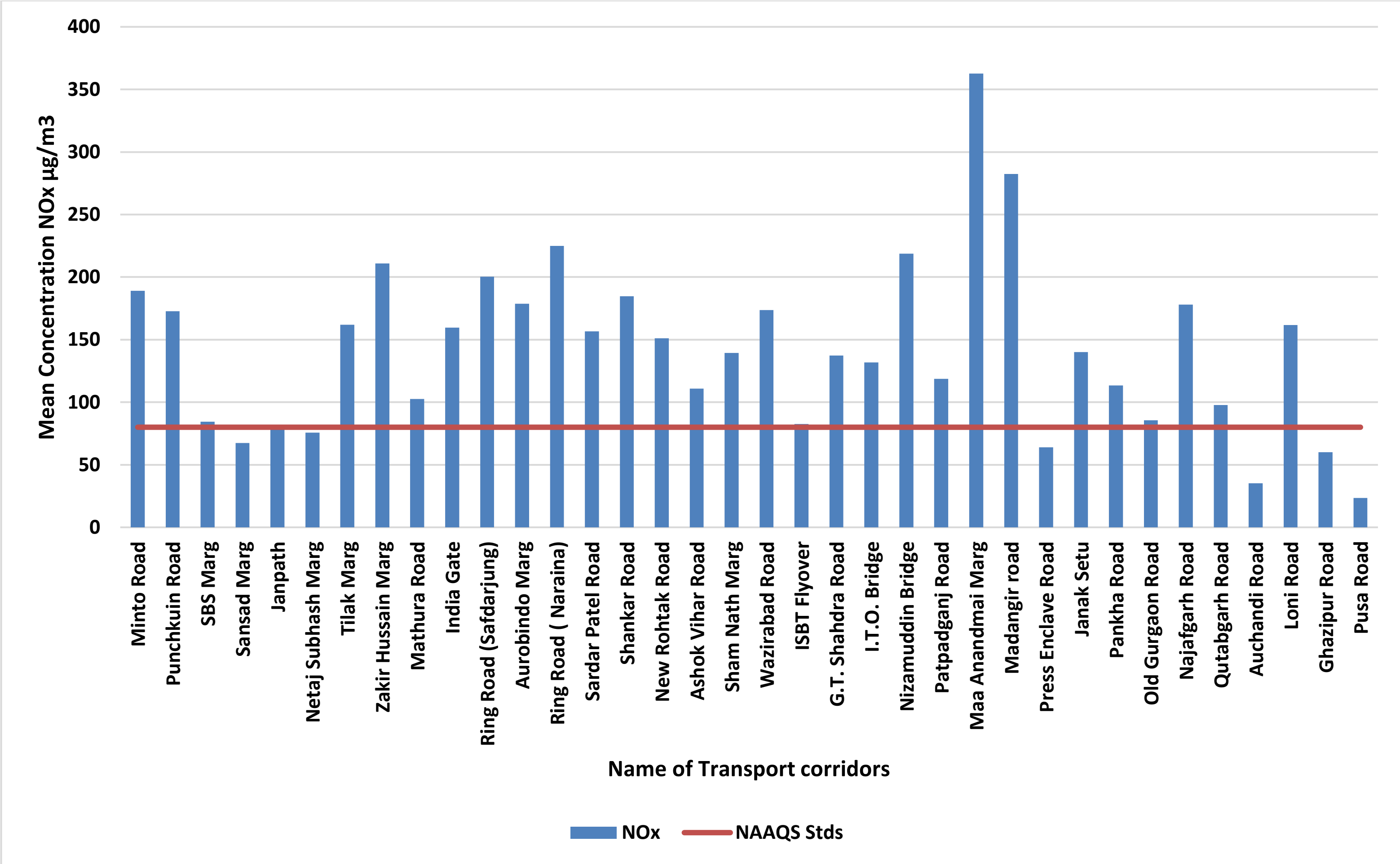

Figure 4.4 (b): Average concentration of NOx at transport corridors

4.3.3 Particulate matter (PM_{10})

During the estimation of PM_{10} emission contributed by vehicles of different categories at all the selected roads, the highest emission was found at Ring Road (Safdarjung) at 113 Kg/day followed by ITO Bridge which recorded relatively very low value of 47 Kg/day (Fig. 4.5a). All other roads were reported to be in the range of 6 -38 Kg/Day of emission of PM_{10}. Several road stretches joined the list of lowest emitters such as Auchandi Road, Ghazipur Road, and Patpadganj Road. As shown in the graph, the emission ranged from a peak value close to 113 Kg/Day of PM_{10} at Ring Road (Safdarjung) to a minimum value near 6-7 Kg/Day clocked at Auchandi Road, Ghazipur Road and Patpadganj Road.

The trend of PM_{10} concentration at all the urban roads is shown in Figure 4.5b, which presents that the concentration of PM_{10} is exceeding its limits from those prescribed in NAAQS at 10 roads barring Sansad Marg, SBS Marg, Janpath, Tilak Marg, Auchandi Road, Loni Road etc. The maximum concentration was reported at Ring Road (Safdarjung) i.e., 422 $\mu g/m^3$, while many of the roads in the megacity were found to be in non-compliant to the permissible limits. Only Auchandi Road shows conformance to the standard in-question reporting a value of about 23 $\mu g/m^3$.

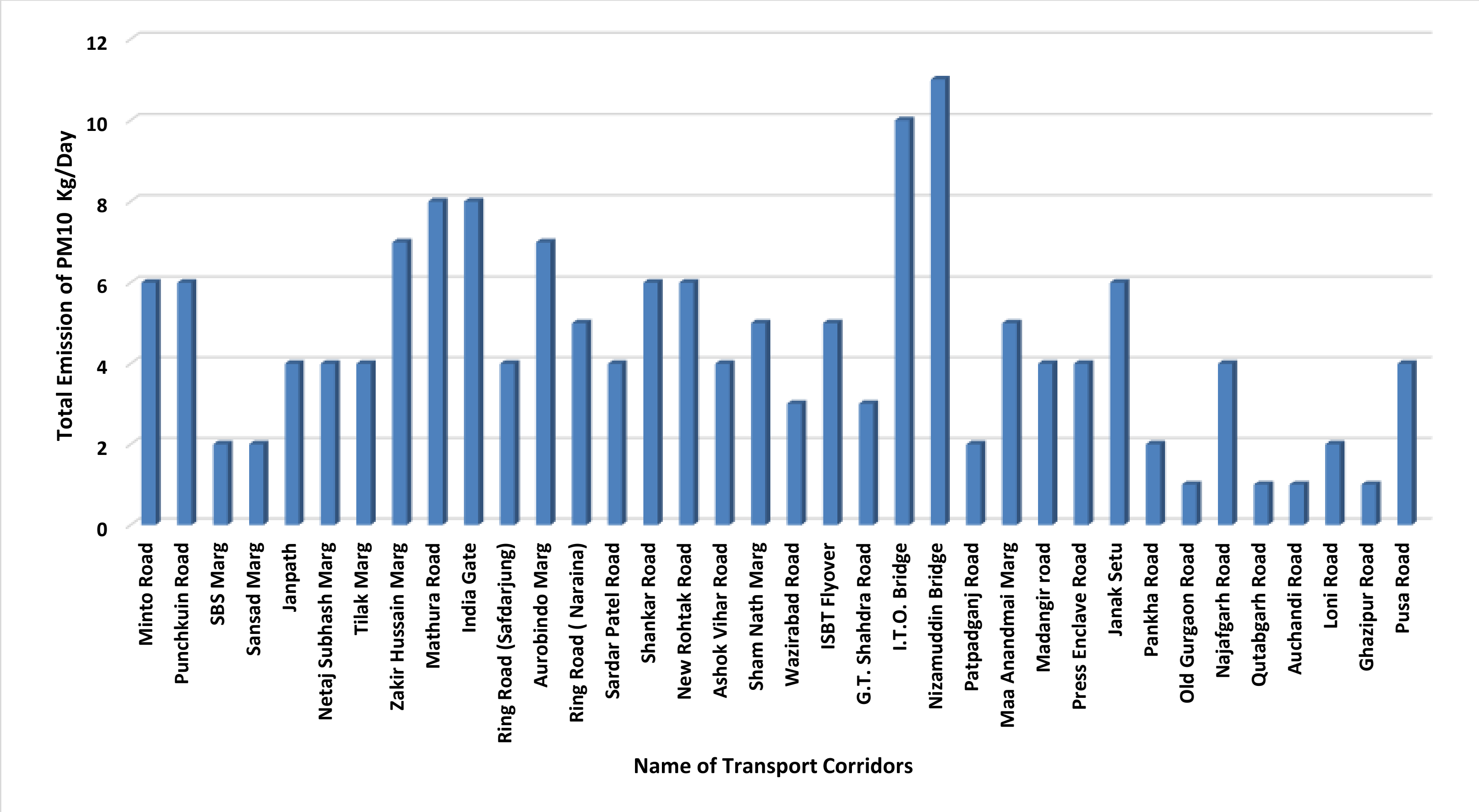

Figure 4.5 (a): PM_{10} emissions from transport sector at transport corridors

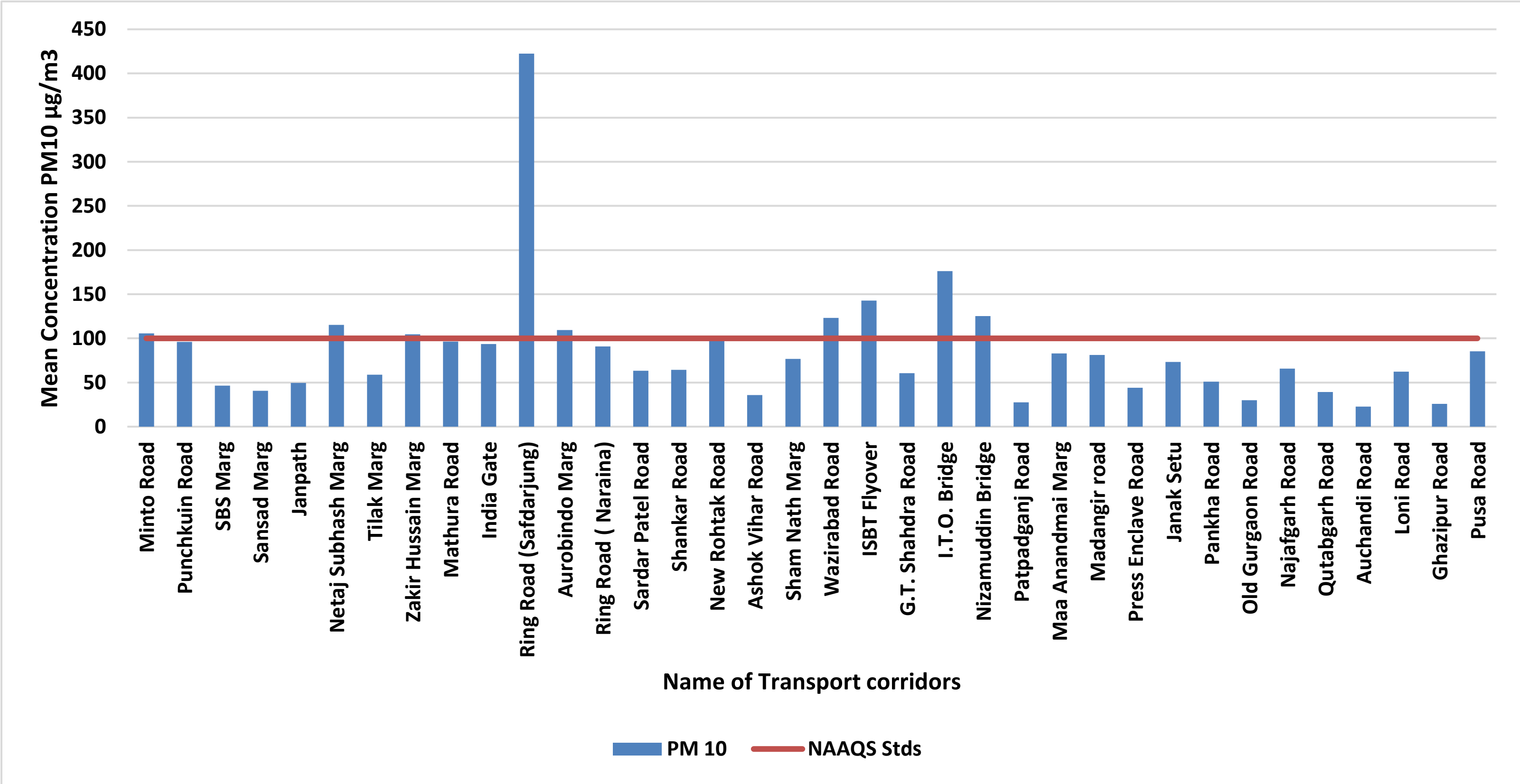

Figure 4.5 (b): Average concentration of PM_{10} at transport corridors

4.3.4 Fine particulate matter ($PM_{2.5}$)

The emission of $PM_{2.5}$ from transport sector in Delhi was also reported at various selected corridors (Fig. 4.6a). The highest emission was observed at ISBT flyover (145 Kg/Day), while other roads like Wazirabad Road, Nizamuddin Bridge, ITO Bridge and were reported to be emitting second highest values (127, 119 and 110 Kg/day respectively). Further, the $PM_{2.5}$ emission was found to gradually decrease for Ring Road (Safdarjung), Zakir Hussain Marg, and Ring Road (Naraina). On the other hand, as many as 13 roads exhibited values in almost same magnitude, whereas Sansad Marg reported the lowest emission of $PM_{2.5}$ (14 Kg/Day). Along with emission of particulate matter emanated by vehicles, the concentration of the $PM_{2.5}$ was also calculated. The spatial variation of $PM_{2.5}$ concentrations is depicted in Figure 4.6b. From the figure, it can be observed that the concentration of $PM_{2.5}$ is surpassing the permissible limits prescribed in NAAQS at almost all roads barring Sansad Marg.

The maximum concentration was reported at ISBT flyover (542 µg/m^3), whereas the rest of the 30 selected urban roads in the megacity were also found to be violating the standard and all the selected corridors except Sansad Marg showed the range of $PM_{2.5}$ concentration from 100-541 µg/m^3, while the Sanasad Marg itself showed the compliance to the standards in-question reporting a value of about 53 µg/m^3.

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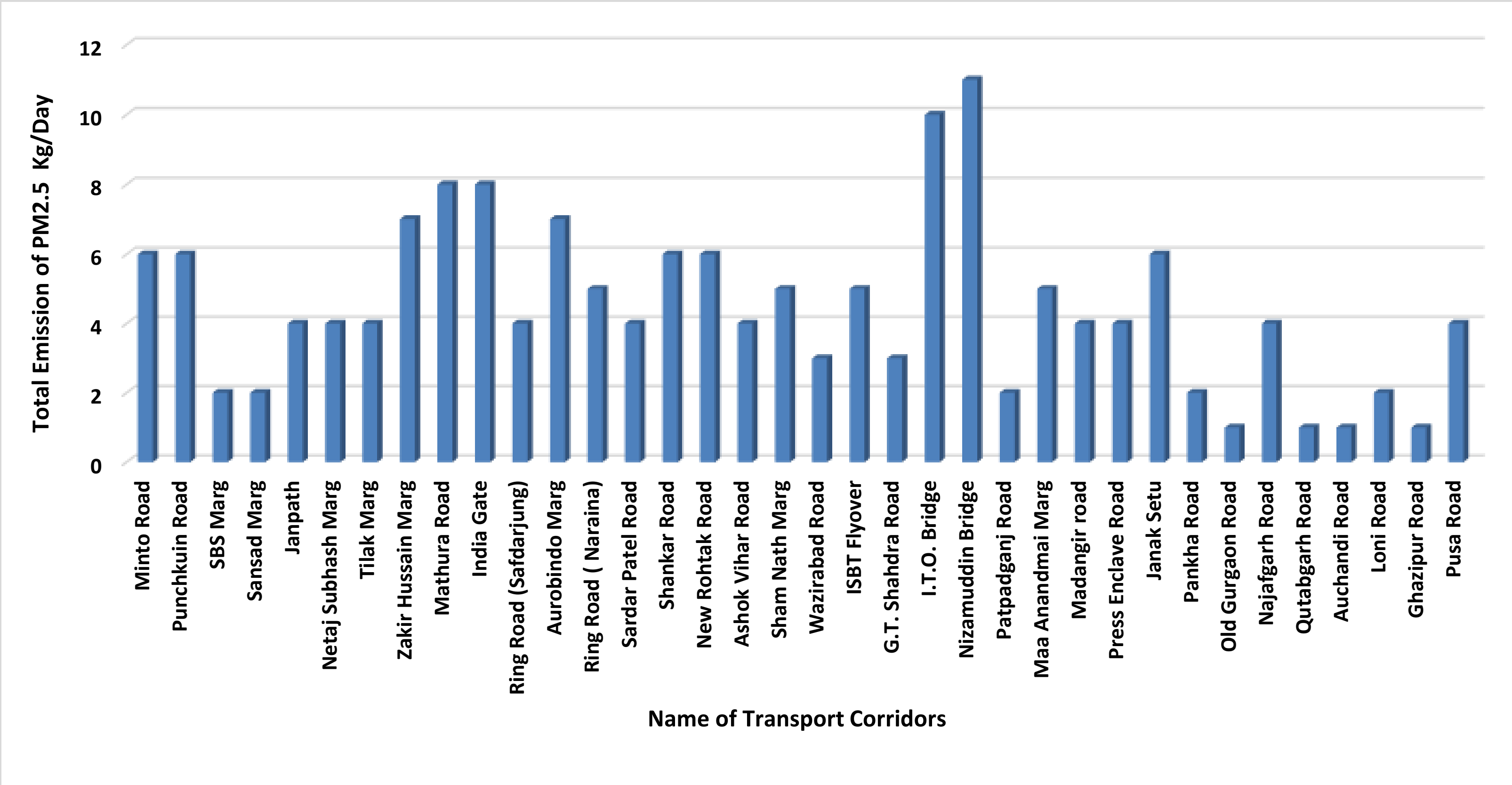

Figure 4.6 (a): $PM_{2.5}$ emissions from transport sector at transport corridors

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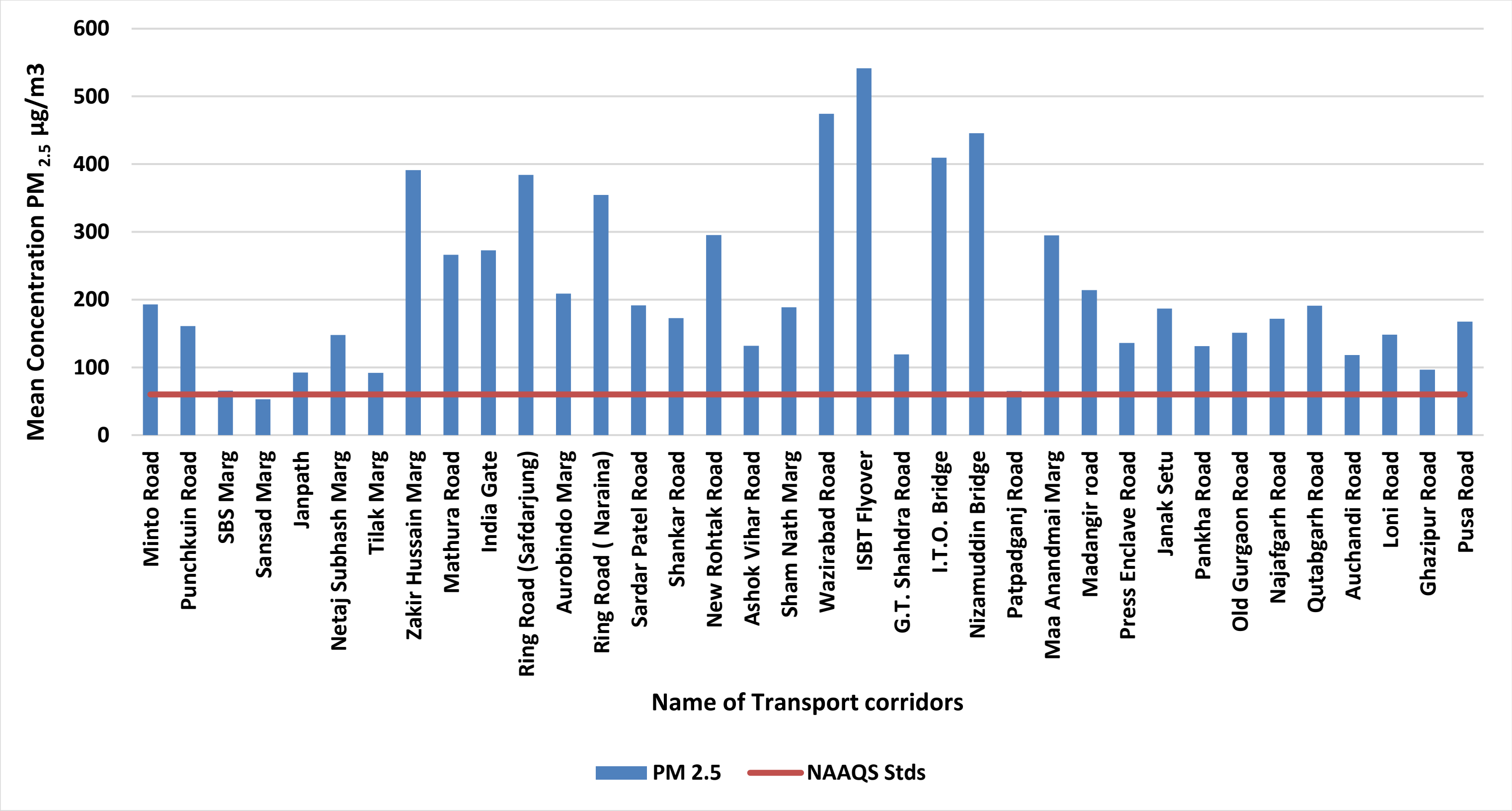


Figure 4.6 (b): Average concentration of $PM_{2.5}$ at transport corridors

4.3.5 Sulphur oxides (SOx)

While studying the emission of oxides of sulphur at major transport corridors in Delhi, the Nizamuddin Bridge was found to bear the highest emission load (11 Kg/Day) followed by I.T.O. Bridge, India Gate, Mathura Road, Zakir Hussain Marg and Aurbindo Marg in descending order (10, 8, 8, 7 and 7 Kg/day subsequently). On the other hand, as many as 7 roads exhibited values in almost same magnitude but below the roads mentioned above, whereas, as many as four corridors, viz., Auchandi Road, Old Gurgaon Road, Ghazipur Road and Qutabgarh Road reported lowest SOx emission recording a value of 1 Kg/Da**y** (Fig. 4.7 a).

Figure 4.7 (b) lays out the data obtained and plotted for the trend of SOx concentration at urban roads of Delhi. Like highest emission, the maximum concentration was also found at Nizamuddin Bridge at 42 $\mu g/m^3$ just followed by I.T.O. Bridge, India Gate, Mathura Road at 38, 32, and 30 $\mu g/m^3$ respectively, whereas the lowest concentration of SOx was reported at Auchandi Road (2 $\mu g/m^3$). Rest of the selected corridors showed the concentration of SOx between 27 and 4 $\mu g/m^3$ which is less than the permissible limits prescribed by Central Pollution Control Board (CPCB) in India.

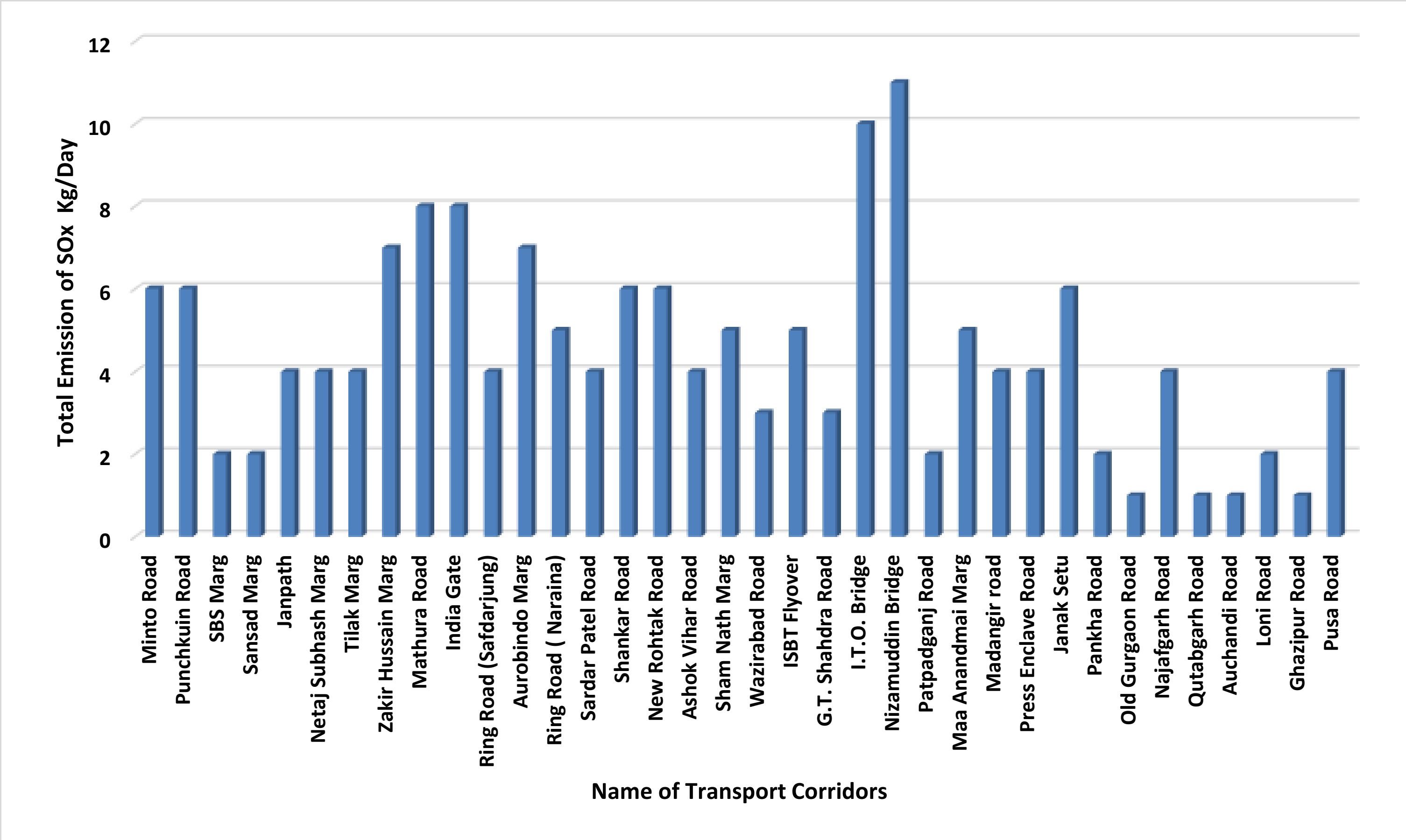


Figure 4.7 (a): SOx emissions from transport sector at transport corridors

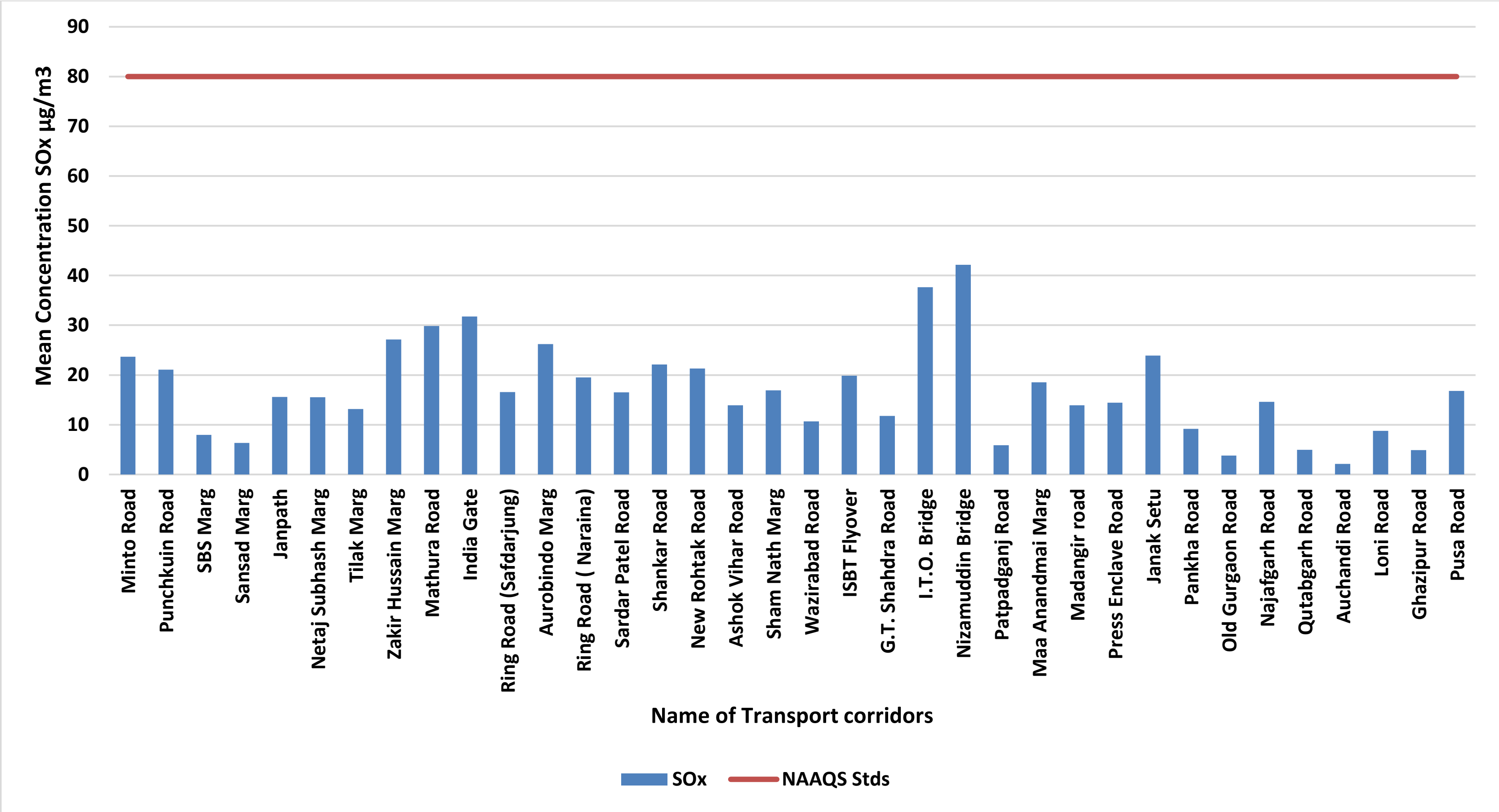


Figure 4.7 (b): Average concentration of SOx at transport corridors

4.3.6 Benzene

Benzene emission from transport sector in Delhi, which was recorded maximum at I.T.O. Bridge (3.8 Kg/Day) followed by Nizamuddin Bridge and Punchkuin Road, whereas Auchandi Road and Old Gurgaon recorded minimum emissions respectively (below 1Kg/Day). As shown in the Figure 4.8(a) the emission ranged from a peak value close to 4 Kg/Day to a minimum value near 0.015 Kg/Day recorded at I.T.O. Bridge and Auchandi Road stretches whereas most of the roads exhibited values in the range of 0.5 to 2 Kg/Day.

Along with the estimation of Benzene emission, the concentration of Benzene was also calculated at 36 various roads of Delhi megacity as shown in Figure 4.8(b). From the study, 18 transport corridors were found in such a state, where the Benzene concentration was violating National Ambient Air Quality Standards (NAAQS) which is 5 $\mu g/m^3$. The highest concentration was observed at I.T.O. Bridge (13.9 $\mu g/m^3$) followed by Nizamuddin Bridge, Ring Road, ISBT Flyover, Punchkuian Road, Minto Road, Mathura Road, New Rohtak Road, India Gate, Aurobindo Marg, Zakir Hussain Marg, JanakSetu, Netaji Subhash Marg, G.T. Shahdra Road, Najafgarh Road, Maa Anandmai Marg, Ring Road (Naraina) and Shankar Road (5.3 $\mu g/m^3$). The remaining corridors were found to be within the permissible limits.

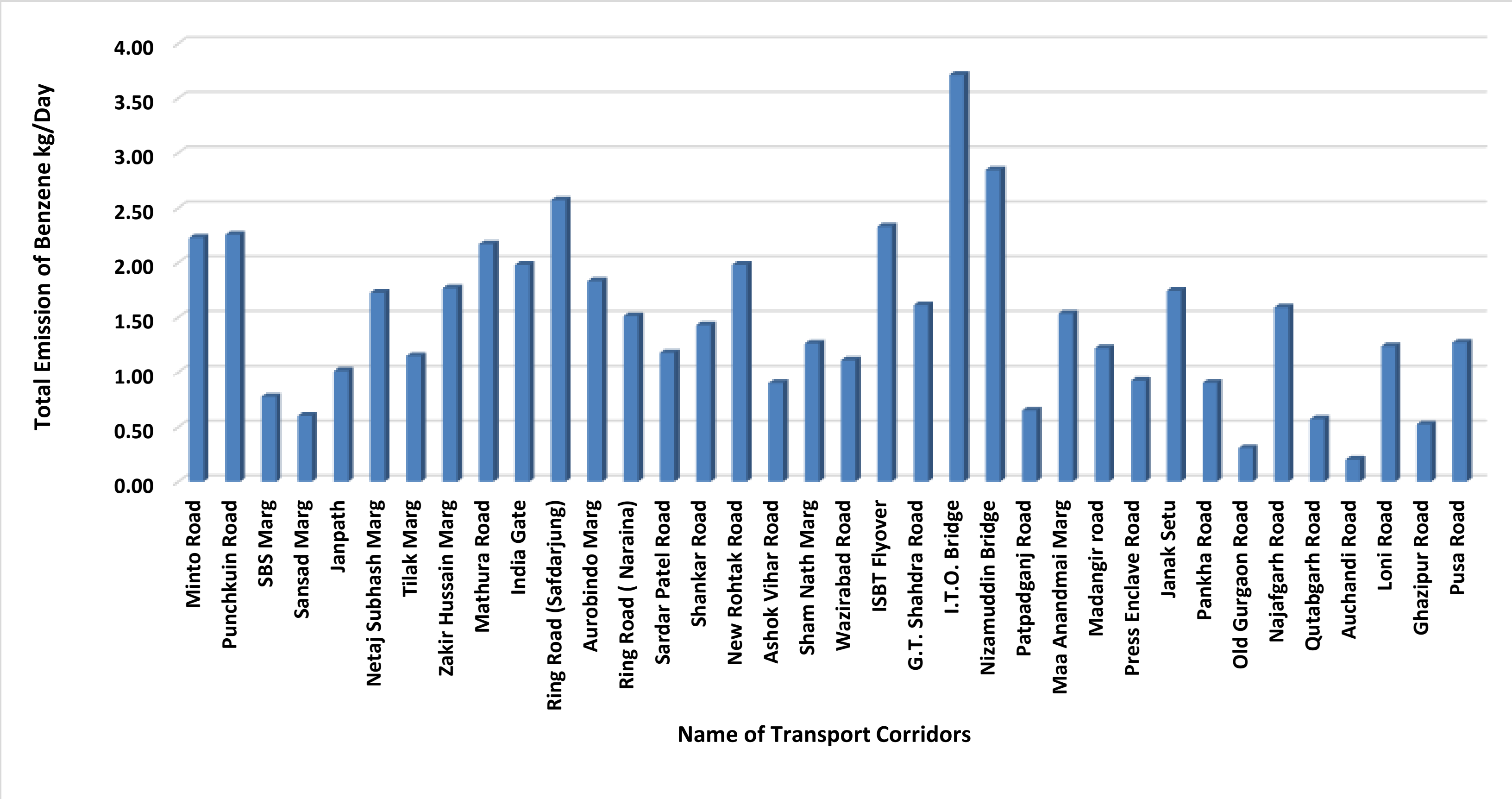


Figure 4.8 (a): Benzene emissions from transport sector at transport corridors

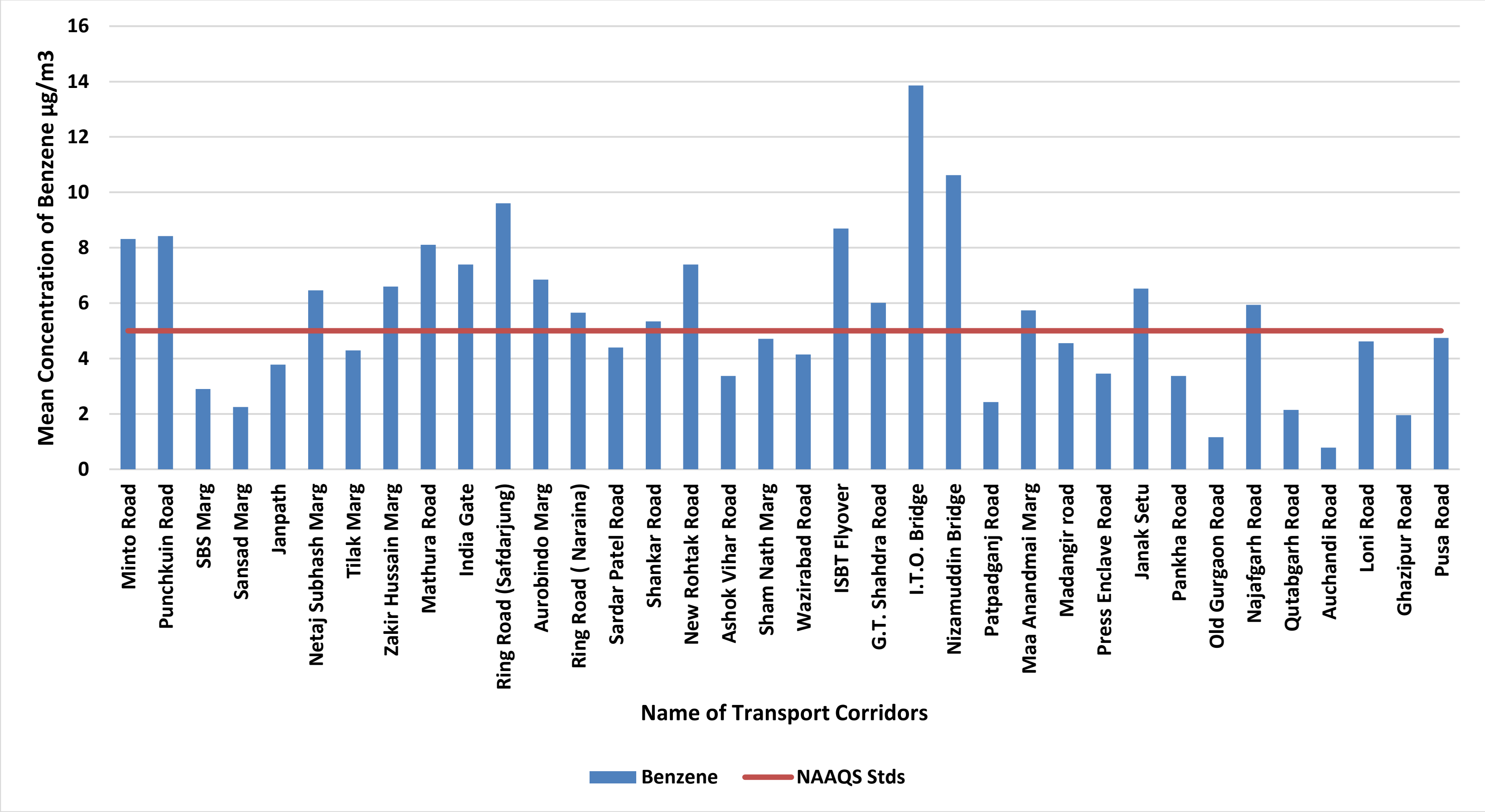


Figure 4.8 (b): Average concentration of Benzene at transport corridors

Figure 4.9 shows the traffic volume at the various transport corridors of Delhi. These transport corridors are vital to the passenger and goods movement to and fro and linking the megacity of Delhi. The highest traffic volume of vehicle was found at I.T.O. Bridge followed by Nizamuddin Bridge, Ring Road (Safdarjung), India Gate, Mathura Road, Aurobindo Marg, Zakir Hussain Marg, Minto Road and ISBT Flyover. The lowest traffic volume was observed at the Auchandi Road.

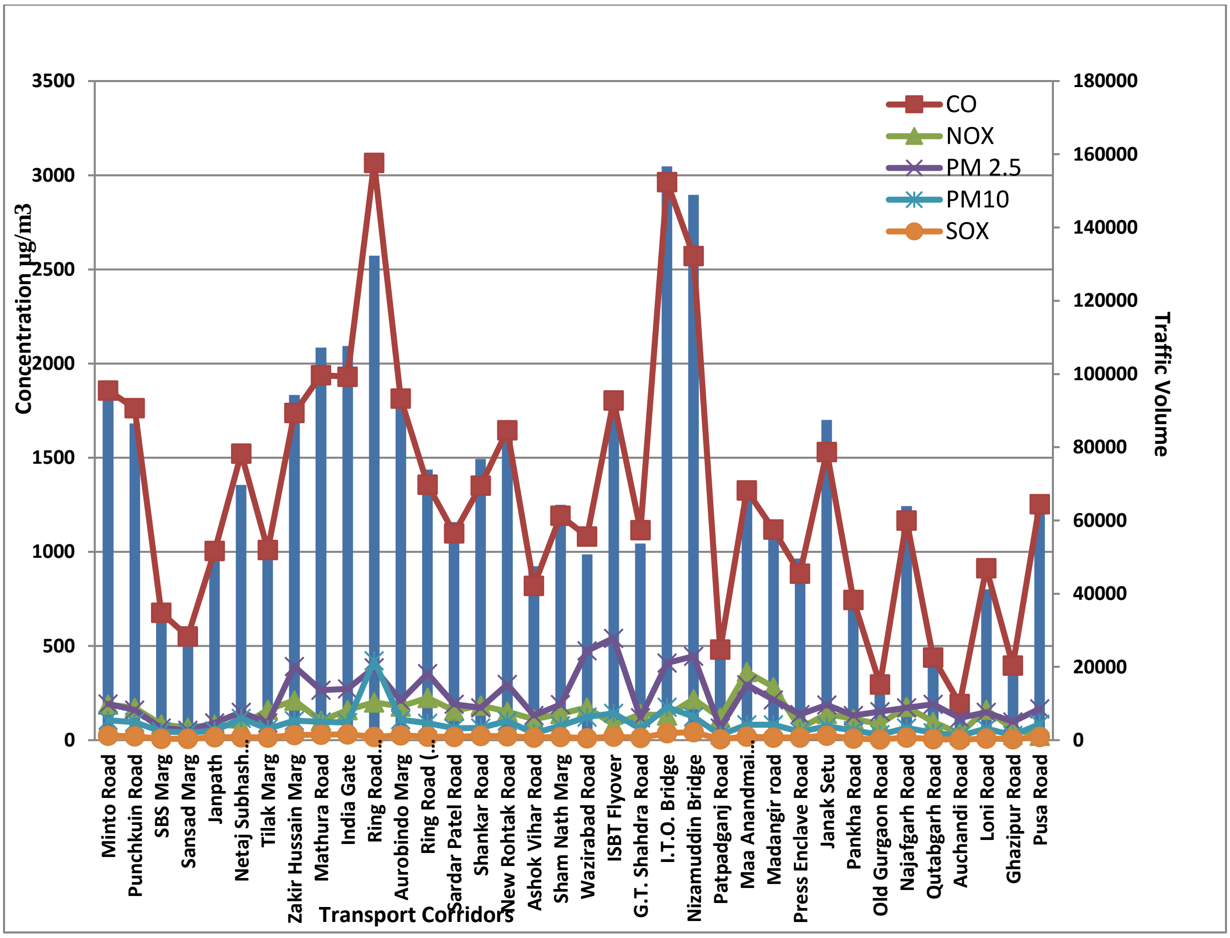


Figure 4.9: Trend variation of the pollutants at transport corridors with traffic volume

4.3.7 Validation of results

To validate the findings of the model with respect to its output, i.e., concentration data for pollutants, nineteen of the thirty-six transport corridors in-question, were selected for the measurement of $PM_{2.5}$, PM_{10}, NOx, SOx and CO. Real-time data pertaining to these pollutants were collected using different instruments. It is to mention here that due to time limitation, all thirty-six corridors couldn't be approached for similar analysis. Further, the justification of selection of nineteen transport corridors is that only those corridors which have not less than 60,000 vehicles plying per day on average basis were selected.

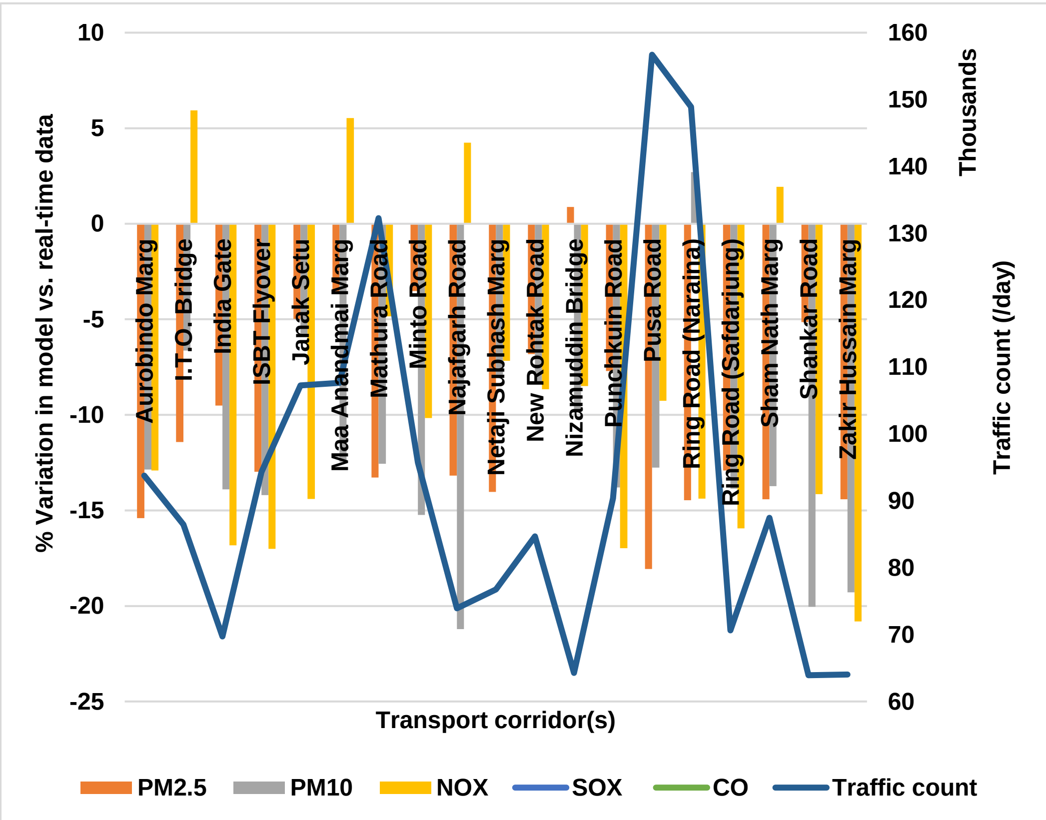


Figure 4.10: Data validation at various transport corridors

Such transport corridors were found to be Najafgarh Road, Pusa Road, Sham Nath Marg, Netaj Subhash Marg, Maa Anandmai Marg, Ring Road (Naraina), Shankar Road, New Rohtak Road, Punchkuin Road, Janak Setu, ISBT Flyover, Minto Road, Zakir Hussain Marg, Aurobindo Marg, Mathura Road, India Gate, Ring Road (Safdarjung), Nizamuddin Bridge, and ITO Bridge. As shown in Fig. 4.10, the comparison finds a good consistency between the two data sets, i.e., model's output data and the real-time monitoring data for nineteen locations.

The maximum observed real-time data for the pollutants were plotted against those calculated by model and it was found that the real-time values were generally higher than the later and however, didn't exceed 21% of the negative variance. However, between the two data sets, some values at certain corridors were reported to be higher in case of model-calculated data, but too small to draw a definitive conclusion (for e.g., five transport corridors, namely, Panchkuin Road, India Gate, Ring Road-Naraina and Jank Setu showed lower values of NOx compared to the model-values by 5.92%, 5.53%, 4.23% and 1.93% respectively). Generally higher values reported by the instrument during real-time application could be due to the presence of another source of air pollution in the vicinity of monitoring site, e.g., road dust and construction dust contributed by construction activities (metro stations, flyovers, building construction, etc.), road cleaning and other anthropogenic activities. It is found that the values calculated by the model for nineteen transport corridors are reported for Minto Road, Punchkuin Road, Netaji Subhash Marg, Zakir Hussain Marg, Mathura Road, India Gate, Ring Road (Safdarjung), Aurobindo Marg, Ring Road (Naraina), Shankar Road, New Rohtak Road, Sham Nath Marg, ISBT Flyover, ITO Bridge, Nizamuddin Bridge, Maa Anandmai Marg, Janak Setu, Najafgarh Road, Pusa Road in terms of difference with real-time observation as +0.88% to -18.05% for PM2.5, +2.69% to – 21.21% for PM10, +5.92% to – 20.81% for NOx, +9.15% to -20.19% for SOx and +5.94% to -18.99% respectively.

4.4. Health risk assessment at various transport corridors

In light of the methodology described earlier this study was conducted to determine the human health risk parameters, i.e., respiratory mortality, cardio-vascular mortality, total mortality, respiratory morbidity (i.e., COPD hospital admission) and cardio-vascular morbidity (hospital admission) alongside various transport corridors in the megacity of Delhi. The determination of referred parameters mainly involved input data related to human population (to be called as grid population) and annual mean concentration of the air pollutants, namely, PM_{10}, $PM_{2.5}$, SO_x and NO_x at the transport corridors, inter-alia other entities as per guidelines of WHO (Table 3.3 mentioned in chapter 3). The numbers of mortality and morbidity cases were calculated using Ri-MAP model results of which are presented here-under human health risk parameter-wise. This is to be mentioned here that in previous studies, (Gurjar *et al*., 2010; Nagpure *et al*., 2014) attempts were made to study the human health risks in Delhi-NCT as a whole or district-wise. However, in this study, the health risks have been presented in terms of various transport corridors at a 4 km^2 grid size with a view to coming up with results of better resolution. Pollution concentration was measured using the instruments while the population data was sourced from Census 2011 and projected for the year 2016 regarding approximate population density. The affected population was determined by multiplying the projected population density with the grid size.

4.4.1 Mortality

Mortality can refer to an individual or to a larger group of people, particularly when you are talking about the total number of deaths within a population, using the phrase mortality rat**e** (Zmirou *et al*., 1998; Kermani *et al*., 2016). The words mortality and mortal come from the Latin root mortis, or "death". One out of every six premature deaths in the world in 2015 about 9 million could be attributed to disease from toxic exposure. The total number of deaths must be corrected for factors such as underreporting of deaths, misreporting of age at time of death, and migration. In addition, mortality rates calculated using census data would be inaccurate if the census were incomplete. In modern societies, on the whole, wealthier people tend to live longer than poor people do, more highly educated people live longer, on average, than people with less education, and where you live can be an indicator of how long you may expect to live. i.e. mortality is the condition of one day having to die or the rate of failure or loss.

4.4.1.1 Respiratory Mortality

The highest numbers of excess cases of respiratory mortality were reported at ISBT Flyover of as 365, closely followed by Wazirabad Road with 362, both corridors in Shahdara sub-district of North-East Delhi district. On the other hand, the lowest number of excess cases were found at Punchkuin Road (sub-district of New Delhi district) with Janpath, Tilak Marg and Sansad Marg transport corridors coming next with forty excess cases of respiratory mortality, each corresponding to the Connaught Place, Pragati

Maidan and Parliament Street sub-districts of the New Delhi district respectively (Figure 4.11).

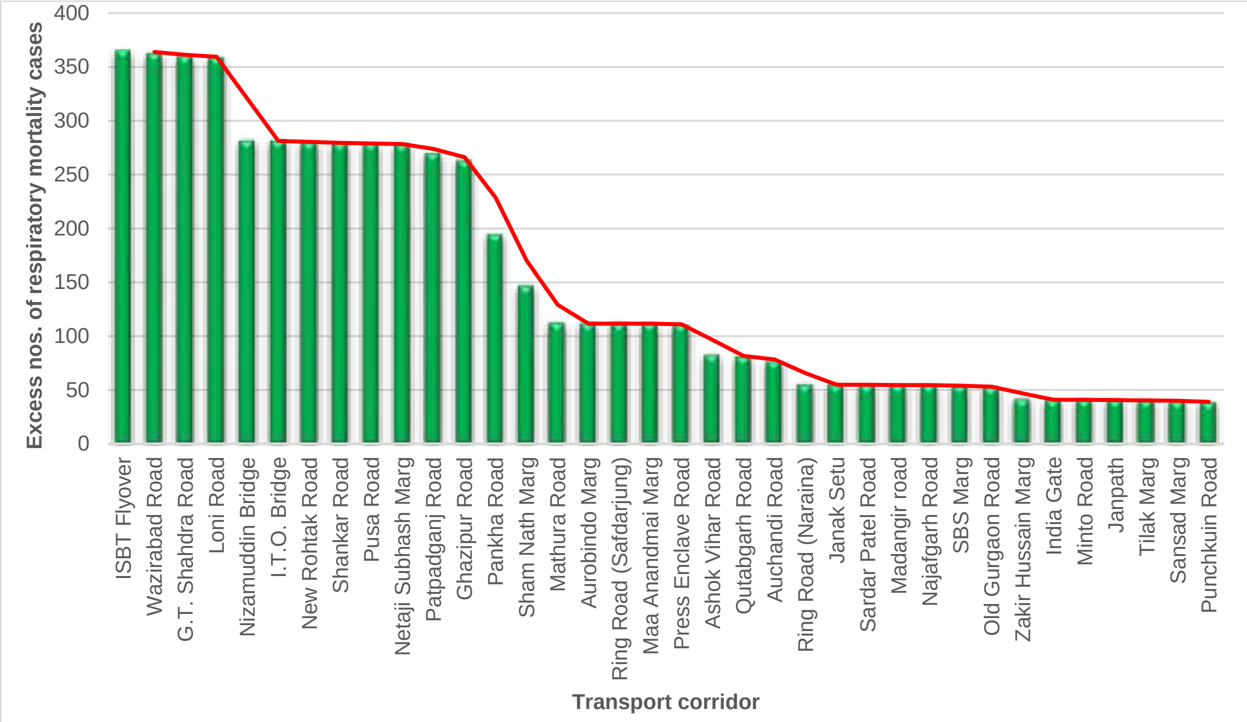


Figure 4.11: Respiratory mortality at various transport corridors

It is found that, the transport corridors in New Delhi district reported comparatively lower number of excess cases of respiratory mortality (for e.g. Minto Road as 41 and India Gate as 41 also) whereas, those in the North-East Delhi district, namely, G.T. Shahdara Road and Loni Road and in Central Delhi, e.g., New Rohtak Road, Nizamuddin Bridge and ITO Bridge were reported with relatively higher numbers of excess cases (280, 281 and 281 severally). This trend of the respiratory mortality is generally consistent with the projected population density for the year 2016, and the excess number of cases is found to be directly proportional to the general grid population in the corresponding district of the transport corridor.

4.4.1.2 Cardiovascular Mortality

The study pointed to the fact that the trend of the excess cases of cardiovascular mortality was similar to the trend exhibited in the case of respiratory mortality, e.g., the ISBT Flyover reported 1399 numbers, with Wazirabad Road nearly following it with 1378 numbers. Interestingly, the trend of the relatively lower number of excess cases of this health risk parameter also matched with those reported for respiratory mortality, for, e.g Punchkuin Road witnessed 148 numbers of excess cases, whereas, Janpath and Tilak Marg transport corridors came next with 155 and 155 numbers of excess cases of cardiovascular mortality each (Figure 4.12).

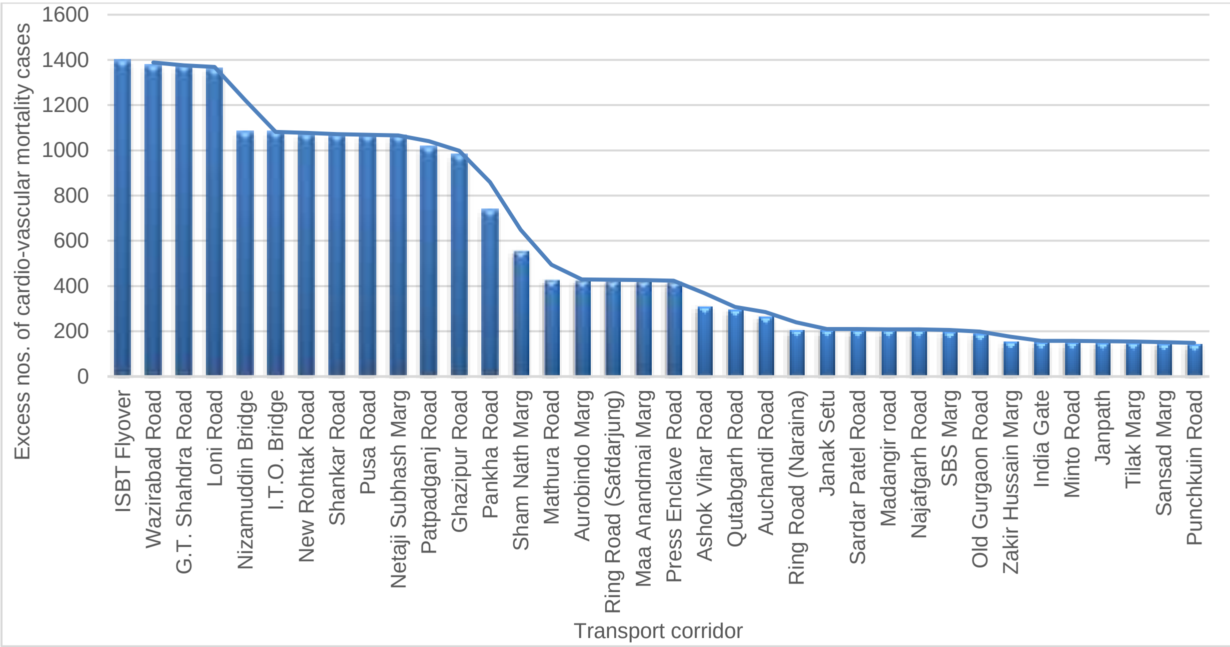


Figure 4.12: Cardio-vascular mortality at various transport corridors

Further, while South-West Delhi district reported the relatively lower number of excess cases of cardiovascular mortality (for, e.g., SBS Marg, Old Gurgaon Road as 204 and 194 respectively), the India gate and Minto Road of New Delhi district recorded 158 and 157 numbers consequently. On the other hand, the transport corridors in Central

Delhi district, namely, New Rohtak Road, Nizamuddin Bridge and ITO Bridge are found to exhibit a relatively higher number of excess cases of cardiovascular mortality ranging from 1073 to 1082. G.T. Shahdara Road and Loni Road corridors of the North-East Delhi district followed at 1375 and 1363 number of excess cases each.

The observed cause of the excess cardiovascular mortality on the different transport corridors is generally consistent with the projected population density for the year 2016 and is directly proportional to the prevailing grid population in the corresponding district, i.e., Corridors with more grid population records more numbers of excess cases and vice-versa.

4.4.1.3. Total Mortality

The scenario of total mortality in various transport corridors also follows the pattern reported by the excess numbers of respiratory and cardiovascular mortality cases with ISBT Flyover recording maximum of 2136 numbers, Wazirabad Road reporting as many as 2096 (both corridors belonging to the North-East Delhi district). Transport corridors like Punchkuin Road and Sansad Marg of the New Delhi districts reported the least number of excess cases with 225 and 227 respectively. (Figure 4.13). There is found a slight difference in transport corridors of different districts in relatively higher and lower cases of total mortality when compared to those in the case of respiratory and cardiovascular mortality cases. For examle Auchandi Road in the North-West Delhi district was found to be with 391 numbers of excess cases.

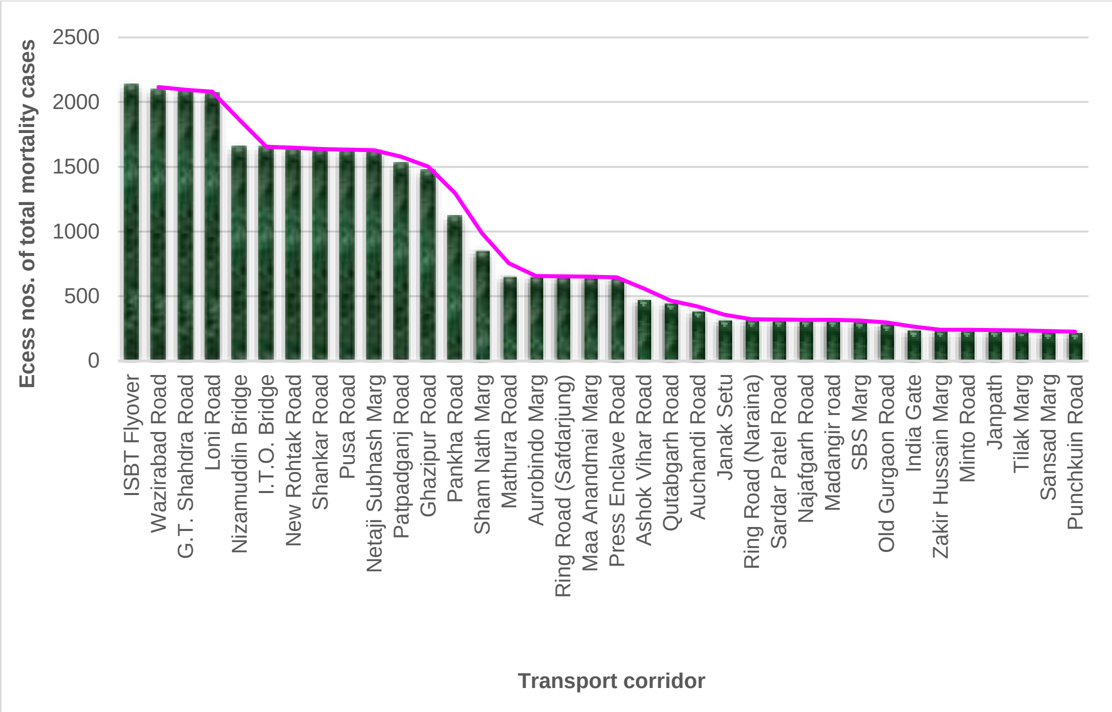


Figure 4.13: Total mortality at various transport corridors

4.4.2. Morbidity

Morbidity comes from the word morbid, which means "or of relating to disease", like the number of cases of any disease in an areas morbidity (Eirini *et al*., 2011). It is exposed directly in humans and estimating population attributable risks. Toxicological studies are necessary for elucidating causal mechanisms, which may be important for determining dose-response relations and extrapolating to low doses in risk assessment related to the morbidity of the study area.

4.4.2.1 Respiratory Morbidity

The respiratory morbidity is generally the excess number of hospital admissions due to COPD (Chronic Obstructive Pulmonary Disease - an umbrella term used to describe progressive lung diseases, including emphysema, chronic bronchitis, refractory asthma, and some forms of bronchiectasis) per thousand of human population, and in the study, the reported excess cases are calculated for the respective grid population prevailing in the particular transport corridor of the given district.

As depicted in Figure 4.14, this variable covered by the study also follows the pattern of the number of excess cases as revealed by the mortality results, i.e., ISBT Flyover and Wazirabad Road corridors of North-East Delhi district reporting 18979 and 18969 numbers as the highest and second highest. On the other hand, the slightly different scenario of the lowest and second lowest numbers of excess cases belonged to Punchkuin Road of the New Delhi district as 1995 and Sansad Marg of the New Delhi district as 2089.

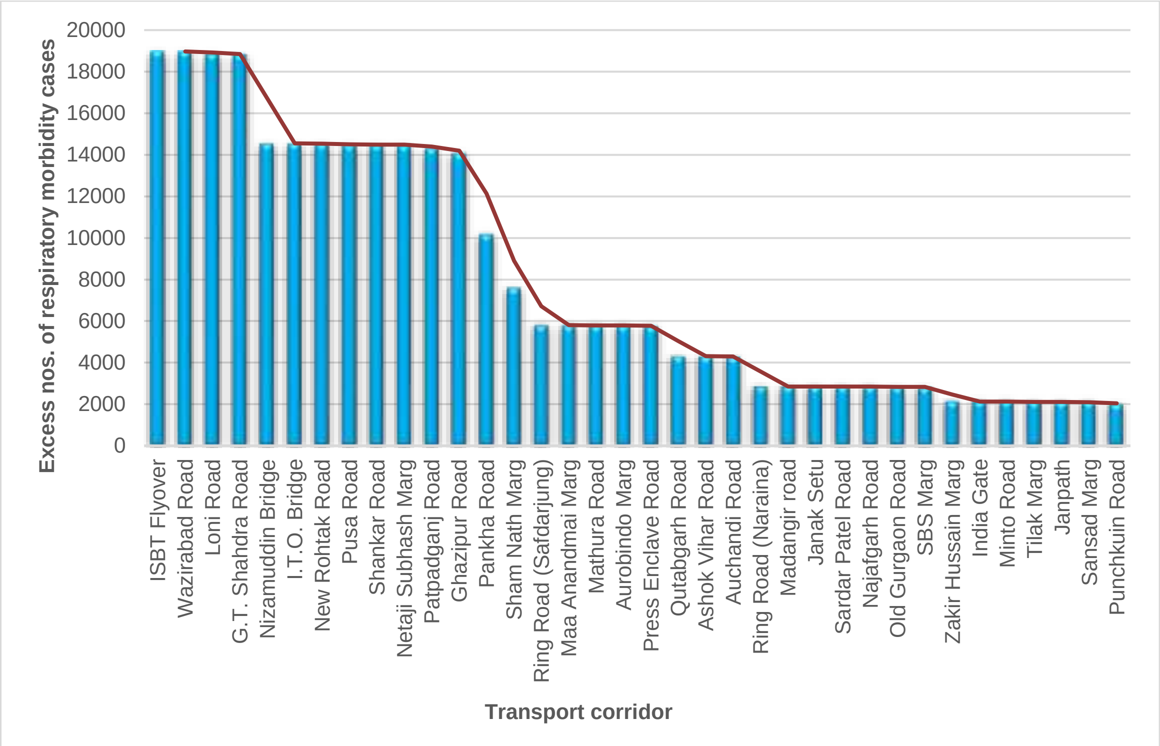


Figure 4.14: Respiratory morbidity at various transport corridors

Following a criteria, that corridors reporting at least 10000 excess number of cases are considered (barring two highest grosser corridors), as many as 11 corridors Loni Road, G.T. Shahdara Road, Nizamuddin Bridge, ITO Bridge, New Rohtak Road, Pusa Road, Shankar Road, Netaji Subhash Marg, Patpadganj Road, Ghazipur Road, Pankha Road and together recorded an excess number of COPD cases as 163411 (66% of the total cases excluding ISBT Flyover and Wazirabad Road, the highest two corridors). From the other perspective, (i.e., the maximum number of excess cases not exceeding 10000) about 21 corridors belonging to North Delhi, South Delhi, North-West Delhi, South-West Delhi and New Delhi recorded just 79939 cases (about 28% of the total cases excluding Sansad Marg and Punchkuin Road).

4.4.2.2 Cardio-vascular Morbidity

As reflected in Figure 4.15, the study reports that the Cardiovascular morbidity (i.e., The number of excess hospital cases due to heart and/or blood circulation-related medical conditions per thousand of human population) excess cases calculated for the respective grid population prevailing in the particular transport corridor of given district exhibit the same pattern as in case of respiratory morbidity. It is found that in North-East Delhi district, ISBT Flyover recorded the maximum number of cases as 4762 with Wazirabad Road corridor closely following with 4761 numbers. On the other hand, Punchkuin Road and Sansad Marg corridors of New Delhi district reported a number of excess cases as 501 and 526 (lowest and second lowest).

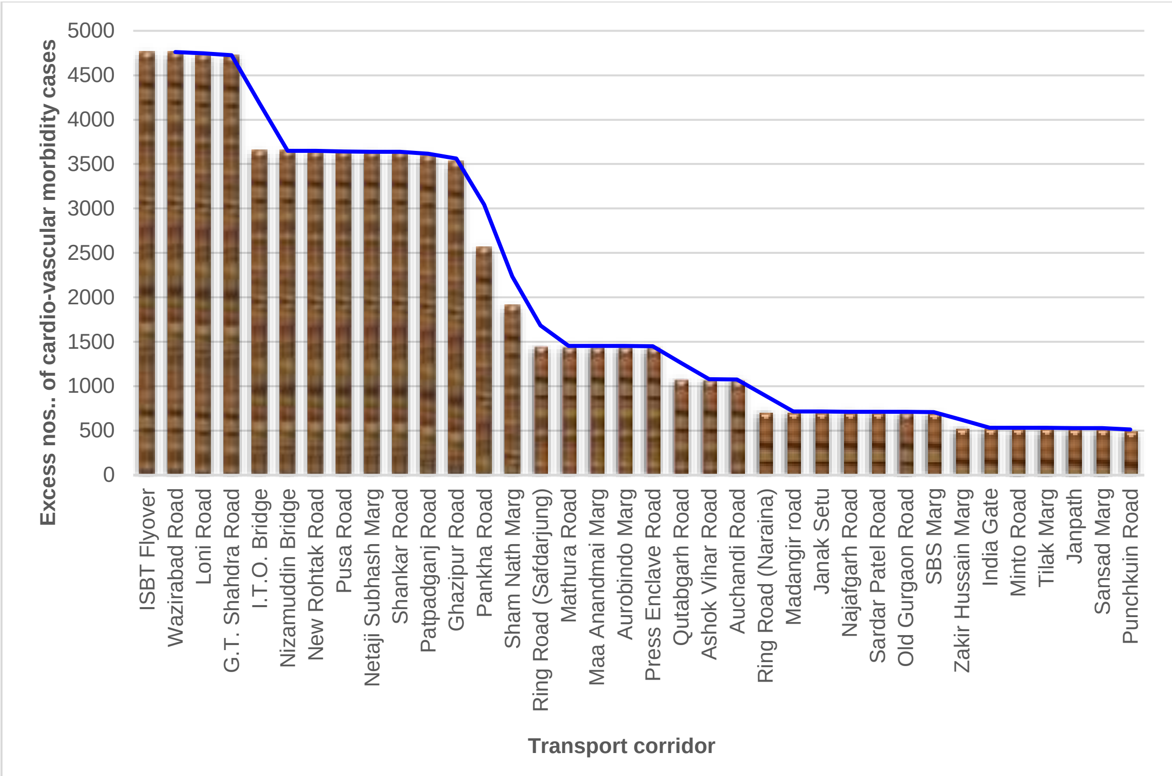


Figure 4.15: Cardio-vascular Morbidity at Various Transport Corridors

Following the similar criteria, that corridors reporting at least 1000 excess number of cases are considered, as many as 20 corridors Netaji Subhash Marg, Mathura Road, Ring Road-Safdarjung, Aurobindo Marg, Shankar Road, New Rohtak Road, Ashok Vihar Road, Shamnath Marg, G.T. Shahdara Road, ITO Bridge, Nizamuddin Bridge, Patpadganj Road, Maa Anandmai Marg, Press Enclave Road, Pankha Road, Qutabgarh Road, Auchandi Road, Loni Road, Ghazipur Road and Pusa Road together recorded an excess number of COPD cases as 53407 (86% of the total cases excluding ISBT Flyover and Wazirabad Road, the highest two corridors). From the point of view, (i.e., the maximum number of excess cases not exceeding 1000) about 12 corridors belonging to South-West Delhi and New Delhi recorded just 7652 cases (about 11% of the total cases excluding Sansad Marg and Punchkuin Road).

4.5 Overall District's Scenario

A district-wise scenario shows that three of the total nine districts of the megacity covered in the study, namely, North Delhi, West Delhi and North-West Delhi district recorded the least number of excess cases for all health risk parameters considered in the study, followed by East Delhi and New Delhi district. The numbers for the three districts were calculated as 146, 194, 239 for respiratory mortality; 560, 738, 885 for cardiovascular mortality; 854, 1120, 1321for total mortality; 7612, 10199, 12896 for respiratory morbidity and 1911, 2561, 3234 for cardiovascular morbidity respectively. In comparison to this, the two districts, namely, Central and North-East Delhi were found to result in the highest number of excess cases of almost all parameters reporting the values as 1948, 1447 for respiratory mortality; 7455, 5514 for cardiovascular mortality; 11373, 8393 for total mortality; 101421, 75656 for respiratory morbidity and 25460, 18972 for cardiovascular morbidity respectively (Figure 4.16). While the bottom three districts constituted about 11% of the total number of health risk excess cases (46225 against 414874), the top two grossed close to 62% (257639 numbers against 414874).

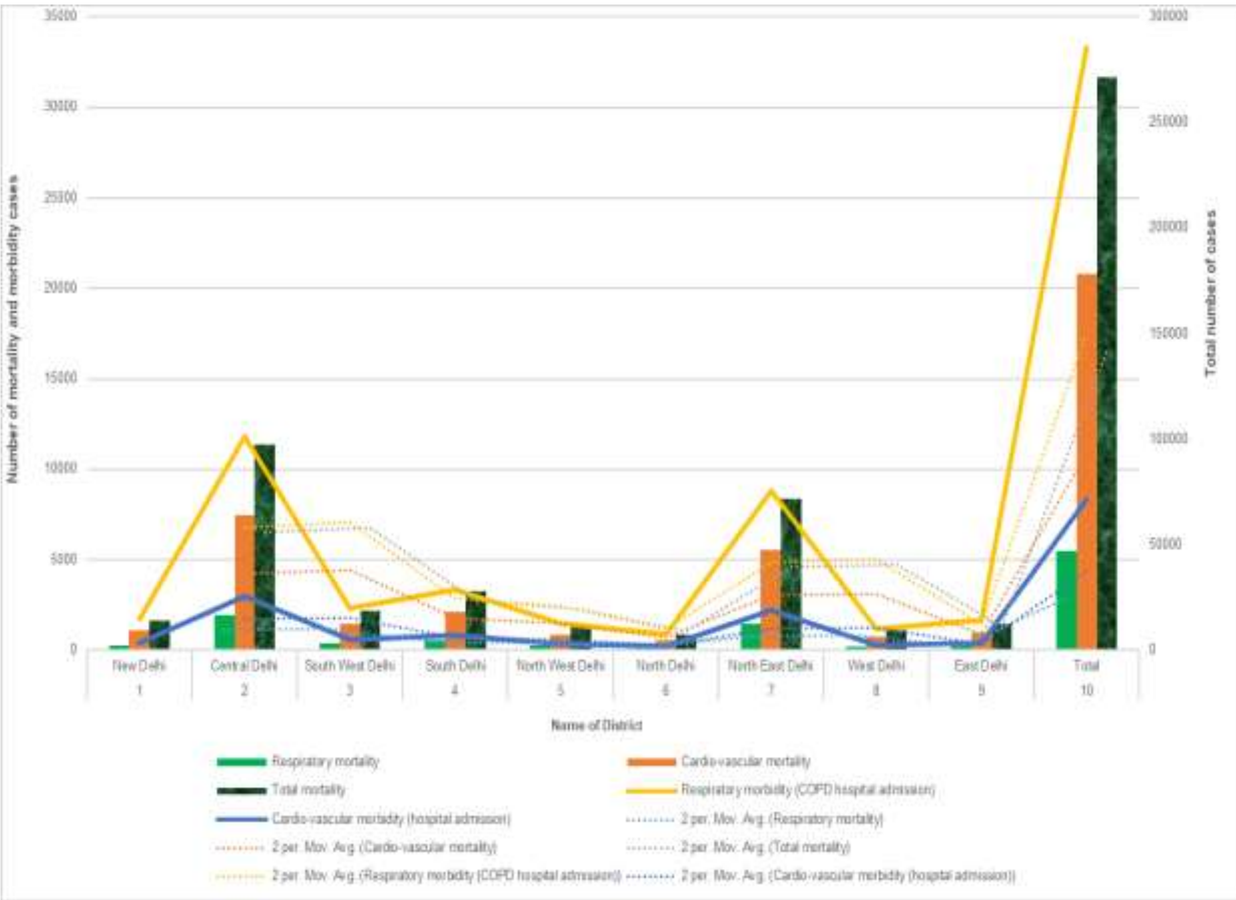


Figure 4.16: District-wise performance of all health risk parameters in Delhi

4.6 Air quality at transport corridors

Air Quality Index (AQI) has been developed and used effectively in many developed countries for over last three decades (USEPA 1976; 2014). An AQI is defined as an overall scheme that transforms weighted values of individual air pollution related parameters (SO_2, CO, visibility, etc.) into a single number or set of numbers. There have not been significant efforts to develop and use AQI in India, primarily due to the fact that a modest air quality monitoring programme was started only in 1984. The theory of an air quality index (AQI) that converts weighted values of specific air pollution related parameters values into a single number or set of numbers is extensively used for air quality communication and judgment represent of particular area. It is present air quality information (almost in real-time) that entails the system to account for pollutants which have short-term impacts. Eight parameters (PM_{10}, $PM_{2.5}$, NO_2, SO_2, CO, O_3, NH_3, and Pb) having short-term standards have been considered for near real-time dissemination of AQI (Kumar and Goyal, 2011).

To assess the severity of the air quality in AQI terms, the CPCB method was utilized to calculate the transport corridor-wise AQI for all 36 corridors which, along with vehicular traffic volume is presented (Figure 4.17). A look at traffic volume data of the transport corridors indicates that I.T.O. Bridge, Nizamuddin Bridge, Mathura Road and India Gate stretches each record a daily traffic volume in excess of 100000, which covers passenger cars, auto rickshaws, 2-wheelers, buses and goods carriers of various categories. It is important to see that the passenger cars have the largest share in traffic volumes of almost all transport corridors of the megacity barring only a few corridors. In addition, from the perspective of source apportionment, it is evident that the ambient air pollution is most aggravated by the vehicular sources.

As can be seen in the figure, the I.T.O. Bridge recorded maximum value of AQI as 1101 falling in the "severe" category along with as many as 20 transport corridors, viz., Minto Road, Netaji Subhash Marg, Zakir Hussain Marg, Mathura Road, India Gate, Ring Road (Safdarjung), Aurobindo Marg, Ring Road (Naraina), Shankar Road, New Rohtak Road, Sham Nath Marg, Wazirabad Road, ISBT Flyover, Nizamuddin Bridge, Maa Anandmai Marg, Madangir Road, Janak Setu, Pankha Road, Najafgarh Road and Pusa Road which reported AQI values as 512, 700, 571, 540, 493, 503, 716, 604, 419, 542, 585, 919, 860, 791, 483, 500, 525, 422, 497 and 591, respectively. These 21 transport corridors, i.e., about 58% of the total was flagged in "severely" polluted category of ambient air pollution. Further ten transport corridors were reported to in "very poor" category, namely, Panchkuian Road, SBS Marg, Sansad Marg, Tilak Marg, Sardar Patel Road, Ashok Vihar Road, Press Enclave Road, Old Gurgaon Road, Qutabgarh Road and Loni Road with calculated values as 352, 389, 354, 351, 397, 309, 312, 324, 355 and 322 subsequently.

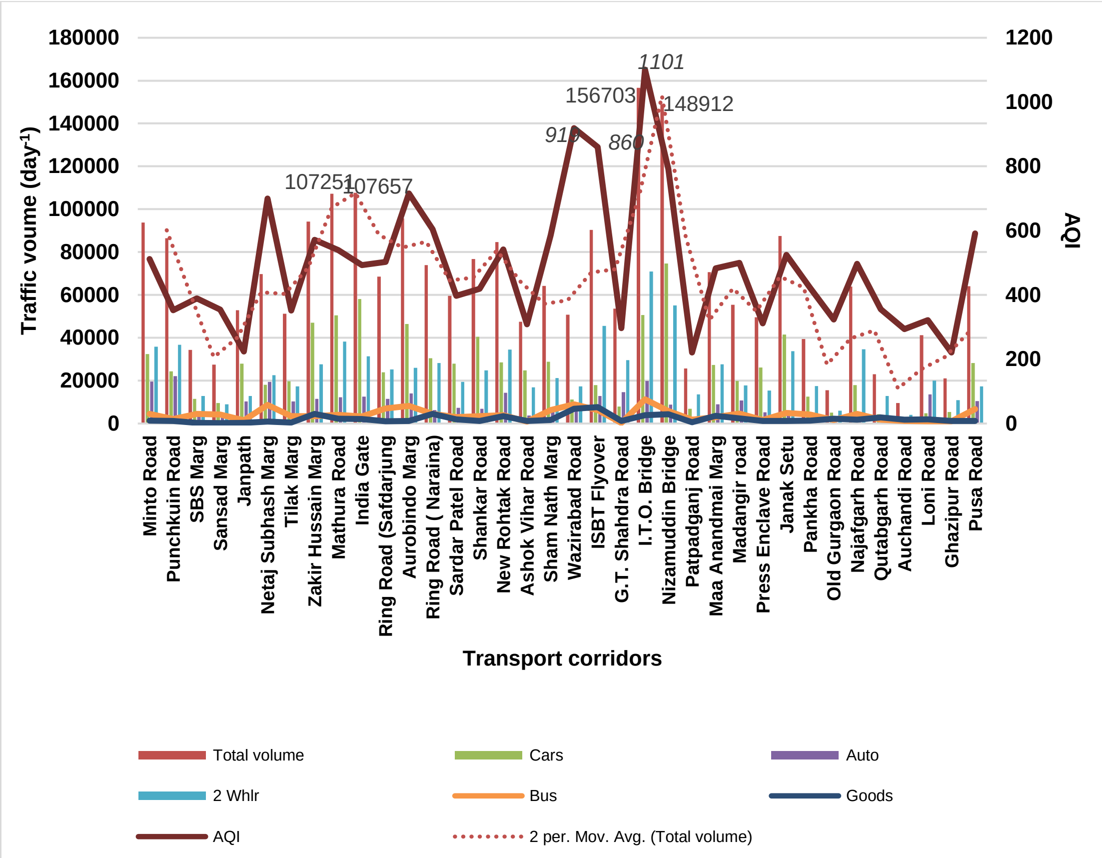


Figure 4.17: Air quality index at selected transport corridors

It is evident that out of 36 transport corridors undergone the study, 31 were found to be belonging to either "severe" or "very poor" AQI category thereby indicating the grave status of ambient air quality in the megacity of Delhi.

Ambient concentrations, corresponding standards and likely health impact, a sub-index is calculated for each of these pollutants. The worst sub-index reflects overall AQI. Associated likely health impacts for different AQI categories and pollutants have also been suggested, with primary inputs from the medical expert members of the group. Table 4.3. Presents the AQI values and the overall category as good/ satisfactory/ moderate/ poor/ very poor and severe based on the same.

Table 4.3. Indian air quality index

Good	**(0-50)**
Satisfactory	**(51-100)**
Moderate	**(101-200)**
Poor	**(201-300)**
Very Poor	**(301-400)**
Severe	**(401-500)**

The table 4.4 as show the AQI values and corresponding ambient concentrations (health breakpoints) as well as associated likely health impacts for the identified six pollutants are as follows:

Table 4.4. Air quality index of various pollutants and health Breakpoints

AQI category (Range)	CO (8-hr)	SO_x (24-hr)	NO_X (24-hr)	PM_{10} (24-hr)	$PM_{2.5}$ (24-hr)	O_3 (8-hr)
Good (0-50)	0-1.2	0-40	0-40	0-50	0-30	0-50
Satisfactory(51-100)	1.1-2.0	41-80	41-80	51-100	31-60	51-100
Moderately polluted (101-200)	2.1-10	81-380	81-180	101-250	61-90	101-168
Poor(201-300)	10-17	381-800	181-280	251-350	91-120	169-208
Very Poor (3001-400)	17-34	801-1600	281-400	351-430	121-250	209-748
Severe (401-500)	34+	1600+	400+	430+	250+	748+

Source: MOEF, 2014

4.7 Mapping of vehicular pollutant parameters

For the present study, five criteria ambient air pollutants, namely CO, NOx, PM_{10}, $PM_{2.5}$, SOx, and C_6H_6 were selected. The study area of Delhi has been classified under five categories (high, moderately high, moderate, moderately low and low), based on concentration level of pollutants recorded at monitoring sites corresponding to all districts of Delhi. The value of these categories varies with the calculated concentration of pollutants as shown in Table 4.5. The area under each distribution class of pollutant values is shown in Table 4.6.

Table 4.5. Classification of the values of vehicular pollution parameters

Parameters	**Low**	**Moderately low**	**Moderate**	**Moderately high**	**High**
CO (µg/m^3)	<193.28-556.03	556.03- 850.05	850.05-1209.41	1209.41-1797.46	>1797.46-3066.032
NOx (µg/m^3)	<23.51-89.81	89.81-128.35	128.35-174.60	174.60-249.10	>249.10-362.57
PM_{10} (µg/m^3)	<22.82-43.05	43.05-69.87	69.87-116.07	116.07-203.99	>203.99-422.42
$PM_{2.5}$ (µg/m^3)	<52.78-156.75	156.75-198.71	198.71-253.43	253.43-333.70	>333.70-541.71
SO_X (µg/m^3)	<2.12-6.51	6.519-10.40	10.40-15.53	15.53-24.54	>24.54-42.16
C_6H_6 (µg/m^3)	< 0.77-2.25	2.25-3.34	3.34-4.62	4.62-6.68	> 6.68-13.85

Table 4.6 Area in sq. km under each distribution class of pollutants values in Delhi

Class	CO	NO_X	PM_{10}	$PM_{2.5}$	SO_X	C_6H_6
Low	283.55	221.39	445.66	549.17	200.63	222.64
Moderately Low	480.78	391.84	648.62	627.34	510.29	308.88
Moderate	440.81	635.69	288.39	133.33	433.85	849.30
Moderately High	195.70	140.61	77.422	110.95	277.90	1.62
High	82.17	93.48	22.90	62.20	60.33	100.56
Total Area (sq. km)	1483	1483	1483	1483	1483	1483

4.7.1 Carbon monoxide (CO)

It is revealed in the present study that high concentration of carbon monoxide for Delhi city, which was recorded in the range of >1797.46-3066.03 µg/m^3 distributed partially over 82.17 km^2 (5.54 %) of the area, corresponds to the border-sharing districts of South-East, East, Shahdara, Central and New Delhi (Figure 4.18). This high value too, are attributable to the large vehicular population in the referred areas having regular trans-border fleets.

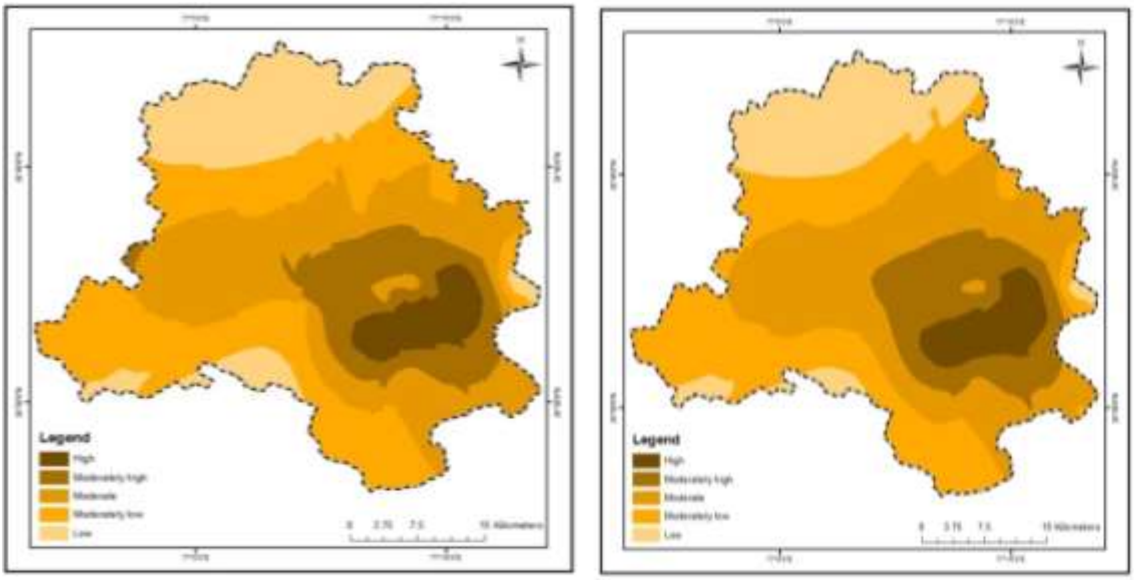


Figure 4.18: Spatial distribution of concentration and emission of CO

Area with moderately high value of CO concentration (1209.41-1797.46 µg/m^3) was found spread over 195.70 km^2 reflecting 13.20 % of the total area which was observed in South, South-East, East, Central, North-West, West and New Delhi districts, while the moderate concentration having range as 850.05-1209.41 µg/m^3 was reported covering the area of 440.81 km^2 (29.72 %) partially distributed in West, New Delhi, South, South-East and Central Delhi districts. The class of moderately low pollutants is the highest covering area of Delhi, i.e. 480.78 km^2 (32.42 %) with a concentration range of 556.03-850.06 µg/m^3, which is partially distributed in South-West, New Delhi, North-West and North districts. The low class concentration of CO was observed in the areas such as North, South-West and New Delhi districts with corresponding values as <193.28-556.03 µg/m^3. It covers the substantial geographic area of the Delhi with 280.55 km^2 (19.12%) of the total area.

4.7.2 Nitrogen oxides (NO_X)

It is evident from Table 4.6 that largest area coverage of concentration range of 128.35-174.60 µg/m^3 of NO_2 relates to 635.69 km^2 i.e., 42.86% of the total study area falling under moderate class. It is clear from Figure 4.19 too, this area belongs to the districts of West, South-West, New Delhi, South, Central, North-East, Shahdara and North Delhi. The area with the high-value class of NO_x with characterized range as >249.10-362.57 µg/m^3 constituting about 93.48 km^2 and reflecting 6.30% of the total area is spatially distributed in the South and South-East districts.

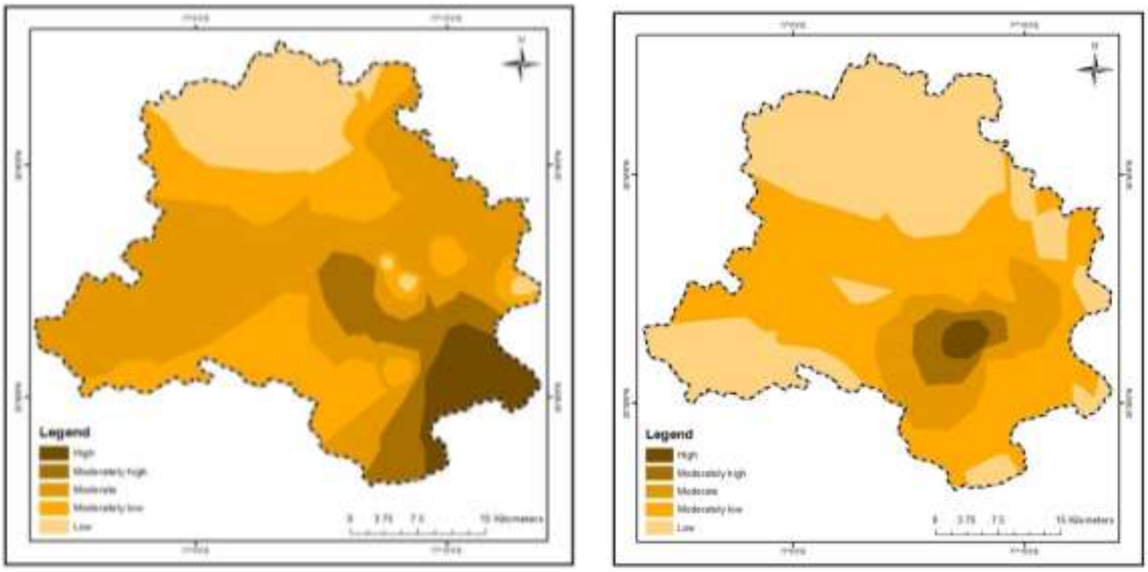


Figure 4.19: Spatial distribution of distribution concentration and emission of NOx

However, the concentration of moderately low value, i.e., 89.82-128.35 µg/m^3 is found to be covered by 391.84 km^2, which is about 26.42% of total area representing North-West, South-West, New Delhi, South and Shahdara districts. It is to be further noted that moderately high level of concentration array of 174.60-249.11 µg/m^3 embraced an area of 9.48% (140.61 Km^2) in New Delhi, South-East, South, East and Central Delhi while area coverage represented by low class spreader over 14.93% i.e., 221.38 km^2 of the study area. This low class of concentration range of 23.51-89.82 µg/m^3 was found in districts of North, East and North-East districts. These areas are mostly affected because of the mixed land use pattern, i.e., characterized by commercial and residential areas and the traffic density, which is highest, compared to all districts.

4.7.3 Particulate matter (PM_{10})

The spatial distribution of PM_{10} as depicted in Figure 4.20, puts forward the high concentration range as 203.99-422.42 µg/m^3 found in the districts of New Delhi and Central Delhi covering the lowest area of about 22.90 km^2 (i.e., just 1.54%) while, low-class values having the respective set out as 22.83-43.05 µg/m^3 were shown having area coverage of 445.66, km^2 (i.e., 30.05%) belonging to the districts such as North, South-West and Shahdara.

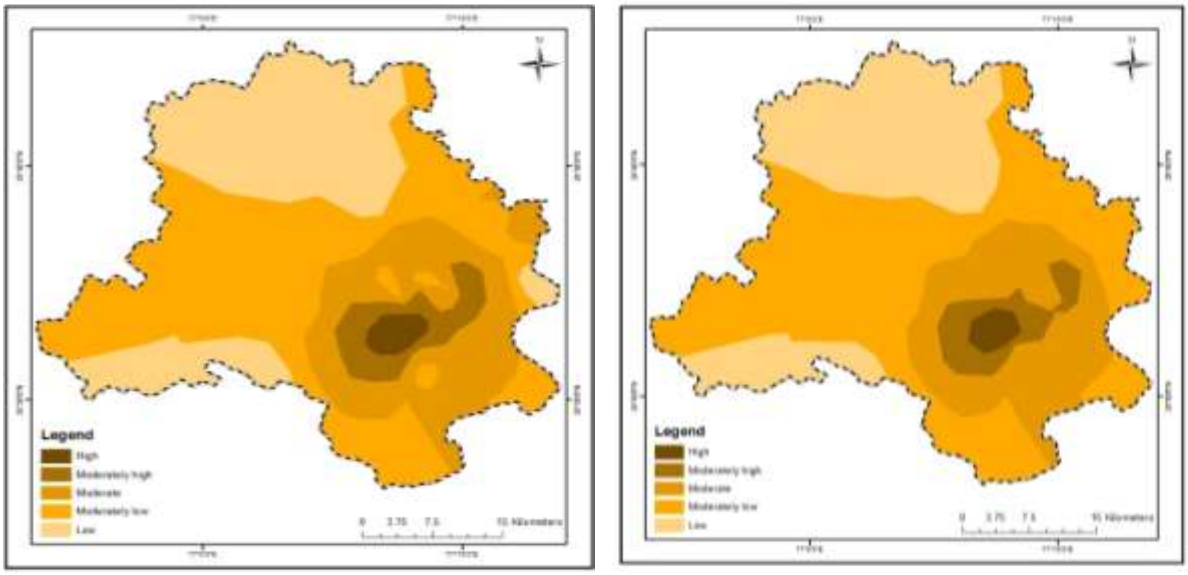


Figure 4.20: Spatial distribution of distribution concentration and emission of PM_{10}

The moderately high concentration range, i.e., 116.07-203.99 µg/m^3 was observed in districts, namely, New Delhi, Shahdara, Central Delhi and North-East reporting an area coverage of about 77.42 km^2 i.e., 5.22% of the total area. On the other hand, moderately low and moderate classes of PM_{10} exhibited spatial distribution corresponding to 648.63 km^2 (43.74%), and 288.39 km^2 (19.44%) areas, respectively. Having concentration ranges as 43.05-69.87 and 69.87-116.07 $\mu g/m^3$ consequently, both the classes represented about 63.18% of the total geographic area. It is revealed that the observed values at about 25% of the total areas exceeded the permissible limit of 100 $\mu g/m^3$ prescribed by NAAQS for PM_{10} in respect of 24-hours average ambient air concentration.

4.7.4 Fine particulate matter ($PM_{2.5}$)

As revealed by Figure 4.21, the moderately low-class value covers 42.30% (627.34 km^2) of the total area having a concentration of $PM_{2.5}$, which ranges as 156.75-198.71 $\mu g/m^3$ covering most of the areas in the districts of North-West, West, South-West, North, Central and Shahdara.

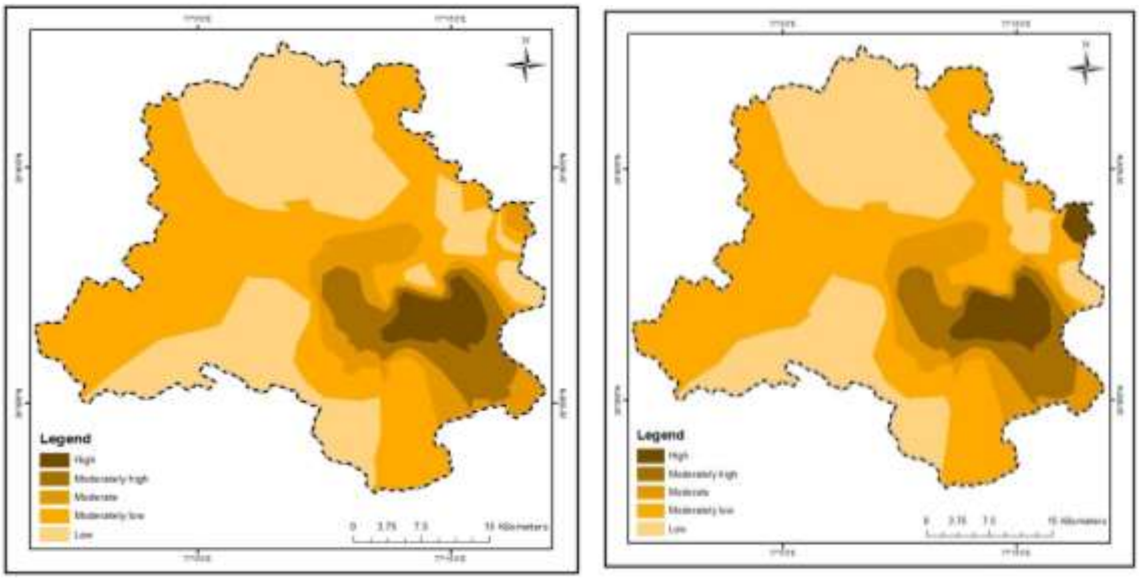


Figure 4.21. Spatial distribution of concentration and emission of $PM_{2.5}$

About 133.33 km^2 i.e., 8.99% of the areas under study fitted in moderate value class with concentration range as 198.71-253.44 $\mu g/m^3$ were found to be from districts of Central, New Delhi, South and South-East Delhi. The low-level concentration range of $PM_{2.5}$ (i.e., 52.78-156.75 $\mu g/m^3$) was found to be distributed over 549.17 km^2 area (i.e., 37.03%) corresponding to North, South-West, New Delhi, South, North-East, Shahdara and East districts of Delhi. Moderate high class of $PM_{2.5}$ pollutant represented about 7.48% (110.95 km^2) of total area exposing New Delhi, South, South-East and East Delhi districts while high class covered just about 4.19% (i.e., 62.20 km^2) of areas covering the districts of South-East, South, New Delhi and Central Delhi. This is to be highlighted that except for marginal presence in South-West and North Delhi (i.e., in about 3% of the total area), $PM_{2.5}$ concentrations was reported to be in excess of both annual and 24-hours average ambient concentration parameters.

4.7.5 Sulphur oxides (SO_X)

The moderately low class with concentration array as 6.52-10.40 $\mu g/m^3$ is found to cover about 34.41% of total area (i.e., 510.28 km^2) contributed by South-West, North, North-East and Shahdara districts (Figure 4.22). This class being highest is followed by moderate value class having range as 10.40-15.53 $\mu g/m^3$ which covered about 433.85 km^2 (i.e., 29.25% of total area) corresponding to districts of North-West, West, South-West, New Delhi, South, South-East, Central Delhi, North-East and Shahdara. On the other hand, the low-class range of 2.12-6.52 $\mu g/m^3$ was found to be covered by 220.36 km^2 (i.e. 13.53%) in the districts of South-West, New Delhi and North Delhi. The area with moderately high value of SOx concentration range (i.e., 15.53-24.54 $\mu g/m^3$) constituting about 277.90 km^2 and reflecting 18.74% of the study area was reported from the districts of Central Delhi, North-West, West, New Delhi, South-East and East Delhi. The high concentration range of 24.54-42.17 µg/m^3 was mostly found in the districts of only East and Central Delhi. It covered about 60.33 km^2 (i.e., 4.07 %) area. None of the districts exhibited any values in violation of corresponding NAAQS annual or 24-hours average standard as 50 and 80 µg/m^3 respectively.

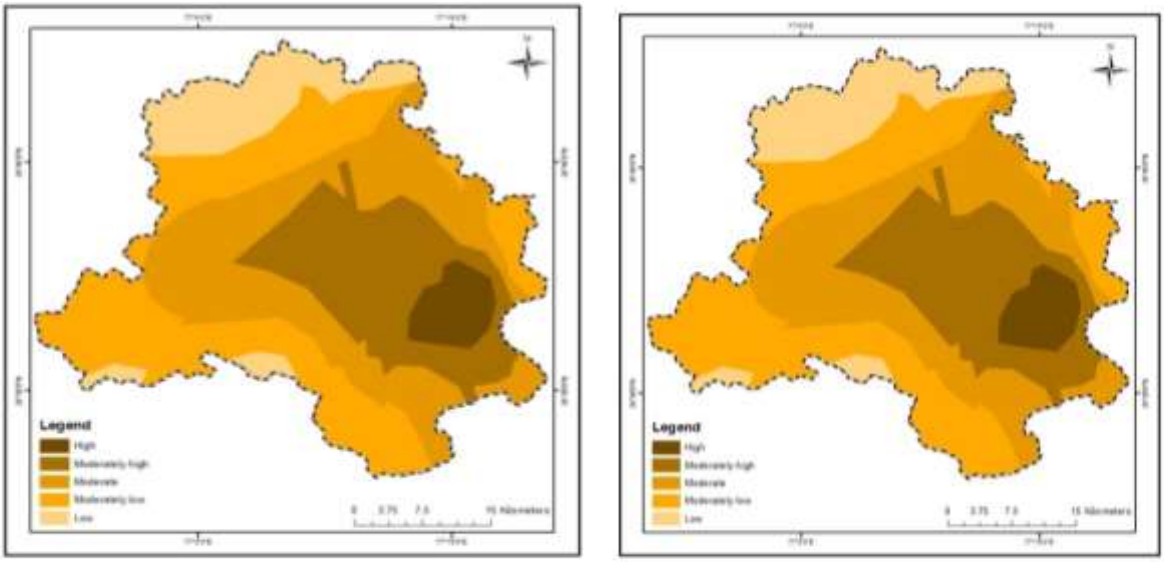


Figure 4.22: Spatial distribution of concentration and emission of SO_x

4.7.6 Benzene (C_6H_6)

It is found in this study that about 57.27% (849.3 km^2) of the geographical area of the mega city of Delhi shows moderate values of benzene in the range of 3.35 - 4.62 µg/m^3, distributed partly in the districts of North-West, West, South-West, New Delhi, South, South-East Delhi, Central, Shahdara, North and North-East Delhi areas shown Figure 4.23. Further, the values of benzene corresponding to the moderately higher class, i.e. 4.62-6.68 µg/m^3 is presented by the lowest area which is just 0.11% (1.62 km^2) of the total area of Delhi city concentrated in Central Delhi district. It is to be further noted that about 6.78% area (100.56 km^2) was reported to be representative of a high class of benzene concentration (i.e. > 6.68-13.85 µg/m^3) in the border-sharing districts of East, Shahdara, North-East, Central and New Delhi. The cause of this relatively higher observed concentration of benzene in such districts of Delhi is attributable to the highest vehicle density in these areas. The low observed concentration in North-West districts is mainly due to the high abundance of vegetation or plantation cover.

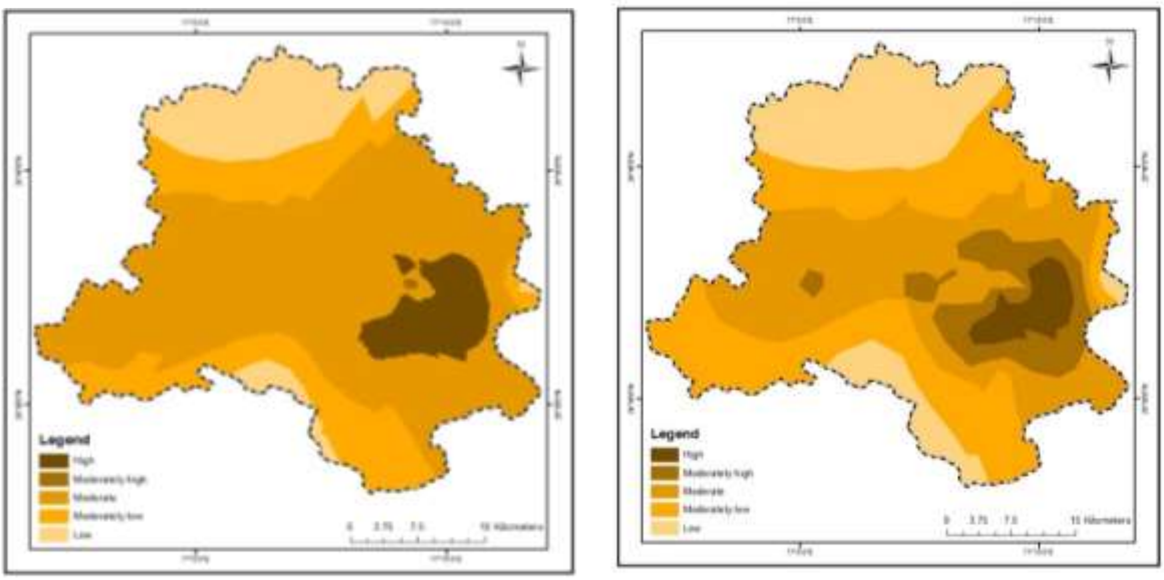


Figure 4.23: Spatial distribution of concentration and emission of benzene

4.8 Mapping of cardiovascular mortality and morbidity

The Figure 4.24 represent the cardiovascular mortality and morbidity over the Delhi city due to vehicular pollution. The distribution of cardiovascular mortality in km^2 area cover like high (25.02), moderately high (79.46), moderate (207.66), moderately low (309.32 km) and low (858.53) are area covers in cardiovascular mortality map. Along with the cardiovascular morbidity distributed like high (26.85), moderately high (90.65), moderate (184.84), moderately low (352.59) and low (828.06) are area covers in cardiovascular mortality map.

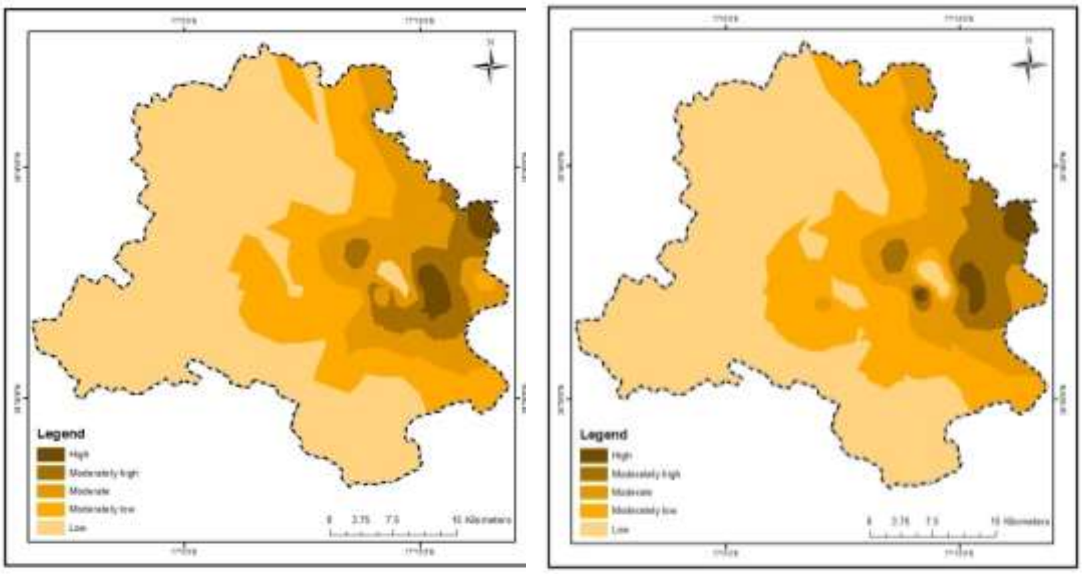


Figure 4.24: Spatial distribution of cardiovascular mortality and morbidity

4.9 Mapping of respiratory mortality and morbidity

The Figure 4.25 represent the Mapping of respiratory mortality and morbidity (Chronic Obstructive pulmonary disease) COPD over the Delhi city due to vehicular pollution. The distribution respiratory mortality in km^2 area cover like high (81.59), moderately high (28.37), moderate (198.30), moderately low (370.94) and low (803.79).

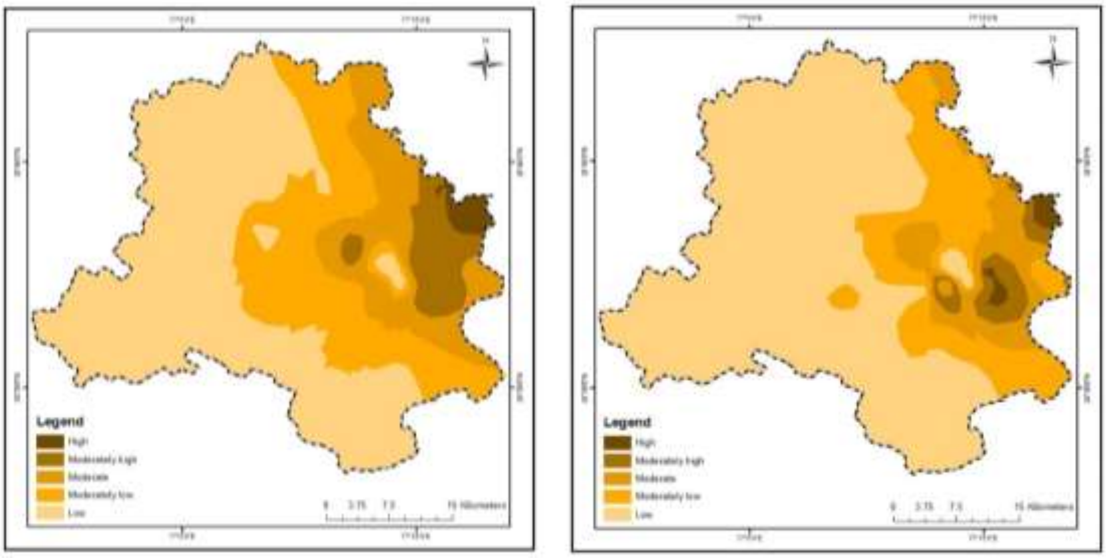


Figure 4.25: Spatial distribution of respiratory mortality and morbidity

On the other hand, respiratory morbidity (COPD) distributed high (15.86), moderately high (45.99), moderate (198.30), moderately low (264.36) and low (1020.23).

4.10 Mapping of total mortality and vulnerability status

The Figure 4.26 shows the distribution of total mortality and vulnerability condition in Delhi. The distribution respiratory mortality in km^2 area cover like high (25.34), moderately high (96.84), moderate (224.58), moderately low (380.43) and low (755.78). The visual representation of vulnerability condition, as distributed in km^2 i.e. high (12.23), moderately high (110.21), moderate (283.40), moderately low (299.25) and low (777.89).

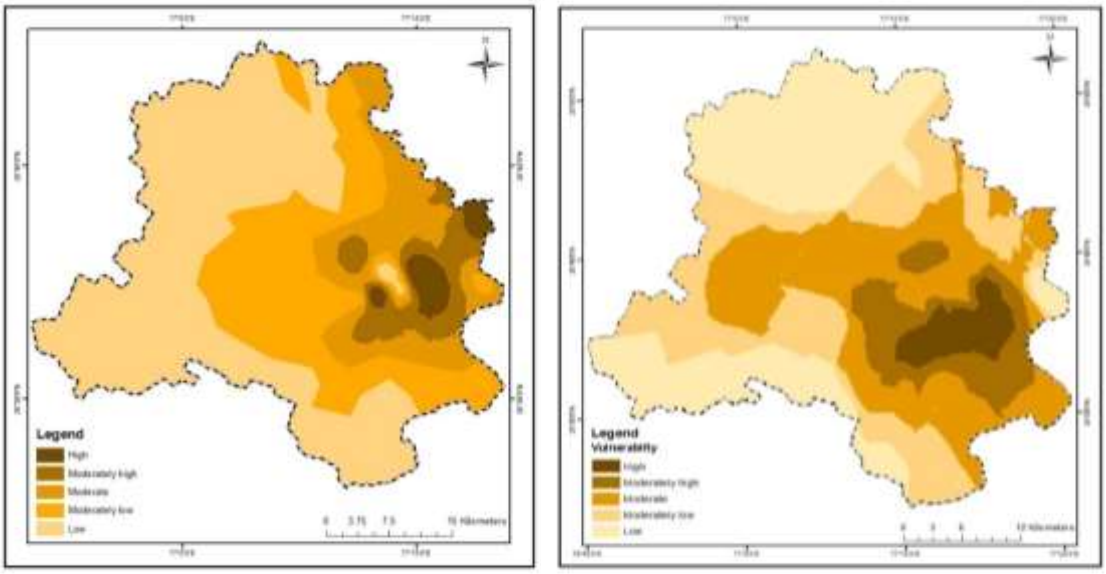


Figure 4.26: Spatial distribution of total mortality and vulnerability condition

4.11 Questionnaire Survey

A questionnaire survey was also conducted based on air quality and health risk assessment. This survey was aimed at investigating the perceptive of public and their opinion about health effects being caused due to exposure to air pollution during their day-to-day activities in life. This interviewer-assisted questionnaire was developed based on thorough literature review. This survey has been done in the vicinity of transport corridors falling within study area. The respondents were chosen from nearby residential areas, pedestrians using the walkways, motorists, cyclists, rickshaw-pullers etc. also, the shopkeepers, students, working labor's along the transport corridors, vendors, traffic police, doctors etc.

Questionnaire survey is one of the best way to assess the health issues regarding air pollution in megacity, where there is no proper hospital data available. Delhi do not have such type of data related to the hospital intake due to air pollution. To assess the objective of this research work, questionnaire survey has been conducted in Delhi at selected location. Geographical representation of location with sampled population is depicted in Figure 4.27. Along with monitoring of different vehicular pollutant, questionnaire survey has also been conducted to know the perception of vendor and residents. This research aimed to investigate the control measures used by public transport commuters and their health effects due to exposure to air pollution during their daily commute. Approximately 918 people (response rate approximately 60%) were interviewed at 36 locations in Delhi. The questions were carefully read aloud to participants by the interviewers in two languages Hindi and English. As shown in Table 4.7, the majority of the respondents were aged 26 to 50 years (48.3%) and > 51 to 75 were 30.1%. By occupational group, the majority of the respondents were from private sector (32.7%) Govt. (21.2), and student (31.5%). The ethnic and gender distribution of the study participants closely matched that of the general Delhi working population (69.6% male, 28.5% female and 1.9% transgender). Respondent's residential area traffic.

were 29.2% high, 38.2% moderate and 32.6 low traffic congestion and fallowed by the respondent's working area were 35.7% high, 46.1% moderate and 18.2% low traffic congestion.

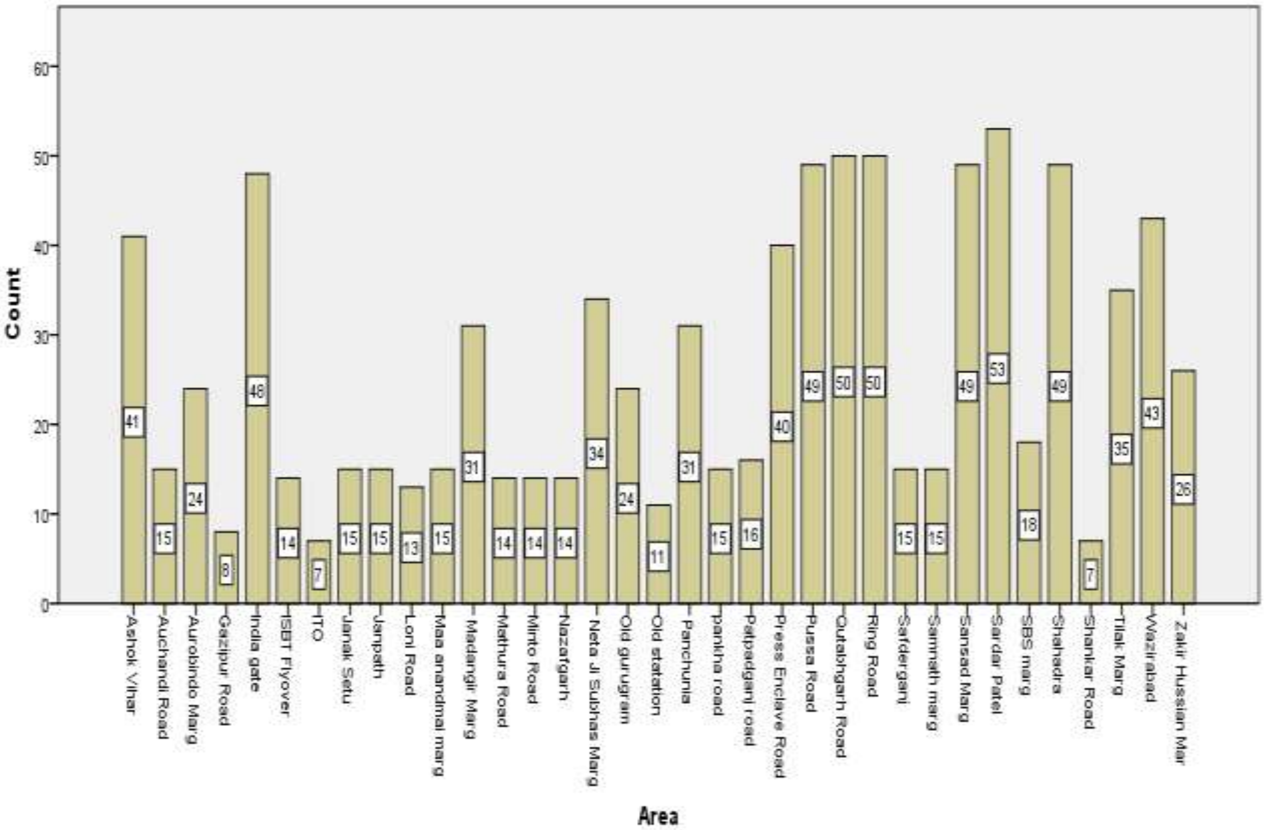


Figure 4.27: Graphical representation of location with sampled population

The questionnaire consisted of 12 questions in three sections (See Annexure). First section contains the demographic data, second section is asked the questions about health risks, commuting time duration, and the presence of chronic diseases in respondent. In the third section, the two questions probed participants' control measures used to reduce the effect of air pollution during their daily commute. The response options included strongly disagree, agree, neutral, agree, and strongly agree and scored as 1, 2, 3,4 and 5, respectively. Thus, total possible scores ranged from 1 to 5, with a higher score implying a higher level of control measures. The second section assessed participants' self-reporting of adverse health experiences (6 items of health issues i.e. eye irritation, breathing problem, running nose or congested nose sneezing bouts, throat irritation, headache) from exposure to air pollution during their daily commute days with each requiring a "yes" or "no" response. Each "yes" response was rated as 1 and each "no" response was rated as 2. Therefore, with a higher score implying higher levels of adverse health.

During the daily commute under normal conditions, the three highest adverse health experiences were eye irritation (53.3%), headache (41.1%), throat irritation (40.7%), running nose and congested nose (39.2%), sneezing bouts (36.8%) and breathing difficulties (35.4%).

Descriptive analysis was performed to determine the frequency distribution of gender, age, occupation, traffic commercial, traffic residential, control measures, and adverse health experiences. Table 4.7 explains in detail the frequency distribution of questionnaire.

Table: 4.7 Frequency distribution of demographic data of gender, age, occupation, traffic commercial, traffic residential and Mode of travel

Gender					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Male	639	69.6	69.6	69.6
	Female	262	28.5	28.5	98.1
	Transgender	17	1.9	1.9	100.0
	Total	918	100.0	100.0	
Age					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	<25 age	151	16.4	16.4	16.4
	26-50 age	443	48.3	48.3	64.7
	51-75 age	276	30.1	30.1	94.8
	>75	48	5.2	5.2	100.0
	Total	918	100.0	100.0	
Occupation					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Student	289	31.5	31.5	31.5
	Government	195	21.2	21.2	52.7
	Private Limited	300	32.7	32.7	85.4
	Other	134	14.6	14.6	100.0
	Total	918	100.0	100.0	

Traffic congestion in commercial zone

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	High	328	35.7	35.7	35.7
	Moderate	423	46.1	46.1	81.8
	low	167	18.2	18.2	100.0
	Total	918	100.0	100.0	

Traffic congestion in residential zone

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	High	268	29.2	29.2	29.2
	Moderate	351	38.2	38.2	67.4
	low	299	32.6	32.6	100.0
	Total	918	100.0	100.0	

Daily mode of travel

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Bus/Metro	496	54.0	54.0	54.0
	Personal Car	275	30.0	30.0	84.0
	Two-wheeler	124	13.5	13.5	97.5
	Three-wheeler	23	2.5	2.5	100.0
	Total	918	100.0	100.0	

In the above Table 4.7, in the section of daily mode of travel section represents that 54% respondent are using public transport (city bus and metro), 30% using personal car and 16% using three-wheeler and two-wheeler. In Delhi outdoor air pollution is notorious in health concern. Most of the respondents spend their 6 to 10 hours (48.6%) time outside the home due to their work profile (Figure 4.28).

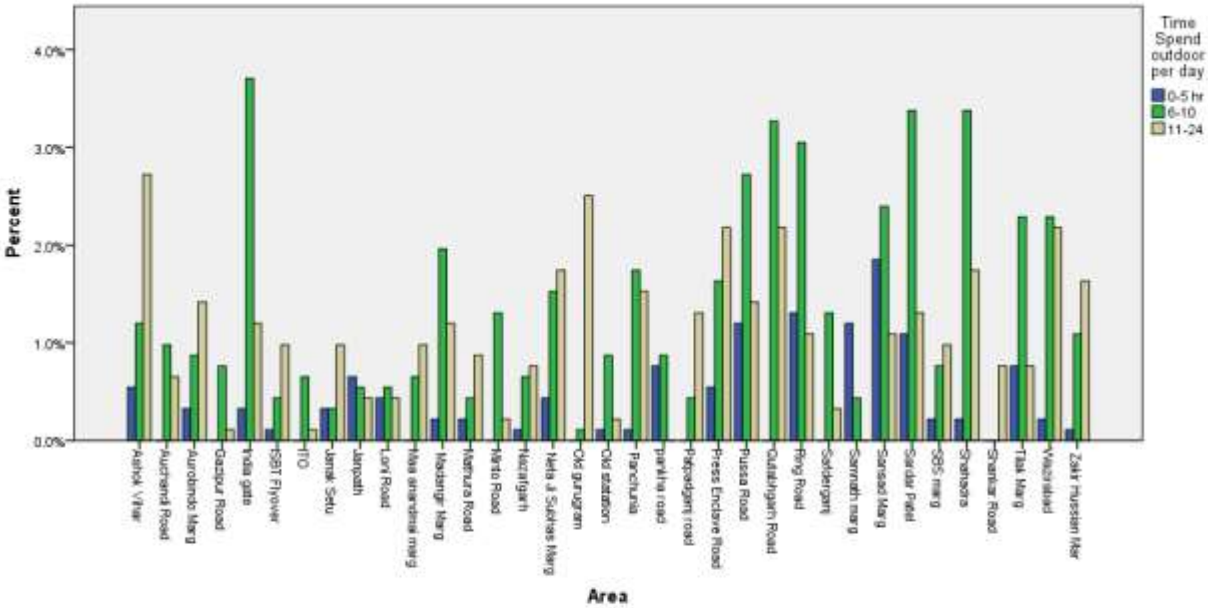
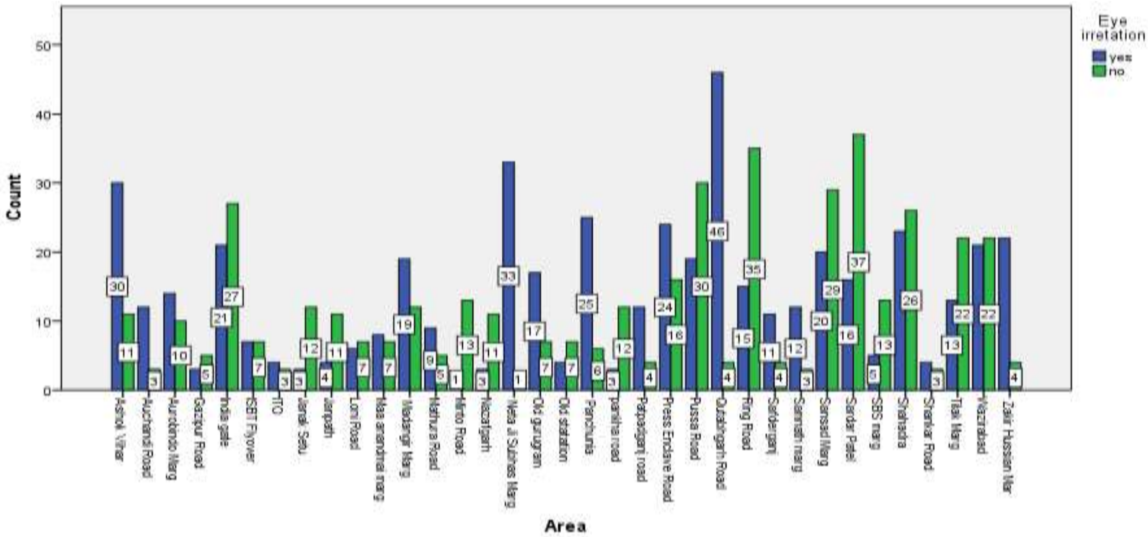
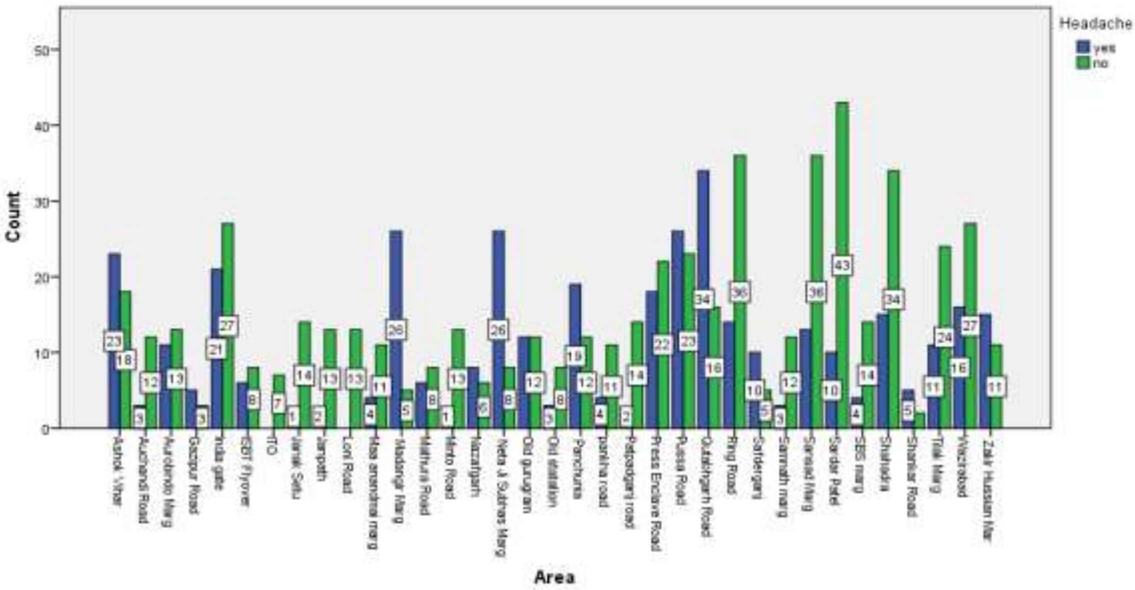


Figure 4.28: Graphical representation of time spend outside in day to day activities

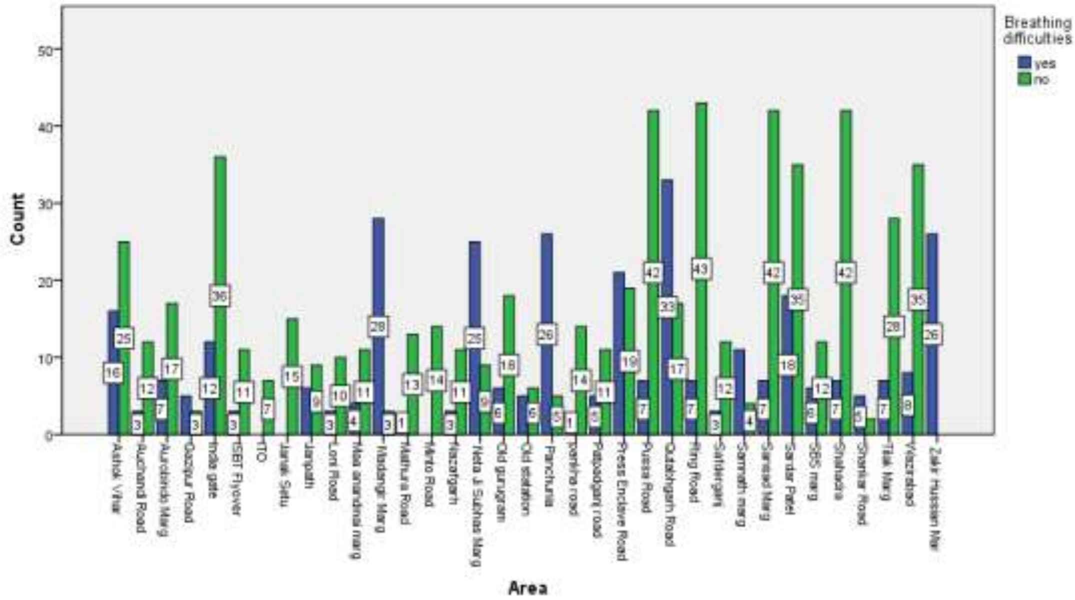
In concern of health issues regarding air pollution in Delhi, graph 4.29 represents that the most of the respondent were suffering from the eye irritation (53.3%), headache (41.1%) and throat irritation (41.1%).



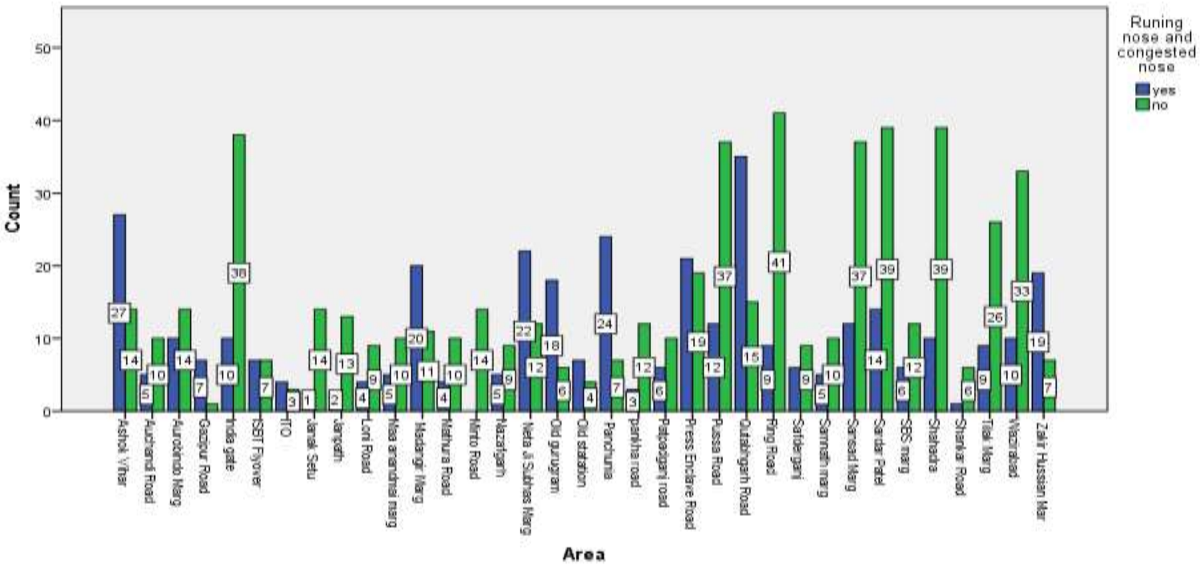
(i)


Headache
yes
no
Count
Area
Ashok Vihar
Auchandi Road
Aurobindo Marg
Gazipur Road
India gate
ISBT Flyover
ITO
Janak Setu
Janpath
Loni Road
Maa anandmai marg
Madangir Marg
Mathura Road
Minto Road
Nazafgarh
Neta Ji Subhas Marg
Old gurugram
Old statation
Panchuna
panhira road
Patpadganj road
Press Enclave Road
Pussa Road
Qutabgarh Road
Ring Road
Safdarganj
Samrath marg
Sarsad Marg
Sardar Patel
SBS marg
Shahadra
Shankar Road
Tilak Marg
Wazirabad
Zakir Hussain Mar

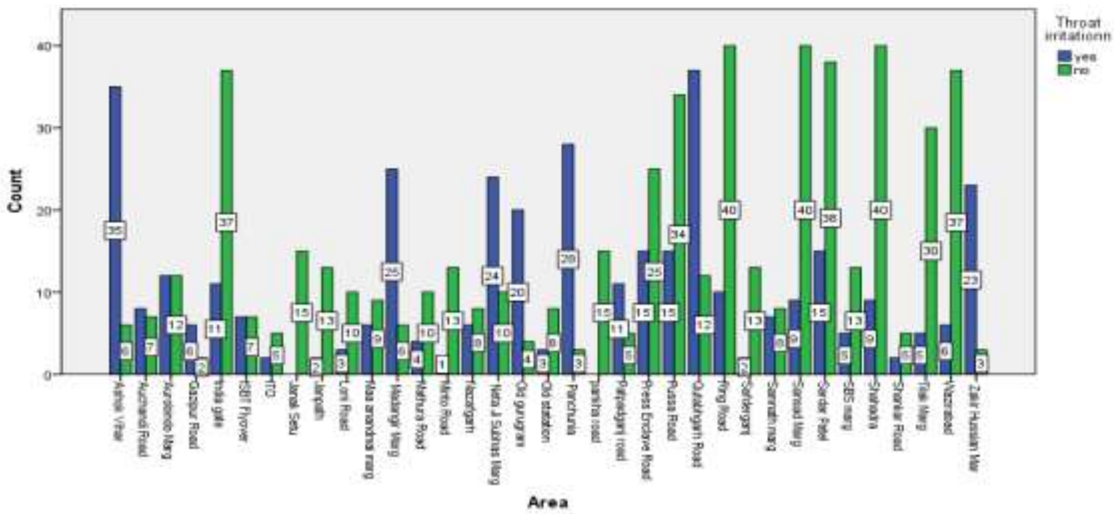
(ii)


Breathing difficulties
yes
no
Count
Area

(iii)



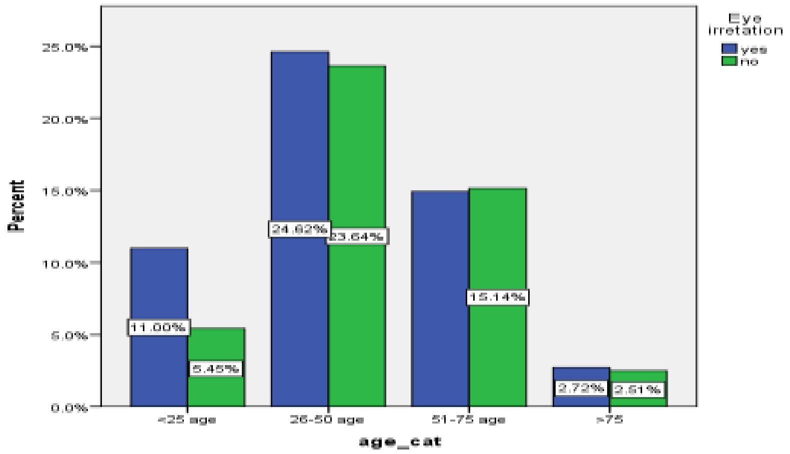
(iv)



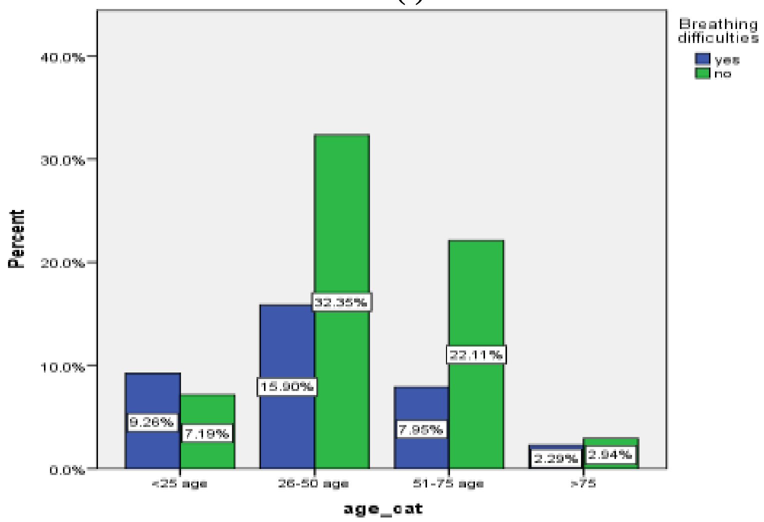
(v)

Figure 4.29: Health issues analysis at selected location in section I; II; III; IV and V

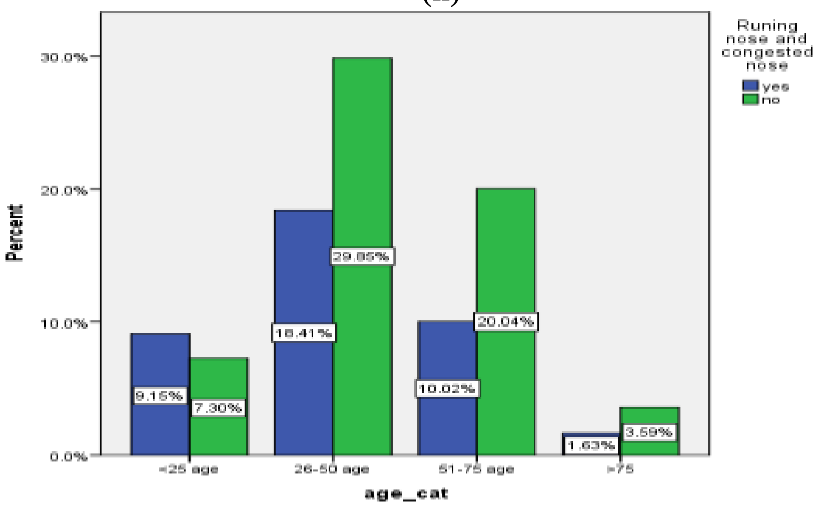
During this survey health impact was also analysis among different age group (Figure 4.30) From the analysis, the eye irritation was found in most of the people who were in the age group of 26 to 50 years) 24.6%) followed by breathing difficulties 15.9%, running nose and congested nose 18.41%, sneezing bouts 18.6%, headache 19.5%, throat irritation 17.5%.


Eye
irretation
yes
no
Percent
25.0%
20.0%
15.0%
10.0%
5.0%
0.0%
11.00%
5.45%
24.62%
23.64%
15.14%
2.72%
2.51%
<25 age
26-50 age
51-75 age
>75
age_cat

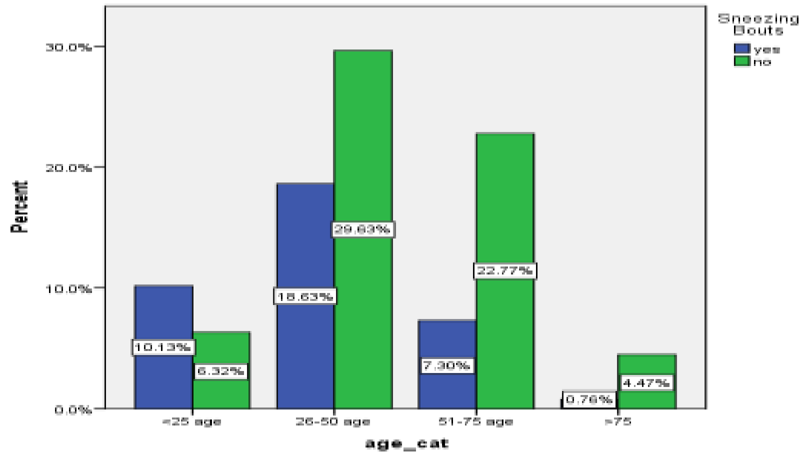
(i)


Breathing
difficulties
yes
no
Percent
40.0%
30.0%
20.0%
10.0%
0.0%
9.26%
7.19%
15.90%
32.35%
7.95%
22.11%
2.29%
2.94%
<25 age
26-50 age
51-75 age
>75
age_cat

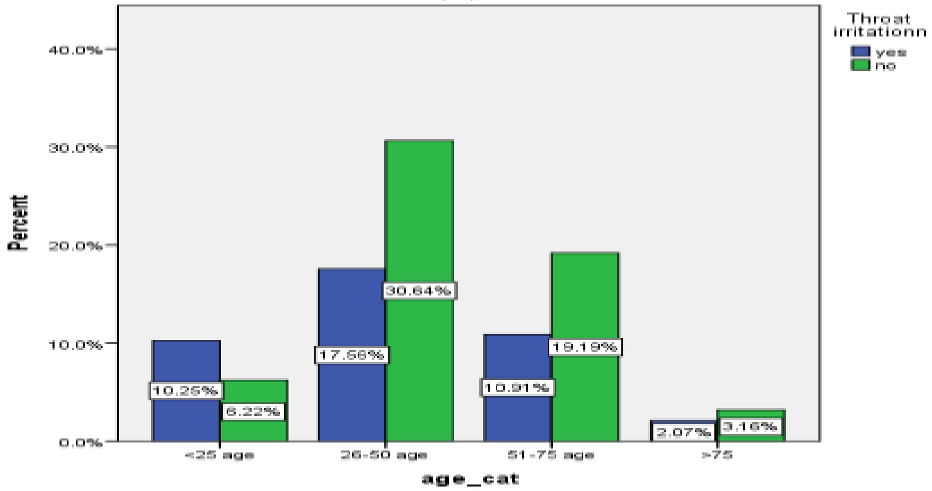
(ii)


Runing
nose and
congested
nose
yes
no
Percent
30.0%
20.0%
10.0%
0.0%
9.15%
7.30%
18.41%
29.85%
10.02%
20.04%
1.63%
3.59%
<25 age
26-50 age
51-75 age
>75
age_cat

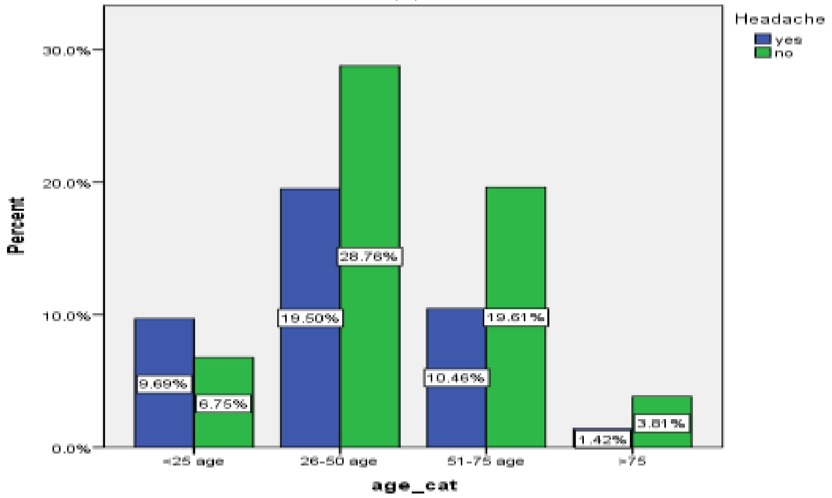
(iii)



(iv)



(v)



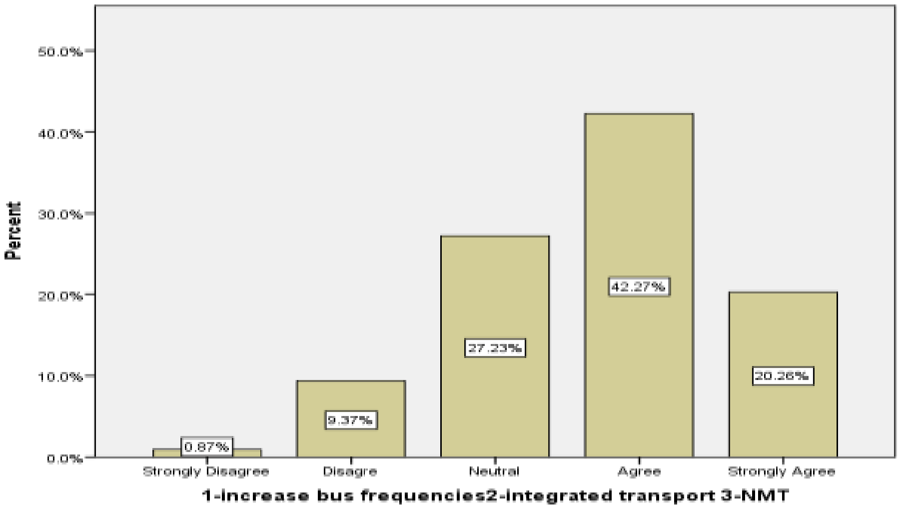
(vi)

Figure 4.30: Health issues with different age group in section I; II; III; IV; V and VI

Third section of questionnaire, which contain two question related to air pollution control strategy in Delhi at present scenario. First question contains possible solution from government side. In this question, there is following set of solution for the mitigation of vehicular pollution in Delhi. i.e. Increase the bus frequency in Delhi, implementation on full scale of integrated transport, encourage by law and subsidies to non-motorizes transport and the second question is related to mitigation strategies from public and private sector with the following sets of solution like carpooling, strict car loan, No free parking, High parking charge. Both question was scale on strongly disagree, disagree, neutral, agree and strongly agree along with representation of 1, 2, 3, 4, 5 number.

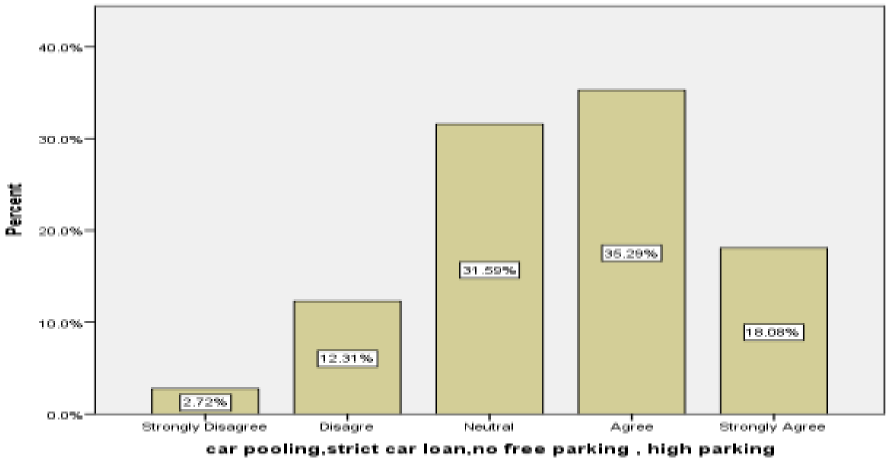
Figure 4.31(i) shows that, in the first question, which was related to mitigation, strategy from the government sector has 20.26% strongly agree response from sampled population (918 person) along with 27.23% neutral response. There is only 0.87% strongly disagree response and 9.37% disagree response for the first question's set of solution. This result shows that strongly disagree and disagree have very less response compare to strongly agree response, which is supporting this questionnaires survey for analyzing the mitigation strategy of vehicular pollution in Delhi.

Figure 4.31 (ii) shows the response of second question, which is related to mitigation strategy of vehicular pollution from public and private sector. In this, 35.29% respondents are agreed with second question's set of solution followed by 18.08% strongly agree response of respondent. Again, there is less response of disagree (12.31%) and strongly disagree (2.72%) compare to neutral response (31.59%). The result of second question justifying the objective of the questionnaire survey. For detail understanding, the analysis has done whereas the response versus ages of respondent (Figure 4.32). The highest peak of 20.37% response for agree in first question and 17.43% agree response in second question are belong to age group of 26 to 50 years. Disagree and strongly disagree have very less percentage among all age group. Output of this survey shows and stand with the suggestive option of questionnaire positively.



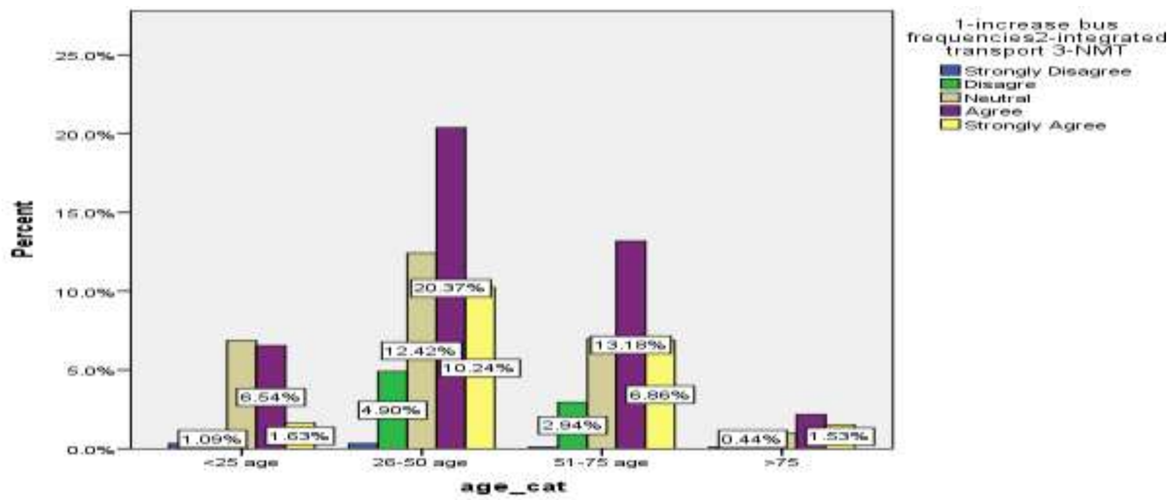
(i)

(ii)

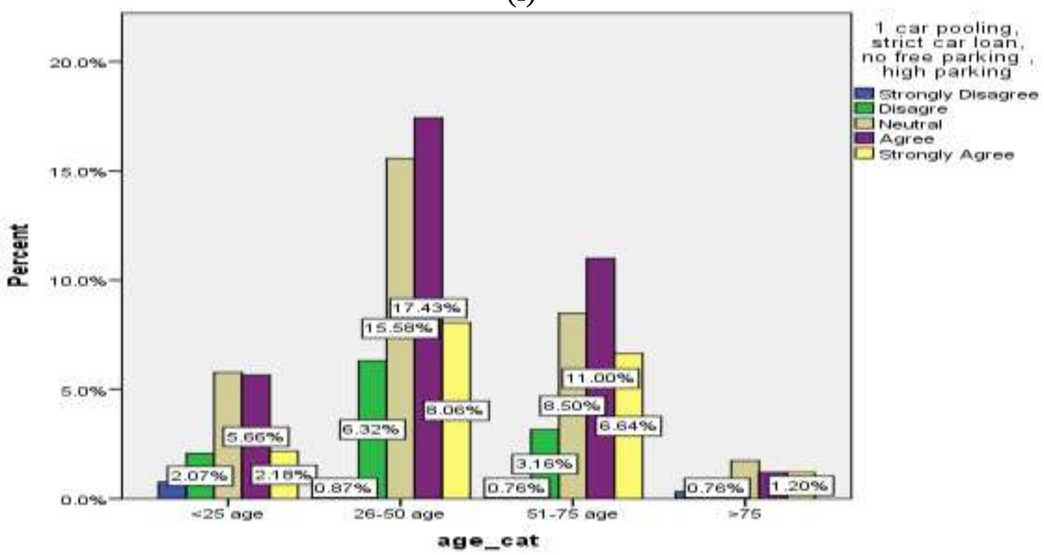


(ii)

Figure 4.31: Suggestive mitigatory measures to cut off vehicular pollution



(i)



(ii)

Figure 4.32: Mitigatory suggestion to reduce pollution

4.12 Summary

This chapter covers the results and discussion part of the research study. The result analysis involves the calculation of the emission and concentration of pollutants at 36 transport corridors. This chapter discussed about the box model and Gaussian equation and their application to calculate the emission and concentration of pollutants. Along with this, chapter portrays about AirQ2.2 and Ri-MAP model tool for the assessment of health risk at selected corridors. The assessment of respiratory mortality, cardio-vascular mortality, total mortality, respiratory morbidity (i.e., COPD hospital admission) and cardio-vascular morbidity (hospital admission) are also discussed in this chapter.

In addition to this, GIS mapping which is a very important part of this research has been thoroughly covered in this chapter. In addition to this, it also incorporates the detailed analysis of the questionnaire survey conducted at selected transport corridors in Delhi.

CHAPTER 5

CONCLUSION AND FUTURE PROSPECTS

5.1 General

The entire study has covered various aspects of vehicular pollution. During this research study, vehicular pollution and its health exposure assessment have been taken up. The present study is based on the capital city of India i.e. Delhi. The study is mainly focussed on the emission and concentration of pollutants at various transport corridors. The studies also deal with the health risk assessment due to vehicular pollution along the transport corridors. All the generated data integrated with GIS and GIS maps are developed lot the selected locations. This study has been conducted at 36 transport corridors. All these corridors are important corridors for Delhi city. The conclusions drawn from the entire research study have been covered in the following sections.

5.2 Emission and concentration

Emission and concentration of various vehicular pollutants at different urban roads were measured and analysed across the megacity of Delhi. Observation and analysis were done for five criteria pollutants namely CO, NOx, PM_{10}, $PM_{2.5}$, SOx and C_6H_6 at 36 different transport corridors across the city. Among all the selected corridors, the Ring road (Safdarjung) showed the maximum emission as well as concentration of two key pollutants, viz., CO (3066 μg/m^3) and PM_{10} (422 μg/m^3), whereas the highest emission and concentration of SOx (42 μg/m^3), and $PM_{2.5}$ (542 μg/m^3) were found at Nizamuddin Bridge and ISBT Flyover respectively. From the study, it is concluded that the four major roads namely Ring Road (Safdarjung), ITO Bridge, ISBT Flyover and

Nizamuddin Bridge recorded relatively higher concentrations of all the considered criteria pollutants and therefore, need special attention to control the higher magnitude of vehicular air pollution. Auchandi Road showed the lowest concentration of pollutants among all selected transport corridors. Other corridors, which reported to be under low concentration of measured pollutants, were G.T. Shahdra road, Sansad Marg and Patpadganj Road. Out of 36 observed roads, all the roads are reported to have higher concentrations in comparison to the national air quality standards with respect to one or more pollutants including the Auchandi Road, which finds itself among the lowest emitters of pollutants. It is also observed that bridges report higher concentrations as compared to road stretches and that the number of vehicles or vehicle density has a direct impact on the concentration of pollutants at any place or corridor. Along with other vehicles, buses are observed to have a significant effect on the peak observed value of any pollutant. An excessive number of goods vehicles are also observed to contribute heavily to the increase in pollutant concentration at any corridor. Recently, there has been a ban imposed by the government on the late-night entry of heavy goods vehicles into Delhi from neighbouring state, which is yet to be evaluated for its impact on ambient air quality. The roads with a very low number of goods vehicles recorded relatively lower concentration of every pollutant.

The estimation of traffic induced emission as well as concentration was carried out to quantify the emission as well as concentration of benzene, at ITO Bridge (13.6 µg/m3), The highest emission of benzene compounds was found at ITO Bridge (3.71 kg/day) and minimum was observed at Auchandi Road. The observations related to quantification of concentration showed that 18 transport corridors surpass the National Ambient Air Quality Standards for benzene. The higher emission as well as concentration of benzene compounds at the above-mentioned corridor may be due to the higher traffic volume, higher percentage of heavy vehicles, presence of more traffic signals and stagnation of vehicles at flyover for a long period of time during peak hours, traffic congestion etc. Keeping in mind the emission and concentration of above discussed toxic pollutants, special attention like integrative traffic management plan may be required to curb the pollution level.

5.3 Traffic induced mapping of pollutants

In the present study, the ambient air quality of the megacity Delhi has been assessed in terms of the exposure of five vehicular pollutants along 36 transport corridors covering all eleven districts. The study presents the air quality mapping and evaluation of the impact of vehicular pollution, making use of integrated mapping approach coupled with GIS bringing about the mapping of vehicular pollutants in the megacity. Driven by the fact that the knowledge of the spatial distribution of various vehicular pollutants is an essential tool required for planning and management of the transport system. The spatial maps of ambient air quality are generated during this study. Analysis of these maps shows that the air quality is excessively poor in South West, West, New Delhi,Central, North-East, East and South-East for four air pollutants (reported highest concentration range of PM_{10} as 203.99-422.42 µg/m^3; $PM_{2.5}$ as 333.71-541.72 µg/m^3; benzene as 6.68-13.86 µg/m^3, NO_x as 249.10-362.57 µg/m^3) respectively. Comparison of the observed values with corresponding 24-hours and/or annual average values of the NAAQS indicates the severity of the air pollutants citing 2 to 5 times higher values in the present study in various districts of Delhi. Taking into account the sensitivity of air pollution, it is, therefore, of paramount importance to the policy makers to attempt to bring in suitable remedial measures to control the worsening scenario and also focus to management of vehicular pollutants in ambient air. While in such an attempt, recently, the Government of NCT of Delhi implemented the odd-even driving scheme in two phases in Delhi. It is important to ascertain the effect of this scheme on ambient air pollution, and with its results yet to roll out, the comprehensive process and ways to study urban pollution need to be established towards sustaining any such policy and its aftermath.

5.4 Health risk assessment analysis

Various health risk parameters such as Respiratory mortality, Cardiovascular mortality, Total mortality, Respiratory morbidity (COPD hospital admission) and Cardiovascular morbidity (hospital admission) were calculated so as to assess the impact of aggravating multiple air pollutants at 36 transport corridors of National Capital Territory (NCT) of Delhi, India. The study attempted a "first-time and extensive" transport corridor-wise study by allocating grid-wise population and health-related aspects of key air pollutants such as PM_{10}, $PM_{2.5}$, SO_2 and NO_2 utilizing the Risk of Mortality/Morbidity due to Air Pollution (Ri-MAP) model in a bid to assess the direct health impacts in the year 2016.

A total of 281107, 20791, 31636 excess number of cases of respiratory mortality, cardiovascular mortality, total mortality was estimated at all 36 transport corridors whereas 281107 and 71608 excess cases of respiratory morbidity in terms of COPD hospital admission and Cardiovascular morbidity (hospital admission) were estimated from across the corridors.

It is observed that even though North Delhi, West Delhi and East Delhi districts recorded the least number of excess cases for all health risk parameters considered in the study as 146, 194, 263 for respiratory mortality; 560, 738, 982 for cardiovascular mortality; 854, 1120, 1473 for total mortality; 7612, 10199, 14082 for respiratory morbidity, and 1911, 2561, 3530 for cardiovascular morbidity respectively. The argument extends to the New Delhi district, which has least number of excess number of cases of mortality and morbidity, i.e., 282, 1079, 1647, 14674 and 3685 respectively, for respiratory mortality, cardiovascular mortality, total mortality, respiratory morbidity and cardiovascular morbidity aspects while maximum numbers of excess cases of respiratory mortality, cardiovascular mortality, total mortality and cardiovascular morbidity were calculated for Central Delhi as 1948, 7455, 11373, 101421 and 25460 respectively. The calculated AQI presents the severity of ambient air pollution in all 36 transport corridors in the megacity as 31 of these correspond to either “severe” or “very poor” class posing a direct threat to the neighbouring human populations. It is evident from the study that areas more populous are more prone to both mortality and morbidity health effects and these excess number of cases were reported in 4 km^2 grid sizes alongside the transport corridors throughout the megacity of Delhi. The alarmingly high traffic volume in most of the corridors further characterized by the highest share of passenger cars presents evidence of traffic-induced human health risk in different residential and other areas. Such studies with a more focused approach would inform a better transport corridor plan but also health institutions to be better prepared in battling with an excess number of such peculiar health cases in the city and elsewhere.

5.5 Questionnaire based survey

The analysis of questionnaire-based survey revealed that the public is suffering from eye irritation, breathing difficulties, running nose, congested nose, sneezing bouts, throat irritation and headache due to continuous exposure towards vehicular pollution according to their commuting time, personal health status and location. During the analysis, eye irritation (53.3%) was observed as a highest kind of adverse health effect among people due to vehicular pollution followed by headache (41.1%), throat irritation (40.7%), running nose and congested nose (39.2%), sneezing bouts (36.8%) and breathing difficulties (35.4%). During the perception-based analysis, it was found that most of the people showed their positive response towards the reduction of vehicular pollution in Delhi through integrated bus transport system, increase in bus frequencies, carpooling, strict car loan and high parking charges.

5.6 Future prospects of study

The present study covers the analysis of vehicular emission and its concentration at various selected transport corridors in Delhi. During the study period, the health risk mortality, morbidity and GIS mapping of vehicular pollution has been assessed at selected transport corridors. On the basis of entire study and its outcomes, following suggestion are recommended for future research.

The vehicular pollution requires proper attention of people and policy makers. There is a need to study the effect of vehicular pollution with the integration of biomarkers for exposure on human health, so that heterogeneity of passenger exposure can be related to air pollutants in public transport microenvironments. Health risk analysis of school going children and comparative health analysis of commuter's exposure towards PM, BC, BTX and UFP in urban and rural transport microenvironments of Delhi can also be carried out in future.

5.7 Summary

In chapter 5, the conclusion part of research has been discussed thoroughly. Preceding chapter concluded the emission and concentration of various pollutants. Along with health risk calculation and mapping at the various transport corridors. The ambient air quality in south, central, east, and New Delhi areas were found to be in high and moderately high classes necessitating adequate control measures. Many different avenues available for the continued research is required for future, is also mentioned mention in this chapter.

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ANNEXURE-I
(Questionnaire Survey)

DELHI TECHNOLOGICAL UNIVERSITY
(Formerly Delhi College of Engineering)
Department of Environmental Engineering
QUESTIONNAIRE SURVEY FOR AIR QUALITY ASSESSMENT.

(Please fill this survey for us to understand your awareness about pollution and its effects on your health)

1. Write the name of residence area……………………………

2. Gender
   a. Male ☐
   b. Female ☐
   c. Transgender ☐

3. Please mark your age range.
   a. <25 age ☐
   b. 26-50 age ☐
   c. 51-75 age ☐
   d. >75 ☐

4. What is your occupation?
   a. Student ☐
   b. Government ☐
   c. Private Limited ☐
   d. Other ☐

5. Traffic Commercial
   a.) Heavy b.) Moderate c.) Low
6. Traffic Residential
   a.) Heavy b.) Moderate c.) Low

7. How do you travel every day?
   a. Bus/ Metro ☐
   b. Personal Car ☐
   c. Two-wheeler ☐
   d. Three wheeler (Auto etc.) ☐

8. On an average how many hours do you spend Outdoor……………….and Indoor…………..

9. What type of Cooking fuel used in home ……………………………………………

10. Did you / adult family member/ children in your family have any of the following symptoms during the past 2 months?

Symptoms	You	Adult Family members	Children	No. Of Family member
Cough	Yes/No	Yes/No	Yes/No	
Breathing difficulty	Yes/No	Yes/No	Yes/No	
Running Nose or Congested Nose	Yes/No	Yes/No	Yes/No	
Sneezing Bouts	Yes/No	Yes/No	Yes/No	
Throat Irritation	Yes/No	Yes/No	Yes/No	
Fever	Yes/No	Yes/No	Yes/No	
Any other complaint related to health				

11. What should be done to reduce the air pollution especially vehicular pollution in our cities? Give your suggestions.
   a. Increase number of buses. Yes/No ☐
   b. Improve reliability and frequency of buses: Yes/No ☐
   c. Integrate bus routes, metro lines, autos: Yes/No ☐
   d. Create extensive well designed and usable footpaths and cycle tracks across the city. Protect this from encroachment: Yes/No ☐
   e. Others (Please specify)
   ……………………………………………………………………………………………………

12. Reduce car numbers by
   a. High parking charges and no free parking (in both residential and commercial areas) ☐
   b. Higher taxes for multiple car ownership by households: Yes/No ☐
   c. Remove and impose high penalty on vehicles with visible smoke Yes/No: ☐
   d. By providing cheaper and more efficient public transport ☐
   e. Stricter standards and regulations on car manufacturers ☐
   f. Do not reduce car numbers ☐

Note: Thank you for your valuable time for the air quality assessment of the mega city, Delhi.

ANNEXURE-II

(Annual average Meteorological parameters)

Transport corridor	Wind speed (m/s)	Wind direction (0)	Ambient Temperature (AT-^{0}C)	Relative Humidity (RH - %)	Solar Radiation	Rain Fall (mm/hr)	Vertical Wind Speed (VWS - m/s)
Minto Road	0.66	163.71	29.23	44.02	90.78	0	0.26
Punchkuin Road	0.66	163.71	29.23	44.02	90.78	0	0.26
SBS Marg	0.55	101.91	22.8	44.02	69.25	0	0.19
Sansad Marg	0.66	163.71	29.23	44.02	90.78	0	0.26
Janpath	0.66	163.71	29.23	44.02	90.78	0	0.26
Netaj Subhash Marg	0.55	101.91	25.72	46.40	84.31	0	0.1
Tilak Marg	0.66	163.71	29.23	44.02	90.78	0	0.26

xxx

Zakir Hussain Marg	0.66	163.71	29.23	44.02	90.78	0	0.26
Mathura Road	0.28	42.77	27.49	47.75	105.32	0	0.29
India Gate	0.66	163.71	29.23	44.02	90.78	0	0.26
Ring Road (Safdarjung)	0.11	194.76	25.56	60.86	87.46	0	0.13
Aurobindo Marg	0.11	194.76	25.56	60.86	87.46	0	0.13
Ring Road (Naraina)	0.51	194.01	23.59	57.58	97.86	0	0.11
Sardar Patel Road	0.51	194.01	23.59	57.58	97.86	0	0.11
Shankar Road	0.55	101.91	25.72	46.40	84.31	0	0.1
New Rohtak Road	0.55	101.91	25.72	46.40	84.31	0	0.1
Ashok Vihar Road	0.55	101.91	25.72	46.40	84.31	0	0.1

Sham Nath Marg	0.55	101.91	25.72	46.40	84.31	0	0.1
Wazirabad Road	0.42	160.01	28.63	45.35	175.43	0	0.12
ISBT Flyover	0.42	160.01	28.63	45.35	175.43	0	0.12
G.T. Shahdra Road	0.58	0.19	27.4	45.17	46.82	0	0.12
I.T.O. Bridge	0.66	163.71	29.23	44.02	90.78	0	0.26
Nizamuddin Bridge	0.66	163.71	29.23	44.02	90.78	0	0.26
Patpadganj Road	0.55	101.91	25.72	46.40	84.33	0	0.1
Maa Anandmai Marg	0.51	194.01	23.59	57.58	97.86	0	0.3
Madangir road	0.51	194.01	23.59	57.58	97.86	0	0.3
Press Enclave Road	0.51	194.01	23.59	57.58	97.86	0	0.3

Janak Setu	0.55	242.66	22.8	44.02	69.25	0	0.19
Pankha Road	0.55	242.66	22.8	44.02	69.25	0	0.19
Old Gurgaon Road	0.15	52.47	24	51.03	137.24	0	0.3
Najafgarh Road	0.58	163	28.13	44.38	174.52	0	0.7
Qutabgarh Road	0.33	179.1	29	60.79	134.1	0	0.8
Auchandi Road	0.29	174.2	29.59	58.10	149.16	0	0.7
Loni Road	0.58	0.19	27.4	45.17	46.82	0	0.12
Ghazipur Road	0.42	160.01	28.63	45.35	175.43	0	0.13
Pusa Road	0.58	163	28.13	44.38	174.52	0	0.11

LIST OF PUBLICATIONS

Book Chapter

Amrit Kumar; Pradeep Kumar; Rajeev Kumar Mishra and Ankita Shukla "Study of Air and Noise Pollution in Mega Cities of India" Environmental Pollution Water Sci., Technol. Library, Vol. 77, Vijay P Singh et al. (Eds): Environmental Pollution, Singer Nature, 978-981-10-5791-5, 448031_1_En, (7)

Research Paper

1. Amrit Kumar; Rajeev Kumar Mishra (2018) Human Health Risk Assessment of Major Air Pollutants at Transport Corridors of Delhi, India. Journal of Transport & Health, Volume 10, Pages 132-143 (IF 2.84)

2. Abhinav Pandey□; Rajeev Kumar Mishra; Govind Pandey□; Amrit Kumar (2018) The effect of odd-even driving scheme on PM□$_{2□.5}$ and PM□$_{1.0}$ emission, (Transportation Research Part D) In Press (IF 2.34)

3. Amrit Kumar; Rajeev Kumar Mishra (2017) Traffic Emission Modelling at Transport Corridors in Delhi. International Journal of Environmental Technology and Management, volume 20(3-4) pp. 240-258. Scopus (Elsevier)

4. Amrit Kumar; Rajeev Kumar Mishra (2017) Air Pollution Health Risk Based on AirQ+ Software Tool, International Journal of Applied Research and Technology, Vol-2, (3)90-199. 5. Ishan Saraswat; Rajeev Kumar Mishra; Amrit Kumar (2017) Estimation of PM10 concentration from Landsat 8 OLI satellite imagery over Delhi, India, Remote Sensing Application Society and Environment, volume 8, (4)25-257. Elsevier (IF 0.667)

6. Amrit Kumar; Rajeev Kumar Mishra (2017) Estimation of motor vehicle toxic emissions and concentrations in the metropolitan city of Delhi, IJTTE, volume 1(7) pp. 134-143. Scopus, (IF 1.15)

7. Anuj Kumar , Rajeev Kumar Mishra and Amrit Kumar (2015) Noise Pollution Analysis in Different Mega Cities of India during Deepawali Festival, Journal of Environmental Research and Development 2015.

8. Rajeev Kumar Mishra; Tarun Joshi; Nikhil Goel; Himanshu Gupta Amrit Kumar (2015) Monitoring And Analysis of PM10 Concentration at Delhi Metro Construction Sites, Int. J. of Environment and Pollution 2015 - Vol. 57, No.1/2 pp. 27 - 37,Scopus, Elsevier (I.F, 0.57)

9. Amrit Kumar; Rajeev Kumar Mishra; S.K Singh (2013) GIS Application in Urban Traffic Air Pollution Exposure Study: A Research Review SuanSunandha Journal of Science and Technology, Thailand, 2013, Vol. 2 No. 1 PP-1-13

CURRICULUM VITAE

EDUCATION:

Delhi Technological University, Delhi, India
2012-2018

Ph.D. Environmental Engineering

DTU JRF and SRF

Supervisor: Dr. Rajeev Kumar Mishra, Assistant Professor, DTU Delhi

Thesis: "Mapping of Urban Traffic Emission and Associated Health Risks in Delhi"

Sam Higginbottom University of Agriculture, Technology and Sciences,

2007-2009

formerly Allahabad Agricultural Institute, Allahabad, Uttar Pradesh, Allahabad

Master of Science in Environmental Science

Supervisor: Prof. Biswarup Mehera, Dean of College of Forestry

Co-Supervisor: Dr. Alok Lehri**,** Head, Central Instrument Facility, National Botanical Research Institute (CSIR), Lucknow.

Thesis: “Evaluations of heavy metals and Lindane pesticide residues in some medicinal plants, essential oils, and oil seeds”

Sido Kanhu Murmu University, Dumka, Jharkhand, India
2001-2005

Bachelor of Science in Botany Honours

RESEARCH INTERESTS:

- Air quality monitoring and modeling
- Environmental pollutants and its exposures
- Health risk assessment
- Water-air-soil Interactions
- Climate change
- GIS and Remote Sensing

RESEARCH EXPERIENCE:

Delhi Technological University (August 2012- 2018)
Air quality monitoring and modeling, assessment of vehicular emission, Assessment of Health Risks,
Mapping of air pollutants.

CSIR-NBRI, Researcher Experience (Oct-2009- July -2012)

Project Assistant II, "Exploratory studies on climate change and adaptation of species complex National Botanical Research Institute (CSIR), Lucknow from October 2009 to 6th February 2012.

DST Project titled "Strategic Knowledge for climate change on Agricultural and forest Ecosystem in Indo-Gangetic Plains (IGP) of U.P." National Botanical Research Institute (CSIR), Lucknow from 6th February 2012 to 30th July 2012.

TEACHING EXPERIENCE:

- Introduction to Environmental Science
- Earth Science, GIS & Remote Sensing
- Instrumentation
- Environment and Sustainable Development
- Air Quality Modeling
- Global Warming and Climate Change
- Environmental Law and Policy

PROFESSIONAL EXPERIENCE:

1. 6 months (Jan-July, 2009) on "Evaluations of heavy metals and Lindane pesticide residues in some medicinal plants, essential oils, and oil seeds" under the supervision of Dr. Alok Lehri**,** Head, Central Instrument Facility, National Botanical Research Institute (CSIR), Lucknow.
2. The XIX Annual conference of Indian Association for Angiosperm Taxonomy (IAAT) & International Symposium on "Angiosperm Systematic & Phylogeny: Retrospect's & Prospects**"** organized at NBRI, Lucknow, November 12 - 14, 2009.
3. International Workshop attended on Instrumentation for global climate change presented by LI-COR Bioscience (U.S.) and Elron instrument company Pvt. Ltd, on Dec.7 to 8, 2010 at Central Research Institute for Dryland Agriculture (ICAR), Hyderabad.
4. Water Sector Training and Capacity Building Programs for the National Capital Territory of Delhi, India 16 to 20th September 2013 at DTU organized by DTU and NTU Nanyang Technological University, Singapore.

5. TEQIP-II sponsored (World Bank, NPIU) One Week Faculty Development Program (UECCS-2015) Urban Environmental Challenges and Their Control Strategies, July 13 – 17, 2015. Environmental Engineering Department, DTU, Delhi
6. TEQIP-II sponsored (World Bank, NPIU) One Week Faculty Development Program (RTGE-2016) Recent Trends in Geo-Environmental Engineering, 18 April to 22nd April 2016. Department of Civil Engineering, DTU, Delhi.
7. TEQIP-II sponsored (World Bank, NPIU) One Week Faculty Development Program on Geotechnical Engineering for Urban Infrastructure (GEUI-2016), 11th July to 15th July 2016, Department of Civil Engineering, DTU, Delhi.
8. TEQIP-II sponsored (World Bank, NPIU) One Week Faculty Development Program on Recent Development in Fluid Mechanics and Hydraulics, 18 July to 22nd July 2016, Department of Civil Engineering, DTU, Delhi.
9. TEQIP-II sponsored (World Bank, NPIU) Short Term Training Program on “Research and Publication” which is held from 25th to 29 July 2016, Organized by the Department of Humanities, DTU, Delhi
10. Global Initiative on Academic Network (GAIN) on “Environmental Human Health Risk Assessment of Chemicals” (Sources, properties, distribution, exposure, and regulation) Organized by the Department of Civil Engineering at Indian Institute of Technology Hyderabad from 29th August to 3rd September 2016.
11. E-Resources: A Gateway for research workshop held from 5th September to 9th September 2016 organized by Central Library, Delhi Technological University, and Delhi.
12. FDP on 'Environmental Pollution: Monitoring & Control' at the Delhi Technological University from 24th to 28th October 2016.
13. GIAN course on “Intelligent Transportation Systems” at the Delhi Technological University from 27th November to 1st December 2017.
14. Recent Advances in Alternative Energy Sources held at the mechanical Engineering, DTU, on 28 January 2018.
15. TEQIP-III sponsored One Week Short Term Training Program On Advances in Image Processing and Computer Vision which is held from 2nd April to 6th 2018, Organized by the Department of Electronics & Communication Engineering, DTU, Delhi.
16. One Day workshop on patent Filing Procedure, conducted by Rajiv Gandhi National Institute of Intellectual property management (RGINIIPM), Nagpur and DTU on 28 May 2018.

HONORS AND AWARDS

Awarded **first prize** for the paper entitled “Diurnal pattern of soil carbon flux in different forest types in the tropical moist deciduous forest of Uttar Pradesh, India” under poster session at International Workshop on “Biodiversity and Climate Change, BDCC-2010” held between Dec. 19 to 22, 2010 at Indian Institute of Technology(IITKG), Kharagpur, India.

DTU JRF, MHRD, Fellowship for 2012-2014.

DTU SRF, MHRD Fellowship for 2014-2017.

International Society of Urban Health and the Scientific Committee for the International Conference on Urban Health that you have received a scholarship to attend the 2017 Conference in Coimbra, 14th International Conference on Urban Health Equity: The New Urban Agenda and Sustainable Development Goals 26-29 September 2017” Coimbra, Portugal.

JOURNAL REVIEWER:

International Journal of Engineering research and Technology (IJERTREW2169), ISSN2278-0181

Country Visited: Portugal (2017)

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PUBLICATIONS:

Book Chapter

Amrit Kumar; Pradeep Kumar; Rajeev Kumar Mishra and Ankita Shukla “Study of Air and Noise Pollution in Mega Cities of India" Environmental Pollution Water Sci., Technol. Library, Vol. 77, Vijay P Singh et al. (Eds): Environmental Pollution, Singer Nature, 978-981-10-5791-5, 448031_1_En, (7)

Research Paper

1. **Amrit Kumar;** Rajeev Kumar Mishra (2018) Human Health Risk Assessment of Major Air Pollutants at Transport Corridors of Delhi, India (Transport and Health, *Elsevier*, In Press ***(IF 2.84)***
2. Abhinav Pandey□; Rajeev Kumar Mishra; Govind Pandey□; **Amrit Kumar** (2018) The effect of odd-even driving scheme on $PM_{2.5}$ and $PM_{1.0}$ emission, (Transportation Research Part D) In Press ***(IF 2.34)***

3. **Amrit Kumar;** Rajeev Kumar Mishra (2017) Traffic Emission Modeling at Transport Corridors in Delhi. International Journal of Environmental Technology and Management, volume 20(3-4) pp. 240-258. Scopus (Elsevier)
4. **Amrit Kumar;** Rajeev Kumar Mishra (2017) Air Pollution Health Risk Based on AirQ+ Software Tool, International Journal of Applied Research and Technology, Vol-2, (3)90-199.
5. Ishan Saraswat; Rajeev Kumar Mishra; **Amrit Kumar** (2017) Estimation of PM_{10} concentration from Landsat 8 OLI satellite imagery over Delhi, India, Remote Sensing Application Society and Environment, volume 8, (4)25-257. *Elsevier* ***(IF 0.667)***
6. **Amrit Kumar;** Rajeev Kumar Mishra (2017) Estimation of motor vehicle toxic emissions and concentrations in the metropolitan city of Delhi, IJTTE, volume 1(7) pp. 134-143. Scopus, *(IF 1.15)*
7. Anuj Kumar , Rajeev Kumar Mishra and **Amrit Kumar** (2015) Noise Pollution Analysis in Different Mega Cities of India during Deepawali Festival, Journal of Environmental Research and Development 2015.
8. Rajeev Kumar Mishra; Tarun Joshi; Nikhil Goel; Himanshu Gupta **Amrit Kumar (2015)** Monitoring And Analysis of PM10 Concentration at Delhi Metro Construction Sites, Int. J. of Environment and Pollution 2015 - Vol. 57, No.1/2 pp. 27 - 37,Scopus, Elsevier ***(I.F, 0.57)***
9. **Amrit Kumar;** Rajeev Kumar Mishra; S.K Singh (2013) GIS Application in Urban Traffic Air Pollution Exposure Study: A Research Review SuanSunandha Journal of Science and Technology, Thailand 2013, Vol. 2 No. 1 PP-1-13
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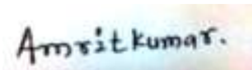

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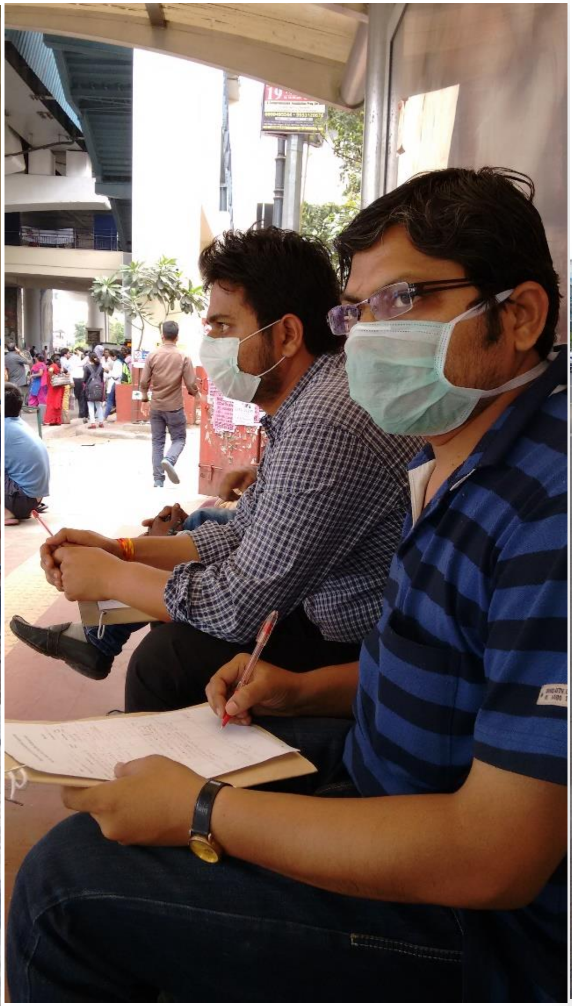
Glimpse capture during research work at various transport corridors

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